



**Agrinula : Jurnal Agroteknologi dan Perkebunan  
2021 vol. 4 (1): 43-60**

website : <https://journal.utnd.ac.id/index.php/agri>

E-ISSN : 2655-7673

DOI : <https://doi.org/10.36490/agri.v4i1.123>

**SEED-BORNE FUNGAL DISEASES OF MAIZE (*Zea mays* L.): A REVIEW**

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Article Information	ABSTRACT
Submitted: February 03, 2021  Revised: February 10, 2021  Accepted: February 11, 2021  Published: February 14, 2021	<ul style="list-style-type: none"> <li>• <b>Introduction:</b> Maize (<i>Zea mays</i> L.) is one of the most important cereal crops. It is ranked as 3<sup>rd</sup> after wheat and rice. Due to its wide adaptability, diversified uses, and low production costs, it has great potential as a cereal crop. In the case of yield losses, various factors are involved. The fungal diseases of maize play a significant role in the reduction of both quantity as well as the quality of maize.</li> <li>• <b>Review Results:</b> At the seedling stage, maize suffers from numerous diseases and many of them are seed-borne diseases. Anthracnose stalk rot (<i>Colletotrichum graminicola</i>), Charcoal rot of maize (<i>Macrophomina phaseolina</i>), Crazy top downy mildew disease (<i>Sclerophthora macrospora</i>), Corn grey leaf spot disease (<i>Cercospora zea-maydis</i>), Aspergillus ear and kernel rot (<i>Aspergillus flavus</i>), Corn smut (<i>Ustilago maydis</i>),</li> </ul>

	<p>Southern corn leaf blight disease (<i>Bipolaris maydis</i>) etc. are important among these diseases. Chemical control of seed-borne pathogens of maize is rather difficult to achieve as a reasonably good. Due to the hazardous environmental effects of chemicals, the Integrated Management of the seed-borne fungal pathogens of corn is mostly preferred. The distribution, disease cycle, symptoms of the damage, effects of environmental factors, economical importance of disease, and integrated disease management options of major seed-borne fungal pathogens of maize have been reviewed in this review article from various currently available sources.</p> <p><b>Keywords:</b> disease cycle; distribution; integrated disease management; losses; symptoms</p>
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## INTRODUCTION

Agriculture is an important resource that provides shelter, food and fibre for all (Rehman et al., 2020a; & Kalsoom et al., 2020). Agriculture is an important element in Pakistan's economy and according to government estimates, it accounts for 25.9% of GDP in 1999-2000 (Pakistan-Agriculture). Pakistan's agriculture sector directly supports the population of Pakistan and employs about half of the labor force (Rehman et al., 2020b). It contributes a considerable share of income from foreign exchanges. Wheat, cotton, rice, sugarcane, maize, vegetables, and fruits are the most important agricultural items for us along with taking advantage of beef, mutton, and eggs in addition. Maize is a cereal crop first raised by humans about 10,000 years ago by indigenous peoples of the Southern Mexico (Benz, 2001). The plant's leafy stalk produces pollen inflorescences and distinct ovuliferous inflorescences named as ears that produce fruit kernels or seeds. In several parts of the world, maize is becoming a staple food, with total maize production surpassing those of wheat and rice. Maize is often used for ethanol production, animal feed production as well as other maize products, including corn starch or corn syrup, in addition to being eaten by humans directly (Murdia et al., 2016).

Dent maize, pod maize, flint maize, popcorn, sweet corn, and flour maize are the six main types of maize. Sugar-rich varieties of maize named sweet maize are most commonly grown as kernels for man's consumption, while field varieties of maize are used for animal feed, various human food purposes based on maize (such as grinding into maize, pressing into maize oil, fermenting and distilling into beverages such as whiskey, bourbon), and as a chemical feedstock. In ethanol production and several other biofuels, maize is mostly used. Maize is commonly cultivated worldwide, and maize is produced annually at a higher weight than any other crop. The worldwide production of maize according to the survey of 2014 is 1,04 billion tonnes. Maize is a commonly cultivated grain crop worldwide. Maize is used both for feed and food purpose and it is 3<sup>rd</sup> most important cereal crop (Ali et al., 2020a; Ali et al., 2020b; Adnan & Bilal, 2020;

Adnan, 2020; Ali et al., 2020c; Ali et al., 2020d; Wasaya et al., 2019; Asif et al., 2020). There are numerous abiotic and biotic factors that limit the yield in maize and result in many diseases as well as poor crop management. Maize plants are affected by a large number of diseases the most important of which are fungal and bacterial pathogens that are present in various fields of Pakistan. Maize is prone to several fungal diseases, to a fewer group of bacteria, viruses, many other mycoplasma-like organisms, nematodes, and various other higher parasitic plants. The various bacterial and fungal species have been reported as devastating for maize crops (Cobo-Díaz et al., 2019).

