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INTEGRATED MANAGEMENT AND BREEDING APPROACHES FOR CHARCOAL ROT AND STALK ROT RESISTANCE IN MAIZE (*ZEA MAYS* L.): A REVIEW

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ABSTRACT

Maize (*Zea mays* L.), often termed the "Queen of cereals," plays a crucial role in global food security, serving as a key source of food, feed, and industrial raw material. In India, it ranks third after rice and wheat, with major production in Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Karnataka, and Andhra Pradesh, where hybrid maize cultivation predominates. However, the crop's yield potential is severely constrained by stalk rot diseases, particularly charcoal rot and Fusarium stalk rot, caused by *Macrophomina phaseolina* and *Fusarium verticillioides*, respectively. These soil-borne pathogens persist through infected debris and contaminated farm implements, with disease expression intensified under abiotic stress such as high plant density, moisture deficiency, and nutrient imbalance. *M. phaseolina* produces microsclerotia and pycnidia, while *F. verticillioides* synthesizes fumonisins mycotoxins with notable health and economic repercussions. Integrated disease management (IDM) strategies comprising soil solarization, bio-solarization, balanced fertilization, use of organic amendments, and biological control agents such as *Bacillus*, *Pseudomonas*, *Streptomyces*, and *Trichoderma* spp. have shown promise in disease suppression. Parallelly, breeding for host resistance through systematic germplasm screening, including landraces, wild relatives, and elite inbreds, remains a cornerstone of sustainable disease management. Resistance evaluation utilizes both phenotypic tools (e.g., disease severity index, rind penetrometer resistance) and molecular approaches such as quantitative trait loci (QTL) mapping, marker-assisted selection (MAS), and genomic selection (GS). Combining IDM with the deployment of genetically resistant cultivars offers a sustainable and environmentally sound solution to mitigate the impact of stalk rot diseases in maize production systems.
Keywords **:** Maize, stalk rot, *Fusarium verticillioides, Macrophomina phaseolina*, disease resistance, biological control, germplasm screening, QTL mapping, (MAS).

Introduction

Maize (*Zea mays* L.), popularly known as the "Queen of cereals," is one of the world's most important cereal crops due to its diverse applications as food, feed, fodder, and biofuel. Its exceptional genetic plasticity allows cultivation across a wide range of agro-climatic zones from tropical to temperate regions. In India, maize ranks third after rice and wheat in terms of area and production. It is extensively grown in both traditional maize-producing states such as Bihar, Madhya Pradesh, Rajasthan, and Uttar Pradesh (collectively referred to as the BIMARU states), and in non-traditional yet rapidly expanding regions like Karnataka and Andhra Pradesh (KAP). This widespread adaptability underlines the crop's pivotal role in ensuring food and livelihood security, particularly in rainfed and semi-arid zones. Despite its high yield potential, maize cultivation is frequently challenged by a range of biotic and abiotic stresses. Among biotic constraints, diseases caused by fungi, bacteria, viruses, and mollicutes pose a significant threat, affecting various plant parts including leaves, tassels, ears, kernels, stalks, and roots. Stalk rot diseases, in particular, have emerged as major impediments to sustainable maize production. These diseases compromise the plant's structural integrity and reduce grain yield, often culminating in lodging and premature plant death.

In India, two stalk rot diseases are especially destructive: charcoal rot, caused by *Macrophomina phaseolina*, and Fusarium stalk rot, caused by *Fusarium verticillioides*. Charcoal rot is predominantly reported from Maharashtra, Telangana, and Karnataka, while Fusarium stalk rot is prevalent in Rajasthan and adjoining regions. The severity of these diseases is frequently exacerbated by environmental stressors such as drought, high plant population density, and nutrient imbalance particularly excessive nitrogen or moisture stress.

Effective diagnosis and management of stalk rot diseases remain a persistent challenge. Traditional detection methods often lack precision and timeliness, leading to underestimation of disease incidence and ineffective control. Therefore, there is an urgent need to develop integrated and sustainable management strategies. Equally important is the identification and deployment of genetically resistant germplasm, which provides a long-term, environmentally sound solution for minimizing yield losses and ensuring crop stability under pathogen pressure.

