

REVIEW

Root rot caused by *Macrophomina phaseolina*: Epidemiology, symptoms, and management in crops

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Abstract: Root rot caused by *Macrophomina phaseolina* is one of the most economically important soilborne diseases, affecting several crops, including soybean, maize, cotton, and common bean. This study aimed to conduct a literature review on the epidemiology, symptomatology, diagnosis, and management of this pathogen. *M. phaseolina* exhibits a high survival capacity in soil due to the formation of microsclerotia and is favored by high temperatures and water deficit conditions. Infection compromises the root system, reducing water and nutrient uptake and causing symptoms such as root necrosis, wilting, premature senescence, and yield reduction. Disease diagnosis can be performed through field symptom assessment, fungal isolation, and molecular techniques such as polymerase chain reaction (PCR). Disease management is primarily based on integrated strategies, including crop rotation, the use of resistant cultivars, proper soil management, and biological control. Therefore, understanding the biology and epidemiology of *Macrophomina phaseolina* is essential for developing effective control measures and reducing agricultural losses associated with the disease.

Keywords: *Macrophomina* genus, Root rot, Soilborne pathogen, Phytopathogen, Integrated management.

1. Introduction

Root rot caused by *Macrophomina phaseolina* (Tassi) Goid is one of the most economically important diseases among soilborne plant pathogens, affecting major crops worldwide, including soybean, maize, cotton, common bean, sorghum, and sunflower. The pathogen is widely distributed across tropical and subtropical regions, where high temperatures and low soil moisture favor disease development (Gupta et al., 2012; Marquez et al., 2021). Due to its broad host range, estimated at more than 500 plant species belonging to different botanical families, *M. phaseolina* is considered one of the most polyphagous phytopathogenic fungi in agriculture (Kaur et al., 2012; Marquez et al., 2021).

The importance of this pathogen is associated not only with its extensive distribution and infective capacity but also with its potential to cause significant

economic losses. Under favorable environmental conditions, particularly drought stress and temperatures ranging from 30 to 35 °C, yield losses may exceed 50% in susceptible crops, compromising both profitability and sustainability of agricultural production systems (Gupta et al., 2012; Marquez et al., 2021; Shirai; Eulgem, 2023). Furthermore, climate change projections suggest that prolonged drought events may increase the incidence and severity of the disease in several crop-producing regions.

The long-term survival of *M. phaseolina* in soil is primarily attributed to the formation of microsclerotia, resistant structures composed of compact aggregates of melanized hyphae. These structures exhibit remarkable tolerance to adverse environmental conditions and can remain viable in soil for several years, even in the absence of host plants, serving as an important source of inoculum for subsequent disease cycles (Gupta et al.,

2012; Kaur et al., 2012). The persistence of microsclerotia represents one of the major challenges for effective disease management.

The infection process begins with the germination of microsclerotia in the soil, followed by colonization of root and vascular tissues of susceptible hosts. During infection, the fungus produces hydrolytic enzymes and metabolites that degrade plant tissues, impairing water and nutrient transport. As a result, the most common symptoms include root darkening and necrosis, lesions at the stem base, wilting, leaf chlorosis, premature senescence, and plant death under severe disease pressure (Farag et al., 2025; Marquez et al., 2021).

In recent years, advances in molecular biology have significantly improved the understanding of the pathogenicity mechanisms of *M. phaseolina*. Genome sequencing studies have revealed numerous genes associated with virulence, cell wall-degrading enzymes, and adaptation to diverse host species, helping to explain the pathogen's broad host range and ecological adaptability (Islam et al., 2012).

Management of root rot caused by *M. phaseolina* remains a major challenge in modern plant pathology due to the pathogen's extensive host range, high genetic variability, and long-term survival in soil. Consequently, individual control measures often provide limited effectiveness, highlighting the need for integrated disease management programs that combine cultural practices, resistant cultivars, proper irrigation management, biological control agents, and continuous disease monitoring (Oder et al., 2025; Marquez et al., 2021; Gupta et al., 2012).