So many of them are important economically. In addition to many species of nematodes which are commonly considered to be pathogenic to maize, have been isolated (Manandhar, 1997). Many of viral pathogens have also been reported on various maize cultivars (Manandhar, 1983). Among the reported diseases of maize, various diseases are economically very important. Pakistan's average maize production is relatively low as compared to those of the world, although its area of cultivation is increasing with each day. There are a lot of causes of the low yield of maize and among them, diseases play a vital role. Moreover, seedborne fungal diseases of maize cause huge losses both in storage as well as in the field. About 112 diseases are has been reported in maize crops (USDA, 1996). Among them, about 70 diseases are seed-borne. Important seed-borne diseases of maize are scutellum rot, head smut, leaf blight, kernel rot, leaf spot, seedling blight, collar rot, anthracnose (Richardson, 1990) (Table 1).

The various maize diseases have been controlled mostly through the cultivation of resistant varieties. The growth and production of plants depend directly on the source of nutrients. Basically, plants need different kinds of nutrients, grouped according to their requirements into two categories, i.e. macronutrients and micronutrients (Tahir et al., 2020; Toor et al., 2021) as magnesium is an essential nutrient and performs an essential for many sink organs like seeds and roots (Adnan et al., 2020; Adnan et al., 2021). Fungal diseases can be prevented by the application of proper nutrients to the plant. In this review article, many of the important and devastating fungal diseases of maize has been reviewed from various currently available sources. The main focus of this paper is also on the main fungal diseases of maize that are reported as a serious constraint on maize productivity.

## **REVIEW RESULTS**

### **Major Fungal Diseases**

Most of fungal diseases of maize are distributed in all fields of maize. Many of them are mostly favored by humid and warm environmental conditions. Some others also prevalent in humid and cool conditions. The major and devastating seed-borne diseases of maize caused by fungi are *Gibberella* stalk rots, *Fusarium* stalk rots, false head smut, head smut, late wilt, and black bundle disease (McGee, 1988). Others include charcoal stalk rot, Anthracnose stalk rot, *Fusarium*, and *Gibberella* ear rots, *Aspergillus* ear rots, charcoal ear rot, *Penicillium* ear rots, gray ear rot, *Nigrospora* ear rot, common smut, downy mildew, black kernel rot, Horse's tooth disease, *Alternaria*

leaf blight and *Acremonium zeae* stalk rot (CIMMYT, 2004). However, Black bundle, Anthracnose rots, Black kernel rot, Crazy top downy mildew, Brown stripe downy mildew, ear and root rot, Java downy mildew, Horse's tooth, *Nigrospora* ear rot, Philippine downy mildew disease, and *Penicillium* ear rot are major seed-borne and seed transmitted diseases of maize (McGee, 1988).

Table 1. Seedborne diseases of maize

No	Disease	Causal Organism	Yield Losses	Mainly Affected Areas	References
1	Anthracnose stalk rot	<i>Colletotrichum graminicola</i>	0-40%	Lower leaves and stalk	Kleczewski, (2014)
2	Aspergillus ear and kernel rot	<i>Aspergillus flavus</i>	10-30%	Ear and Husk	Mukanga et al., (2010)
3.	Charcoal ear rot	<i>Macrophomina phaseolina</i>	20-30%	Leaves, stem and Seedling	Mueller et al., (2016)
4.	Crazy top downy mildew	<i>Sclerophthora macrospora</i>	-	Stalk	Frederiksen & Renfro, (1977)
5.	Corn grey leaf spot	<i>Cercospora zeae-maydis</i>	10–25%	Leaf sheath	Sibiya et al., (2012)
6.	Corn smut	<i>Ustilago maydis</i>	10%	All parts	Aydogdu & Boyraz, (2011)
7.	Southern corn leaf blight	<i>Bipolaris maydis</i>	30-50%	Leaves	Bruns, (2017)

### 1. Anthracnose Stalk Rot

*Glomerella graminicola*, which causes the serious disease "Anthracnose Leaf Blight", is an economically devastating crop pathogen that affects both wheat and maize. Certain genetically modified cereal varieties are also vulnerable to the teleomorph of this fungus. Anthracnose stalk rot is a worldwide disease caused by *Glomerella graminicola* (Tesso et al., 2012). It affects the whole maize plant. At any time, this disease can show its symptoms during the growing season. Usually, this disease can be easily observed in the form of stalk rot or leaf blight.