Charcoal Rot in Maize:

Pathogen- Charcoal rot in maize is caused by the soil-borne fungal pathogen Macrophomina phaseolina, which is widely recognized for its aggressive necrotrophic behaviour and its ability to infect over 500 plant species, including economically important crops such as soybean and sorghum. In maize, the disease is particularly destructive under hot and dry climatic conditions and is often referred to as "dry-weather wilt" due to its association with drought stress. The pathogen produces abundant resting structures called *microsclerotia*, which enable it to survive in soil and plant debris for extended periods, often several years, in the absence of a host. These microsclerotia are the primary source of inoculum for new infections.

Biology and Favourable Conditions : The incidence and severity of charcoal rot are closely linked to environmental and agronomic stress factors. Optimal conditions for disease development include high soil temperatures (30–42°C), low soil moisture, and slightly acidic soil pH (5.4–6.0). The pathogen typically invades the host during the reproductive stages, especially post-flowering, when plants are physiologically stressed and more vulnerable to infection. Under such conditions, *M. phaseolina* rapidly colonizes the vascular tissues of the stalk, leading to internal decay, weakening of structural tissues, and lodging.

Several agronomic factors can exacerbate disease severity, including:

- High plant population density
- Excessive application of nitrogen fertilizers
- Insect injury to stalks (e.g., from stem borers)
- Poor drainage and crop residue accumulation

Macrophomina phaseolina produces both microsclerotia small, black, spherical survival structures and occasionally pycnidia, which may be observed on infected stalk tissues. Disease outbreaks are especially common during extremely hot and dry growing seasons**,** particularly when drought coincides with the flowering or grain-filling stages.

Survival and Spread- The primary mode of survival for *M. phaseolina* is through microsclerotia present in soil, infected plant debris, and lower stalk tissues. These structures are highly resilient and can remain viable in the soil for several cropping seasons. The pathogen spreads primarily through:

- **Contaminated soil** adhering to farm machinery and implements
- **Crop residues** left on the field surface or incorporated into the soil
- **Wind-blown dust particles** carrying microsclerotia
- **Water runoff** in some cases

Although seed borne transmission has been investigated, current evidence suggests that seed is not a significant pathway for the spread of *M. phaseolina*. Importantly, the pathogen has a broad host range, and several alternative hosts including legumes and oilseed crops can maintain inoculum levels in the soil, making crop rotation less effective unless resistant or non-host crops are selected.

Fig. 1 : Maize plant infected by Charcoal rot and Fusarium stalk rot

Symptoms of Charcoal Rot in Maize: Charcoal rot in maize, caused by *Macrophomina phaseolina*, typically manifests during the post-flowering stages, particularly under hot, dry, and moisture-deficit conditions. The disease leads to significant yield loss by compromising plant integrity, accelerating senescence, and increasing susceptibility to lodging. The progression of the disease is often subtle initially but rapidly intensifies under environmental stress. Key symptomatic features include:

- **Sudden wilting of plants**, particularly under drought or high evapotranspiration rates, often without visible leaf necrosis in early stages.
- **Fungal colonization of lower internodes**, which results in weakened stalk tissues as the plant approaches physiological maturity.
- **Premature ripening and senescence**, often associated with disrupted water and nutrient translocation due to vascular tissue degradation.
- **Shredding and breakage at the crown region**, where the basal stalk tissues disintegrate, leading to collapse of the plant near the soil surface.
- **Greyish to brownish streaks on infected stalks**, accompanied by internal discoloration, which can be observed upon splitting the stalk longitudinally.

- **Destruction of pith tissues**, where the central core of the stalk becomes **shredded, dry, and stringy,** sometimes completely hollow.
- **Formation of greyish-black microsclerotia** within the vascular bundles and internal tissues of the stalk, giving a characteristic "charcoal" appearance.
- **Frequent stalk lodging or breakage**, especially near the crown, due to internal structural collapse induced by extensive colonization and tissue maceration.

These symptoms not only hinder mechanical harvesting but also contribute to significant post-anthesis yield penalties**,** making timely identification and intervention critical for effective disease management.

Disease Cycle of Charcoal Rot in Maize: The disease cycle of charcoal rot in maize, caused by *Macrophomina phaseolina*, is characterized by its capacity for long-term survival, broad host adaptability, and rapid colonization under environmental stress. The pathogen's ability to persist in soil and plant debris, along with its facultative parasitic lifestyle, facilitates widespread infection across multiple cropping systems.

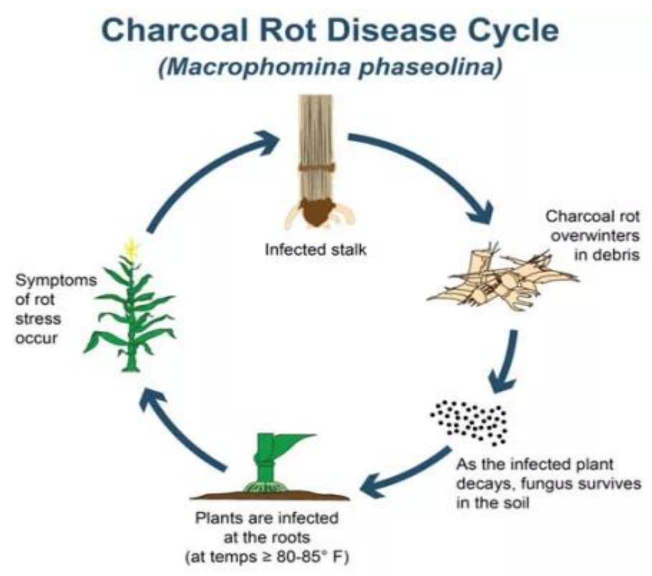

Fig. 2: Disease Cycle of Charcoal Rot in Maize

Wide Host Range: *Macrophomina phaseolina* is a polyphagous pathogen, known to infect over 500 plant species, including economically important crops such as sorghum, pearl millet, finger millet, soybean, chickpea, pigeon pea, and other pulses. This extensive host range contributes significantly to the pathogen's survival and dissemination in diverse agro-ecosystems, particularly under monoculture or cereal–legume rotations.

Survival in Infected Plant Debris: The pathogen survives adverse environmental conditions primarily through the formation of microsclerotia small, melanized, spherical structures that are highly resistant to desiccation and degradation. These structures can remain viable in soil and infected crop residues for up to 15–16 years, acting as the primary survival and inoculum source in subsequent cropping seasons.

Primary Source of Infection: The disease initiates when soil-borne microsclerotia germinate under favourable conditions, particularly at high soil temperatures (30–42°C) and low soil moisture levels. The germinated hyphae invade the root system or basal stalk tissues of the maize plant, especially during post-flowering stages when the host is under physiological stress.

Infection and Colonization: Following entry, *M. phaseolina* rapidly colonizes the vascular and parenchymatous tissues, leading to:

- Disruption of water and nutrient flow
- Internal pith degradation and shredding
- Greyish-black microsclerotia development on vascular bundles
- Stalk discoloration and frequent breakage at the crown

Infected plants may exhibit wilting, premature senescence, and lodging, especially during periods of drought or high evapotranspiration. The pathogen continues its life cycle by producing new microsclerotia within decaying tissues, which return to the soil after plant senescence or harvesting.

Role of Alternative Hosts: Alternative hosts play a crucial role in maintaining the pathogen inoculum between maize-growing seasons. Continuous cultivation of susceptible crops facilitates the buildup of microsclerotia in the soil, reducing the effectiveness of conventional crop rotation as a disease management strategy.

Facultative Parasitism and Saprophytic Survival: *Macrophomina phaseolina* functions as a facultative parasite it behaves as a pathogen under biotic or abiotic stress (e.g., drought, high density, nutrient imbalance) but can also survive and multiply saprophytically on dead organic matter in the absence of a living host. This dual lifestyle ensures its ecological fitness and persistence in a wide range of environmental and cropping conditions.

Management of charcoal rot in maize-

Select Disease-Resistant Varieties- Choosing disease-resistant maize varieties is the first line of defence against charcoal rot. Several hybrid and open-pollinated varieties have been developed, demonstrating resistance to *Macrophomina phaseolina*. Consult local agricultural extension services or seed suppliers for information on resistant varieties that are well-suited to your region.