**Symptoms of Damage.** Depending on which stage of the growing season of corn is in, symptoms may differ. The primary symptom is foliar leaf blight early in the growing season. This also occurs on the lower leaves of the plant as 1-inch-in length and ½ inch in width spindle-shaped or oval-shaped water-soaked lesions. Such tissue can become necrotic and therefore these lesions can spread across the whole leaf, causing it to turn yellow and die. In color, they are light brown, along with the margins that are dark brown or purple (Tesso et al., 2012). If they persist, in the center of the lesion, the black colored fruiting bodies may also appear. Symptoms may appear several weeks after tassels formation on maize during mid-season. The top die-back occurs if the infection spreads over several parts of the plant. The whole plant will become necrotic and die in this dieback, starting from the tassel and then can spread through the whole stalk and the lowest leaves. Another main symptom of this disease occurs late in the growing season and that is the rotting of stalk (Tesso et al., 2012). Firstly, these can

be seen on the internodes of the stalk as a reflective black stripe, which can make the stalk soft, allowing the plants to lodge easily in heavy precipitation or during the wind.

**Disease Cycle.** Fruiting structures from the corn residue in the spring and produce conidial spores which are spread through windblown, splashing, and raindrops (Bergstrom et al., 1999). Conidial spores, through the epidermis or stomata, infect young plants. In cloudy, hot, and humid conditions, Anthracnose spreads very exponentially. Conidia can germinate in 100 percent humidity in less than 6–8 hours under ideal environmental conditions (Bergstrom et al., 1999). The initial symptoms of lesions and necrotic spots can be seen within 72 hours of conidial infection (Mims & Vaillancourt, 2002). The lesions are produced on lower leaves have conidial spores that spread on the upper leaves and stalk and cause secondary infections. The stalk-boring insects i.e. larvae of European maize borer cause the wounds. From these wounds, vascular infections mainly arise, which enable xylem colonization and infection by conidia (Carson, 1999). Maize top can die back and results in stalk rot or vascular wilt. The *C. graminicola* survives on the corn leaf residue during fall. In extracellular secretion, the pathogen mostly survive in winter as conidia on corn stalks. This can stop the desiccation of conidia and protects them from harmful environmental conditions (Bergstrom et al., 1999). For leaf blight occurrence in the spring, the pathogens overwinter on maize residue and serve just like a critical source of primary inoculum. When susceptible corn seedlings emerge in spring from the maize field, the cycle will start all over again.

**Favorable Environment.** The infection and persistence of anthracnose leaf blight are favored by many factors. These are the most suitable conditions for its spread and survival if high temperatures and long periods of wet weather or high humidity occur. A particular temperature from 25 to 30°C is required for the pathogen to successfully infect the host plant. Two other things, which are extended periods of low sunlight due to overcast conditions, and an already weakened host due to infection with other pathogens or pests, may also encourage host plant infection (Bergstrom et al., 1999). In parallel to this, the disease would also be favored by two cultural traditions. Continuous planting of the same host without crop rotation and no-till fields would facilitate the pathogen's persistence between growing seasons (Jirak-Peterson & Esker, 2011).

**Economic Importance.** Anthracnose of maize (*C. graminicola*) is a worldwide disease. Anthracnose of maize can influence the whole plant. Its symptoms can appear at any time in the growing season. Usually, this disease can be seen in the form of stalk rot leaf blight. Anthracnose had not been a concern in North America prior to the 1970s. Significant epidemics devastated the north-central and eastern U.S. in the 1970s. In Western Indiana, within two years of the appearance of *C. graminicola*, the production of sweet corn was almost lost out, and still the production doesn't currently exist (Bergstrom et al., 1999). In the 1980s and 1990s, this disease was observed in various fields of maize in the United States. In 1982 & 1983, a survey done in Illinois demonstrated that 34 to 46% of diseased maize stalks had the spores of *C. Graminicola* (Anderson & White, 1987). The production grain loss due to this disease estimated

varies from 0 to 40 percent. This depends on the hybrid, climate, disease timing, and other stresses.

**Integrated Management.** Ever after *C. Graminicola* is observed on maize residue, specifically on soil surface, the crop rotation of minimum one-year to reduce anthracnose leaf blight of corn is most efficient control methods. A survey in 2009 showed serious symptoms which are caused by *C. graminicola* occur when corn is grown on fields which was used for maize last year compared to fields that was used for soybeans in last year (Jirak-Peterson & Esker, 2011). Cultural practices may be adopted to interrupt the host plant's primary inoculum process and conidial spore infection, including the use of pathogen-resistant hybrid cultivars (Jirak-Peterson & Esker, 2011) and ensuring the host plants safe and managing other pests to make them resistant to disease. Although there are hybrids that resistant to leaf blight or stalk rot which mostly occurs later in growing season. Also there is a cultural practice that disrupts the pathogen's saprophytic phase, and this involves ploughing deep into the soil having maize residue and then using a one-year crop rotation away from the same host plant that was just used in that field (Jirak-Peterson & Esker, 2011). Such techniques move the saprophytic phase into the soil, where other species out-compete and thus do not survive (Jirak-Peterson & Esker, 2011). In biological control, there is also a potential to interrupt conidial spore infection, although the large-scale application of this control has not been studied. This is achieved by adding yeasts to a leaf surfaces that exhibit leaf blight symptoms (Bergstrom et al. 1999).