Crop Rotation- Crop rotation is a key preventive measure against charcoal rot. It helps disrupt the disease's life cycle by depriving it of its preferred host and reducing the pathogen population in the soil. Avoid planting maize in the same field for consecutive seasons. Instead, rotate with non-host crops such as legumes, cereals, or vegetables. Ideally, a three to four-year rotation cycle should be followed to ensure effective control.

Soil Management- Maintaining proper soil health is crucial for managing charcoal rot. The fungus thrives in soils with high moisture levels and poor drainage. Implement good agricultural practices, including improved soil drainage, organic matter incorporation, and balanced nutrient management. Well-drained soils reduce the risk of infection and promote healthy root development, limiting the disease's impact.

Seed Treatment- Treating maize seeds is an effective way to reduce the risk of charcoal rot during germination and early seedling stages. Consult with local seed companies to find fungicide-treated maize seeds specifically designed to combat *Macrophomina phaseolina*. Seed treatments can provide an added layer of protection and increase seedling Vigor, leading to healthier plants and better crop establishment.

Proper Irrigation Practices- Charcoal rot develops and spreads rapidly in wet conditions. Hence, it is essential to implement appropriate irrigation practices to minimize disease incidence. Avoid excessive irrigation or overwatering, as it promotes fungal growth and the disease's spread.

Sanitation and Weed Control- Maintaining proper field hygiene is crucial for managing charcoal rot. Remove and destroy infected maize residues after harvest to reduce inoculum availability for subsequent crops. Effective weed control is also essential, as some weed species can act as alternative hosts for *Macrophomina phaseolina*. Regular weeding and herbicide application, as appropriate, can help minimize disease transmission.

Disease Monitoring- Regular field inspections and disease monitoring are valuable tools for managing charcoal rot. Familiarize yourself with the early symptoms of the disease, such as wilting, yellowing leaves, and black discoloration of stems. Promptly identify and isolate infected plants to prevent further spread. If necessary, consult local agricultural experts for accurate diagnosis and specific control measures tailored to your region.

Biocontrol- Soil application of *P. fluorescens* (or) *T. viride* @ 2.5 kg / ha + 50 kg of well decomposed FYM (mix 10 days before application) or sand at 30 days after sowing.

Fusarium stalk rot- In India Fusarium stalk rot was first reported from Mount Abu, Rajasthan. Fusarium causing disease in maize is probably the one of the most serious diseases among the crop plants all over the world. It not only damages the maize plant, reduces its potential yield and its nutritional values but imposes threatening to the human life through the induction of mycotoxin development. The contamination of human food and animal feed with mycotoxins produced by the Fusarium spp. incur various health issues in human and various livestock, such as equine leukoencephalomalacia, human oesophageal and liver cancer etc.

Pathogen- *F. graminearum* and *F. moniliforme* syn. *Fusarium verticillioides* are two important maize pathogens that cause substantial damage to its ear, stalk and foliage, causing contamination of grains with mycotoxins.

Symptoms of stalk rot disease of maize- The stalk rot symptoms are observed during post flowering and pre-harvest stage.

- Reduced plant growth,
- Rotted leaf sheaths and internal stalk tissue
- Brown streaks in the lower internodes whereas at its maturity, it develops pink to salmon discoloration of the internal stalk pith tissues.
- The Fusarium stalk rot disease may cause premature death of host plant hampering the nutrients and water translocation to leaves and ears.
- The infected maize plant often wilts and appears from a light to a dull colour and lower stalk dries with pith tissues disintegrating to a shredded appearance.
- Tan to dark brown discolouration of the lower internodes and pink to reddish discolouration of the pith tissue are the distinct symptoms of stalk rot caused by *F. graminearum* whereas for *F. verticillioides*, brown streaks appear on the lower

internodes and the rotted pith tissue may be whitish-pink to salmon in colour.

- The systematic and successful infection of seed and root gradually extends towards the internodes, stalk and ear contributing more and more diseases in plant.

Favourable condition for pathogen of Fusarium stalk rot-

- Hot and dry weather conditions especially before or during pollination.
- The water stress at flowering and high soil temperature helps in increasing of the magnitude of the stalk rot symptoms at post flowering stage of maize crop.
- Disease incidence is greater in moist soil and sandy soil than in loam or clay soils.
- Nutrient imbalance (Excessive use of nitrogenous fertilizers).
- High plant population and soil compaction.
- Physical damage through insects.
- Physiological stress.

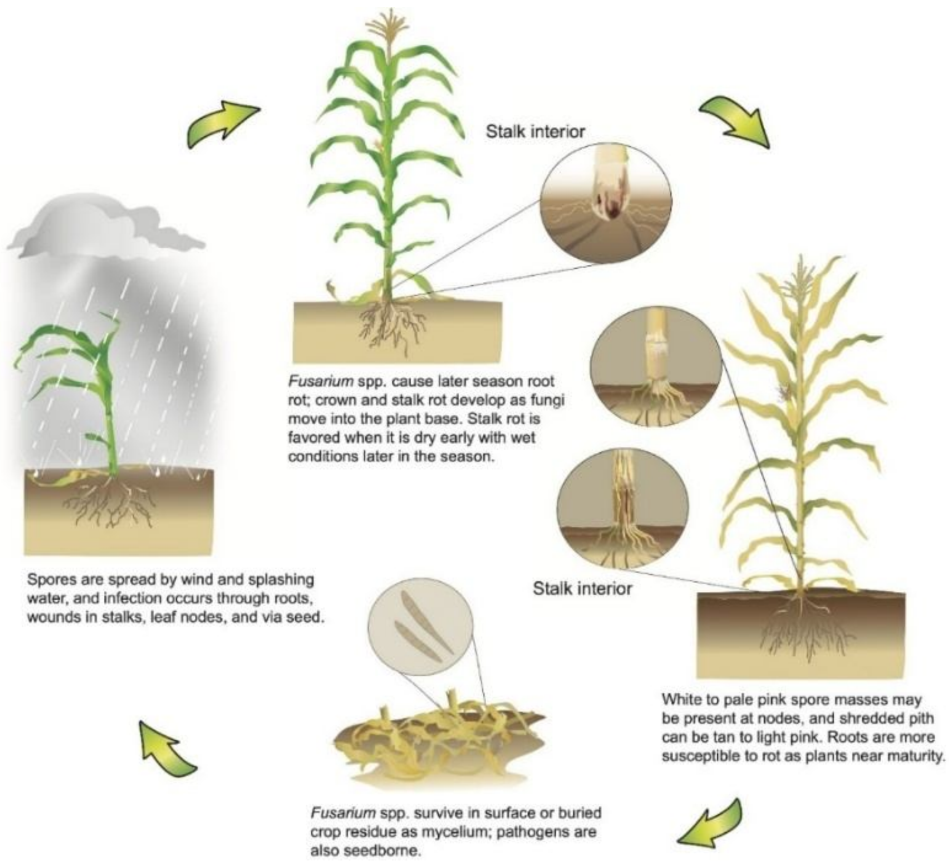

Fig. 3: Disease Cycle of Fusarium stalk rot disease-

Management of Fusarium stalk rot in maize- Post-flowering stalk rot of maize caused by *Fusarium verticillioides* is of major importance as it causes both qualitative and quantitative losses. This disease prevails in regions characterized by the presence of hot and dry weather conditions. It was observed that use of any single management practice is not effective in controlling the stalk rot disease of maize and also too much use of chemicals leads to the development of resistance among fungi and harmful effect on non-target organisms. Although, botanicals and bio-control agents have some antagonistic effect against plant pathogens, they are not very effective when used alone.

- Naturally available biocontrol agents are most promising. Trichoderma a widely used biocontrol agent is well known magical weapon against soil borne pathogens and also known for its mycoparasitic and antagonistic mechanism along with P. fluorescens for the control of fungal disease.
- Application of potassic fertilizers reduces infection.
- Seed from infected areas should not be planted.
- Crop Rotation should be adopted.

- Use of resistant varieties, adoption of seed treatment method with optimum plant population is beneficial to control the disease.