## 2. *Aspergillus* Ear and Kernel Rot

*Aspergillus flavus*, which is widely distributed (Ramírez-Camejo et al., 2012), is a saprotrophic and pathogenic fungus (Machida & Gomi 2010). Cereal grains, tree nuts, and legumes are known best for their colonization. During harvest, storage, or transit, postharvest rot tends to develop. Its name "flavus" originates from a Latin word that means yellow, a link to the color of spores which is commonly observed. The disease may occur when hosts are in the field (preharvest), but before post-harvest storage or transport, they often exhibit no symptoms (dormancy).

**Symptoms of Damage.** *Aspergillus* ear rot occurs on the kernels as an olive-green mold that may begin at the tip of the ear or be linked with insect, bird, or hail injuries. When you pull back the husk, the fungal spores seem powdery and can scatter like dust. At the tip of the ear, these symptoms are most frequently found, but can be distributed across the ear. The colonies of *A. flavus* on the top surface are usually powdery masses having yellowish-green colored spores and reddish-gold color on the underside of the leaf. Infection is reduced in small areas of both grains and legumes. The discoloration of infected areas can be easily observed. Development is vigorous and in texture, the colonies mostly appear as downy or powdery.

**Disease Cycle.** *Aspergillus flavus* can survive within the soil and emerges, either as mycelia or sclerotia, when propagules on dead plants. Sclerotia are germinated to add massive conidia asexual spores. These conidia are the main source pathogen. The

conidia in the soil are dispersed through the wind. The conidia then infect the grains by landing on the maize plant. The spores then enter into the corn by silks. Thus, they infect the kernel. The conidia and conidiophores are mostly produced in the spring season from sclerotia. The conidia present on the leaves are secondary inoculum for *A. flavus*. *A. flavus* then grow and proliferate on leaves after an injury caused by the feeding of insects. Insects are considered to be a potential source of inoculum and promote the production of the inoculum. Wind and insects are the main dispersing agents of the conidia in the soil. Conidia can fall on the plant and infect them. The spores, via the silks, penetrate maize. Therefore, infect the maize kernel. The conidia and conidiophores are formed from sclerotial surfaces in the spring. A secondary inoculum of pathogen and that are conidia are present on the leaves and portions of the stem. Following damage by leaf-feeding insects, *A. flavus* develops on plants. Insects are the main source of inoculum that can also encourage the development of inoculum (Hedayati et al., 2007; Diener et al., 1987).

**Favorable Environment.** The productivity of the plant community (Hadi et al., 2020) as well as the microbial community (Rehman et al., 2020c; Rehman et al., 2020d; Rehman et al., 2021) is affected by climate change drivers. It is unique in the case of *Aspergillus flavus* because this fungus is thermotolerant and can survive at a high temperature at which the other fungi can not. *A. flavus* may contribute to storage rot, especially at high levels of humidity. *A. flavus* can grow in hot and humid climates (Diener et al., 1987). The minimum temperature for growth of pathogen is about 12°C and maximum temperature is about 48°C. Although the mean temperature for growth is about 48°C, the optimum temperature is 37°C. The pathogen has fast growth at a temperature of 30-55°C. Its growth is slow at 12-15°C. The growth at 5-8°C is nearly ceased. The pathogen growth for different crops occurs at various levels of moisture. Growth takes place at 13.0 to 13.2 percent for starchy cereals. Growth happens at 11.5 to 11.8% for soybeans. Growth happens at 14% for other crops (Agrios, 2005). The growth of *A. Flavus* in tropical countries is widespread (Amaike et al., 2011).

**Economic Importance.** Infections with *A. flavus* mostly doesn't decrease the crop yields. It is a post-harvest disease and can decrease 10 to 30 percent of total yield and the total economical loss can be more than 30 percent in developing nations that grow perishable crops. Post-harvest disease results in mycotoxin production in grains and legumes (Agrios, 2005). The biggest economic damage caused by this disease is due to the production of aflatoxin. Annual economic loss figures for maize, peanuts, cottonseed, almonds, and walnuts in the United States are less serious compared to Asia and Africa (Amaike et al., 2011). Following *Aspergillus fumigatus*, the second-main cause of aspergillosis is *A. flavus*.