Maize breeding approaches for Charcoal and Stalk Rot Resistance– Breeding for resistance to charcoal and stalk rots in maize is a crucial strategy to ensure yield stability, especially under climate-induced stress conditions. The primary objectives are to develop hybrids or inbred lines with enhanced resistance or tolerance to these diseases, improved stalk strength for better stand ability, drought tolerance (which indirectly mitigates disease impact), and early maturity to help plants escape terminal stress. Germplasm screening forms the foundation of this effort, involving identification of resistant sources from landraces, wild relatives, and advanced inbreds through field evaluations under natural or artificial inoculation in disease nurseries. Selection strategies include both phenotypic methods such as disease severity index (DSI) and rind penetrometer resistance (RPR) and genotypic approaches, including QTL mapping, marker-assisted selection (MAS), and genomic selection (GS). Resistance mechanisms involve antixenosis (e.g., thick rind), antibiosis (e.g., production of phenolics and lignin), and tolerance (ability to sustain yield under infection). Tools like artificial inoculation, RPR tests, molecular markers, and stress phenotyping support these breeding programs. However, challenges such as polygenic inheritance, genotype-by-environment interactions, pathogen diversity, and drought–disease synergy complicate progress. Nonetheless, success has been achieved by institutions like CIMMYT, with resistant hybrids and mapped QTLs. Future directions emphasize integrating omics technologies, gene editing tools like CRISPR/Cas, and high-throughput phenotyping to develop climate-resilient maize varieties with durable resistance. Ultimately, a holistic breeding approach combining conventional and molecular techniques is essential for sustainable management of stalk and charcoal rots in maize.

While, Effective breeding management for resistance to charcoal rot and stalk rots in maize requires a well-coordinated and multidisciplinary approach. This involves strategic planning from germplasm acquisition and screening to advanced selection techniques that combine both phenotypic and genotypic evaluations. Managing breeding programs efficiently includes establishing disease nurseries, ensuring reliable artificial inoculation protocols, maintaining genetic diversity, and implementing selection methods that account for complex traits influenced by environmental factors. Integration of molecular tools such as QTL mapping, marker-assisted selection (MAS), and genomic selection (GS) significantly enhances selection accuracy and accelerates the development of resistant lines. Moreover, breeding management must prioritize continuous evaluation of hybrids under diverse agro-climatic conditions to ensure stable resistance. The use of data-driven decision-making, precise phenotyping, and emerging technologies such as CRISPR and high-throughput screening further strengthens the breeding pipeline. Ultimately, successful breeding management hinges on sustained efforts, collaborative research, and the adoption of integrated breeding strategies aimed at developing resilient, high-yielding, and disease-resistant maize varieties.

Whereas, several inbred lines and cultivars have shown promising resistance to stalk rots and related stress traits across different geographies. Among them, DML-339 (INGR17022) stands out for its resistance to charcoal rot, coupled with favourable anthesis–silking synchrony, stay-green traits, and stiff stalk architecture, making it a valuable resource for disease-resilient breeding. In an earlier collaborative breeding effort between CIMMYT and IARI, three inbred lines PFSR-13-5, JCY2-2-4-1-1-1-1, and JCY3-7-1-2-1-b-1 were identified for their resistance to post-flowering stalk rots across hotspot locations. Similarly, populations such as PFSR (Y)-C1, Extra-early (White), P-100, P-300, and P-345 exhibited enhanced resistance profiles. In South Africa, field screenings highlighted LS/8541/BR, PAN/5R-591/R, and PAN/4A-156 as top performers with the lowest disease ratings for charcoal stalk rot, in contrast to highly susceptible cultivars like SC506 and US9616. The inbred line18N10118 demonstrated exceptional resistance to *Fusarium graminearum*, attributed to increased defence enzyme activity and structural barriers, ranking it highest among 120 lines tested from China. These lines collectively represent critical genetic resources for developing stalk rot–resistant maize varieties. These following varieties are using against aforesaid Disease like KMH-42283 is fully resistant hybrid, Many KML, KMH, KNMH, NK, and DHM lines are moderately resistant, KMH-152 is resistant inbred, PFSR-135, CML, BML lines and hybrids are resistant genetic material, DMR-PFSR-1, DMR-PFSR-9 & DML-339 are strong resistance and favourable agronomic traits and PFSR-13-5, JCY lines, and various populations are effective resistant sources, LS/8541/BR, PAN series are field-resistant cultivars in South Africa and 18N10118 is also high resistance to stalk rot by *F. graminearum.*

Therefore, the breeding for resistance to charcoal and stalk rots in maize is vital for yield stability under climate stress. The main objectives include developing resistant/tolerant hybrids and inbreds with strong stalks, drought tolerance, and early maturity. Breeding efforts begin with germplasm screening of landraces, inbreds, and populations under field/artificial inoculation, followed by phenotypic tools like disease severity index (DSI) and rind penetrometer resistance (RPR), and molecular approaches such as QTL mapping, marker-assisted selection (MAS), and genomic selection (GS). Resistance mechanisms involve structural barriers (thick rind, stiff stalks), biochemical defences (phenolics, lignin, defence enzymes), and tolerance to infection. Challenges include polygenic inheritance, G×E interactions, and drought–disease synergy, though success has been achieved with resistant hybrids and mapped QTLs from institutions like CIMMYT. Effective breeding management requires multidisciplinary approaches disease nurseries, reliable inoculation, precision phenotyping, and integration of emerging tools like CRISPR and high-throughput screening. Several resistant genetic resources have been identified worldwide, such as DML 339, PFSR lines, CIMMYT–IARI inbreds, and populations (PFSR, P100, P345), along with South African cultivars like LS/8541/BR and PAN hybrids, and Chinese line 18N10118. Resistant Indian hybrids (e.g., KMH 42283) and lines (KMH, KNMH, DHM, CML, BML, DMR PFSR 1, DMR PFSR 9) also contribute to developing durable resistance. Overall, integrating conventional and molecular breeding with new technologies holds the key to sustainable management of stalk and charcoal rots in maize.

Importance of soil and microorganisms in management of Charcoal and Stalk Rot of Maize- Soil plays a critical role in managing charcoal rot and stalk rot diseases in maize. The presence of the soil-borne fungi causing these diseases is influenced by soil conditions such as temperature, moisture, and nutrient balance. Charcoal rot is favoured by high soil temperatures (30–42°C) and low soil moisture, often occurring during hot, dry periods. Maintaining proper soil moisture through irrigation can help reduce disease severity. Nutrient management is important too high nitrogen combined with low potassium increases stalk rot severity, while adequate potassium helps reduce it. Crop residue management also matters; removal or burying of infected maize stubble reduces fungal inoculum in the soil, minimizing disease carryover. The soil microbial community can influence disease outcomes; beneficial microbes like *Bacillus siamensis* or bio-control agents such as *Trichoderma* and *Pseudomonas fluorescens* applied as seed treatments or soil amendments can suppress pathogens and promote plant health. Overall, practices maintaining balanced soil fertility, good moisture, residue management, and promoting beneficial soil microbiota significantly contribute to reducing maize stalk and charcoal rot disease incidence.

Whereas, the soil microbiome plays a vital role in biocontrol by suppressing plant pathogens and enhancing plant health through multiple mechanisms. Soil bacteria and fungi such as *Bacillus, Pseudomonas, Streptomyces, and Trichoderma* produce antimicrobial compounds, enzymes, and organic acids that inhibit pathogen growth. They compete with pathogens for nutrients and ecological niches, reducing pathogen establishment. Some microbes induce systemic resistance in plants by triggering defence responses. Additionally, beneficial microbes enhance nutrient cycling, improve soil structure, and promote plant growth, thus indirectly improving disease tolerance. The diverse microbial communities help maintain soil and plant ecosystem stability, offering sustainable alternatives to chemical controls. Biocontrol using soil microbiomes also supports eco-friendly agriculture by reducing chemical inputs and enhancing resilience to abiotic stresses. However, efficacy depends on soil conditions, microbial diversity, and environmental factors, requiring further research for optimized application in disease management. Soil solarization and soil bio-solarization are soil disinfection methods to destroy the soil borne pathogens. Application of potassic fertilizers also reduces the disease infection.

Integration of biological and chemical control seems to be a promising way of controlling many pathogens with minimum interference in the biological equilibrium in soil. Since soil is highly complex and biologically active substrate through which the fungicide act against fungi, fungitoxicants often give viable success in controlling seedling disease of crops in diverse agro-climatic regions of the world. The use of fungicides and tolerant genotypes has been reported to be effective method to manage stalk rot of maize which holds some promise. Application of farm yard manure and neemcake along with *Trichoderma harzianum* 15-20 days before sowing with two additional irrigations at tasselling and silking stage reduced the stalk rot disease.

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