**Integrated Management.** Some environmental conditions must be introduced before or after harvesting to ensure that grains and legumes remain free of fungal infection. Moisture concentrations should be lower than 11.5%. The temperature of the storage unit must be low because this pathogen cannot grow below 5°C of the temperature. Such temperature encourages slower breathing which will avoid a rise in

moisture. Fumigants can be used to reduce the incidence of insects and mites, which results in promoting the pathogen's rapid growth. Sanitary activities such as the elimination of unripe seeds, the removal of degraded or broken seeds, and common sanitary measures help to reduce the colonization and spread of pathogens (Agrios, 2005). The proper aeration systems is the most efficient management practice for grains.

### 3. Charcoal Rot of Corn

*Macrophomina phaseolina*, belonging to the family Botryosphaeriaceae, is a fungal plant pathogen that in many plant species causes damping-off, charcoal rot, seedling blight, stem rot, root rot, basal stem rot, and collar rot. *Macrophomina phaseolina* can infect almost 500 different plant species of 100 or more families. *Macrophomina phaseolina* is one of the most devastating seed as well as soil-borne fungal pathogens (Babu et al., 2007). The hosts include wheat, maize, peanuts, chickpea, cabbage, tomato, soybean, sweet onion, sunflower, alfalfa, sesame, potato, sorghum, etc.

**Symptoms of Damage.** The fibrovascular framework of its host roots and basal internodes is affected by *M. phaseolina*, preventing nutrients and water transportation to the upper parts of the plant (Kaiser & Das, 1988). As a result, *M. phaseolina* infection is characterized by premature dying, progressive wilting, decreased yield, and loss of vigor. This pathogen also causes various diseases such as damping off, charcoal rot, seedling blight, basal stem rot, root rot, and stem rot (Babu et al., 2007). The formation of brown-colored lesions may occur on the emerging seedlings. After or during flowering several other symptoms may also occur such as discoloration of taproots, or stem, shredding of the tissue in top of the taproot and the stem hollowing. Below the epidermis of the taproot and lower stem, the small black dots may develop, giving a charcoal-sprinkled appearance to the stems and roots. The tiny and the microsclerotia of black colored, the main symptom of disease, can be so much in number when the epidermis is removed. They give the plant tissue a greyish-black tint. In addition, in pith and vascular tissues of stemor root, black streaks, and reddish-brown discoloration can form.

**Disease Cycle.** The fungus *M. phaseolina* has hyphal cell aggregates that form microsclerotia in the stem or taproots of the host plants (Kaiser & Das, 1988). In the crop residue and soil, the microsclerotia overwinter and are main source of inoculum in the spring. They can survive for up to 3 years on the field (Kaiser & Das, 1988). From these microsclerotia, hyphae germinate when conditions are favorable. Microsclerotia germination occurs during the growth period when temperatures around 28 to 35°C (Kaiser & Das, 1988). The germination occurs on the surface of the roots and germ tubes and develops appressoria at the end of microsclerotia which then penetrate into the cell walls of epidermal cells of hosts through natural openings or using turgor pressure. The hyphae infect the plant's roots. Initially, hyphae join and expand intercellularly in the cortical tissue, then invade the roots and vascular tissue (Kaiser & Das, 1988). Mycelia and sclerotia are formed inside vascular tissue and plug vessels (Babu et al.,



2007). This causes the most frequently observed greyish-black color in *M. phaseolina* infected plant. This also blocks the transfer of nutrients of water from roots to the upper plant parts. Therefore, diseased plants sometimes wilt and die prematurely due to this systemic infection.

**Favorable Environment.** These are spherical, oblong structures with black color which allow the fungus to survive in harsh conditions, like low levels of soil nutrients and temperatures above 30°C (Kaiser & Das, 1988). However, microsclerotia persistence is significantly lower in wet soils, often lasting no longer than 7 to 8 weeks, and mycelium is unable to last longer than 7 days (Kaiser & Das, 1988). *M. phaseolina* is a disease that is favored by drought and heat, produces a large number of microsclerotia at comparatively low water and significantly higher temperatures. In particular, charcoal rot usually occurs in maize when the plants undergo severe drought stress.

**Integrated Management.** There are many approaches that are commonly used to treat *Macrophomina phaseolina* infections. Fungicides can also be used to stop the development of mycelia. These fungicides include iprodione, carbendazim, thiram, pyraclostrobin, fluquinconazole, metalaxyl, tolyfluanid, and penflufen + trifloxystrobin (Tonin et al., 2013). There are, however, substitutes to fungicides that organic farmers particularly prefer, including the combination of organic improvement and soil solarization. Soil solarization technique is based on the use of solar energy through mulching of the soil and covering the soil with a typical transparent sheet or polyethylene tarp that captures heat and solar energy in the soil for the control of pathogens in the soil. This technique has proved to be as successful as fungicides in studies. Similarly, crop rotation can be an efficient practice of management.

#### 4. Crazy Top Downy Mildew

*Sclerophthora macrospora* is a protist pathogen of plants belonging to the Oomycota class (Dernoeden & Jackson, 1980). A significant number of cereal crops, including maize, oats, rice, and wheat, as well as turfgrass varieties, are infected by *Sclerophthora macrospora* which causes downy mildew. "Crazy top disease" on maize and yellow tuft disease on turfgrass are the common names of the diseases associated with *Sclerophthora macrospora*. The disease is present worldwide, but in Europe, it is particularly persistent. There is a wide host range for *Sclerophthora macrospora*, consisting of crops such as turf grass, maize, oats, rice, and wheat. The lack of host specificity of the pathogen allows for the extensive prevalence of the disease and affects a number of crops that are economically important.

**Symptoms of Damage.** The pathogen associated with downy mildew (or yellow tuft disease) on maize is *Sclerophthora macrospora*. The major symptoms are shoot proliferation and discoloration on maize cultivars. *Sclerophthora macrospora*, in addition, causes crazy top maize disease. Symptoms of crazy top of maize are phyllody and sudden increase in tassel development. It is important for the grower that the signs and symptoms should be noticed as soon as possible. There are also a large number of

resistant strains bred - most notably in maize. Some rice cultivars are also resistant (Lee et al., 2003).

**Disease Cycle.** *S. macrospora* is an obligate parasite (Dernoeden & Jackson, 1980). The oomycetes develop oospores, like *Sclerophthora macrospora*. Oospores are sexual spores that are formed by antheridium and oogonium fusion. In humid late spring to fall, the oospore germinates and develops sporangium on sporangiophores. Splashing water allows the spread of the sporangium, which is perfectly white and lemon-shaped. Aided by water transport, the sporangium lands on a leaf surface and releases zoospores that invade the plant species by encysting and penetrating the plant tissue with a germ tube near the stoma. Sporangia can release several zoospores when wet conditions continue. The secondary inoculum is produced by the pathogen's zoospores on the infected leaves, causing the disease to be polycyclic.

**Integrated Management.** Effective ways to avoid the disease are cultural regulation, sanitary practices, and chemical control. Common cultural approaches used involve plowing only when the field is dry and when watering is avoided. It is essential to ensure that fields are well-drained so that sporangia does not spread, as the disease proliferates in wet environments. The quantity of pathogens' inoculum in the field can be reduced by preventive fungicides applied under certain guidelines - but success is minimal. Spring applications of the metalaxyl fungicide, marketed under the trade name Subdue, may be particularly effective for the Crazy top disease of maize. It is important to note that most *Sclerophthora macrospora* fungicides are treatments of the preventive type, not curative ones.

## 5. Grey Leaf Spot

The fungal disease that affects foliar parts of the maize is Grey Leaf Spot (GLS). GLS is considered one of the world's most important maizediseases that limit yield. *Cercospora zeina* and *Cercospora zea-maydis* are two associated fungal pathogens that cause Grey Leaf Spot (Ward et al., 1999). *Cercospora zea-maydis* can only infect maize. *Cercosporazeae-maydis* populations are characterized on the basis of geographical distribution, growth rate, molecular examination, and development of cercosporin toxins.

**Symptoms of Damage.** The early symptoms of GLS are dark, wet, and small spots surrounded with yellowish color (lesions forming). As spot size increases, the tissue present in the "spot" starts dying. The characteristic grey color that follows the brownish and yellow color, is because of conidial production on the surface of the lesion. Such symptoms are most prevalent on sheaths of leaves and the corn husks that are similar in shape, size, and discoloration. Northern corn leaf blight Disease (*Exserohilum turcicum*), northern corn leaf spot blight Disease (*Bipolaris zeicola*), and southern corn leaf blight (*Bipolaris maydis*) are also characterized by such purple or dark brown discoloration on leaf sheaths. Mature lesions of the corn grey leaf spot can be detected easily and differentiated from all other types of infections. The grey lesions of the leaf of corn are brown in color with rectangular and vein shape. The width of the

lesion is restricted by secondary and tertiary leaf veins and in some cases, the individual lesions combine and cause a blight on entire leaves.

**Disease Cycle.** *Cercospora zae-maydis* persists only on the infected maize debris. It is, however, a weak competitor of the soil. The debris present on the surface of the soil is the main source of primary inoculum for the next season which infects the very next incoming corn crop. By late spring, *Cercospora zae-maydis* produce conidia (asexual spores) in the debris which are dispersed by rain, or wind. Conidia are transmitted and new maize crops are eventually infected. The high relative humidity and moisture (dew) on the leaves are required by the pathogen to infect the host. In the lower surface of younger leaves, primary inoculation occurs, where conidia are produced across the surface of the leaf and penetrate by a flattened hyphal organ, called an appressorium, via stomata. Unlike other spores that have to penetrate within hours for their survival, *C. zae-maydis* is very typical in that its conidial development and survive for many days before penetration. The conidia in these lower leaf surfaces are formed once infection occurs.

**Favorable Environment.** Under relatively high humidity for two days as well as the abundant moisture on the leaves due to dew, fog, or light rain, the corn grey leaf spot thrives. In addition, heavy rains also favors the pathogen's dispersal. There is also a need for temperatures between 75°F and 95°F. If the temperature during rainy periods drops below 75°F or there is a lack of 12 hours of wetness, the magnitude of the disease would be significantly reduced. Those conditions are favorable for spore production during the summer or spring months in the Midwest and Mid-Atlantic. Depending on the climate and the vulnerability of the corn commodity used, the infection period may take two to four weeks.

**Integrated Management.** The ultimate strategy is to decrease the rate of disease growth in order to effectively prevent and manage maize grey leaf spot. This is accomplished by decreasing the number of cycles of secondary disease and decreasing the damaged area of the leaf until after the formation of maize grain. High risks are divided into eight factors for the maize grey leaf spot, which require complex management strategies. The introduction of resistant plant varieties is the most efficient and economical way to minimize yield losses from the corn grey leaf spot is (Wise, 2011). If sprayed at the start of the season before initial damage, fungicides can be efficient for disease reduction.

## 6. Corn Smut

Corn smut caused by *Ustilago maydis* is maize disease. It is a pathogenic fungus that induces smut on maize. On all above-ground parts of corn plants, the fungus forms galls. It is edible in Mexico. It is also known well known because of the huitlacoche delicacy, which is eaten in tortilla-based foods and quesadillas and in soups, usually as a filling.

**Symptoms of Damage.** By entering the ovaries of its host, the disease affects the whole plant. The infection can cause galls formation whose tissues, shape, and

structural patterns are mushroom-like and grow on the maize kernels. These galls are composed of the infected plant's hypertrophied cells, along with the associated fungal threads like structures called hyphae and their blue or black colored spores. These dull colored spores impart a burnt look to the cob. It is the basis of its generic term *Ustilago*, that is derived from Latin word *ustilare* which means to burn. Development of the fungus within the plant leads to symptoms of disease, including chlorosis, formation of anthocyanin, decreased growth, and the emergence of tumors that harbour the development of teliospore spores (Banuett, 1995).

**Disease Cycle.** It behaves like baker's yeast when grown in laboratory on the simple media, and form the single cells which are called sporidia. By budding off the parent cell, these cells multiply. They turn to a different mode of growth when two compatible sporidia interact on the plant surface. First, to locate one another, they give out conjugation tubes, after that they combine and give out a hypha to penetrate the corn plant. There are dikaryotic hyphae developing in plant; they have two haploid nuclei in each hyphal compartment. Unlike sporidia, the dikaryotic process of *Ustilago maydis* involves the growth and differentiation during the plant infection, and cannot be sustained in the laboratory.

**Favorable Environment.** Though not all the conditions are established that favour the growth of *Ustilago maydis*, depending on both abiotic and biotic factors, there are some environments where maize smut tends to thrive. During pollination, hot and dry weather accompanied by a strong rainy season tends to increase the pathogenicity of corn smut. High winds and heavy rain also increase the spread of the disease as it is easier to transmit the spores of maize smut.

**Economic Importance.** Corn smut, though a worldwide delicacy, can severe economic losses. Aydogdu & Boyraz, (2011) found that maize exposed to maize smut resulted in a yield loss of 33%. With maize being a food source for both animals and humans, a 33% loss of yield may prove devastating for the supply of food. Out of several varieties of maize, however, sweet maize is the most affected by maize smut. Not only is there a lack of yield, but the presence of maize smut, as it has an ugly appearance, makes maize difficult to sell to potential buyers.

**Integrated Management.** There are several ways to manage and control maize smut, at this time, however, maize smut cannot be controlled by any common fungicide, as *Ustilago maydis* infects individual maize kernels instead of infecting the entire cob, such as head smut (Mohan, 2013). Resistant maize varieties, crop rotation, and preventing mechanical damage to the plant are several helpful ways to contain corn smut. A mechanical injury, which increases infection, may make the maize easily accessible to *Ustilago maydis*. In addition, clearing the debris planting area will help control corn smut, as the teliospores winter in debris from corn smut. However, because corn smut can also overwinter in the soil, this is not the best practice; crop rotation is suggested. Finally, the use of fertilizer with low nitrogen levels, or just limiting the amount of nitrogen in the soil, as excess nitrogen in the soil increases the rate of contamination, is another way of controlling maize smut (Djawu, 2017).

## 7. Southern Leaf Blight of Corn

Southern maize leaf blight is found worldwide, where the corn is grown. It is a fungal disease of maize. It is due to the Infection of *Bipolaris maydis*. Its teleomorphic stage is *Cochliobolus heterostrophus*. *Bipolaris maydis* is an Ascomycete and can use ascospores or conidia to cause infection (Agrios, 2005). *Bipolaris maydis* has three races.

**Symptoms of Damage.** *Bipolaris maydis* is an Ascomycete and can infect the maize by conidia or ascospores (Agrios, 2005). There are three Races of *Bipolaris maydis*. The ear husks, leaves, cobs, ears, sheaths, stalks and shanks may be contaminated by *B. Maydis*. If the enough infection occurs earlier on the shank, the ear may be killed prematurely, causing the ear to fall. A felty, black mould that can cause cob rot can cover the SCLB infected kernels (Agrios, 2005). Ear rot is more prominent on cms-T cytoplasm corn with Race T (Calvert, 1973). Infected seedlings can show the symptoms of wilting and the infected plant will die after planting in a few days (Agrios, 2005).

**Disease Cycle.** The *C. heterostrophus* is either asexual conidia or sexual ascospores and release the spores to infect maize plants. In nature, mostly asexual cycle occur and is of primary concern. Conidia that are main source of primary inoculum are mostly released from the lesions present on infected maize under favourable moist and warm conditions and transported to the healthy plants through wind or rain. The germination of *B. maydis* by means of polar germ tubes can easily occur on the tissue once conidia have landed on the surface of leaf or leaf sheath of healthy plant. The germ tubes, like the stomata, either pass through the leaves or reach via natural opening. The fungal mycelium invades parenchymatous leaf tissue. leaf tissues begin to become brown in color and subsequently will collapse. Such lesions result into conidiophores formation that will either further invade the main host plants (husks, kernels, leaves, stalk) or release conidial spores to invade nearby plants under favourable conditions (Agrios, 2005).

**Favorable Environment.** The word 'favourable conditions' for this pathogen means that the water is present on the surface of the leaf. The favourable temperature range from 60 to 80°F. Under such conditions, within 6 hours, spores will pass through the germination and will enter the host plant. This pathogen overwinters as mycelium and spores in the corn debris, waiting for these favourable spring conditions once again (Agrios, 2005).

**Economic Importance.** If the seeds are eventually exposed to Race T, then the estimated losses can extend up to 90 percent. When it was firstly appeared in U.S. in year 1968, bamed epidemic in 1970 and almost 15 percent of crop production of the corn belt was damage at that year (Agrios, 2005). The disease started in the southern U.S. in 1970 and had spread north to Maine and Minnesota by mid-August.

**Integrated Management.** Breeding of resistant host is the best method for handling southern corn leaf blight. Both origins of polygene and single gene resistance have been studied. The distribution of all races can be avoided by other methods of

regulation. For instance, between growing seasons, it is necessary to check for the crop debris. As in leaf or leaf sheath debris, *B. maydis* overwinters. The crop rotation with some other non-host crops is another method that is used to reduce this disease. Further, foliar fungicides can be used. The management of this disease is crucial from 15 days before to 21 days after the tasseling, which is the most important and susceptible period for damage.

## CONCLUSION

The average production of maize in Pakistan is relatively low as compared to the other world, although the area of cultivation is somehow increasing by every day. There are many of causes of low yields of maize and a major role is played by diseases. In addition, both in storage and in the field, seedborne diseases cause tremendous losses. Among them, Anthracnose stalk rot (*Colletotrichum graminicola*), Charcoal rot of maize (*Macrophomina phaseolina*), Crazytopdowny mildew disease (*Sclerophthora macrospora*), Corn grey leaf spot disease (*Cercospora zae-maydis*), Aspergillus ear and kernel rot (*Aspergillus flavus*), Corn smut (*Ustilago maydis*), Southern corn leaf blight disease (*Bipolaris maydis*) etc. are the important diseases. Many others of them are economically significant. Seedborne diseases cause immense losses. Today, there desired need to cope with the seed-borne fungal pathogens of maize by using integrated management of disease to reduce the qualitative and quantitative losses.

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