Given the economic and phytosanitary importance of this pathogen, compiling and discussing updated information regarding its biology, epidemiology, infection mechanisms, symptomatology, and management strategies is essential. Therefore, this study is characterized as a literature review and aims to address the main aspects related to root rot caused by *Macrophomina phaseolina* in crops, emphasizing the factors influencing disease development and the available strategies for its sustainable management.

2. Integrative Literature Review Methodology

This study is characterized as an integrative literature review aimed at gathering, analyzing, and synthesizing scientific information regarding the epidemiology, infection mechanisms, symptomatology, diagnosis, and management strategies of *M. phaseolina* in crops.

The literature search was conducted using the Scopus, Web of Science, SciELO, and Google Scholar databases,

considering scientific articles, review papers, book chapters, and technical documents published between 2010 and 2026. Publications in English and Portuguese addressing aspects related to pathogen biology, host-pathogen interactions, epidemiological factors, diagnostic methods, and management strategies for root rot and charcoal rot caused by *M. phaseolina* were included.

The following keywords were used for the literature search in English: “*Macrophomina phaseolina*”, “charcoal rot”, “root rot”, “soil-borne pathogen”, “microsclerotia”, “plant disease”, “epidemiology”, “disease management”, and “biological control”. In Portuguese, the following descriptors were used: “*Macrophomina phaseolina*”, “podridão radicular”, “podridão de carvão”, “patógeno de solo”, “fungo fitopatogênico”, “epidemiologia de doenças de plantas”, “controle biológico”, and “manejo integrado de doenças”. Keywords were applied individually and in combination using the Boolean operators AND and OR.

The inclusion criteria comprised peer-reviewed studies published in indexed journals that provided relevant information related to the objectives of this review. Duplicated records, conference abstracts without full publication, non-peer-reviewed documents, and studies not directly related to the proposed topic were excluded.

After the selection process, the studies were qualitatively analyzed and organized into thematic categories, including pathogen biology, survival and dissemination mechanisms, epidemiological factors, symptom development, diagnostic approaches, and disease management strategies. The synthesis of the selected literature enabled the identification of major scientific advances, existing knowledge gaps, and future perspectives for the sustainable management of *M. phaseolina* in agricultural production systems.

3. *Macrophomina phaseolina*

3.1. Taxonomic and biological characteristics of *Macrophomina phaseolina*

Macrophomina phaseolina (Tassi) Goid is a widely distributed phytopathogenic fungus in tropical and subtropical regions and is recognized as one of the most important soilborne pathogens due to its broad host range and remarkable ability to survive under adverse environmental conditions (Rangel-Montoya et al., 2022). Taxonomically, the fungus belongs to the Kingdom Fungi, phylum *Ascomycota*, class *Dothideomycetes*, order *Botryosphaerales*, and family *Botryosphaeriaceae* (Gupta et al., 2012; Marquez et al., 2021). Although the genus *Macrophomina* comprises only a few described species, *M. phaseolina* stands out because of its economic

importance and impact on agricultural systems worldwide (Ghosh et al., 2018; Khan; Javaid, 2023).

One of the most notable characteristics of this pathogen is its polyphagous behavior. It is estimated that *M. phaseolina* can infect more than 500 plant species belonging to different botanical families, including economically important crops such as soybean (*Glycine max*), maize (*Zea mays*), common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), cotton (*Gossypium hirsutum*), sorghum (*Sorghum bicolor*), and sunflower (*Helianthus annuus*) (Kaur et al., 2012; Sodji et al., 2025). In addition to crops, the fungus can colonize weeds, forest species, and ornamental plants, expanding its survival sources and complicating disease management strategies in the field (Sohaliya et al., 2025).

The adaptive capacity of *M. phaseolina* is closely associated with its high genetic variability and its ability to exploit different ecological niches. Molecular studies have demonstrated considerable genetic diversity among fungal populations, allowing rapid adaptation to environmental conditions and a wide range of hosts. This characteristic contributes to the persistence of the pathogen in agricultural systems subjected to different management practices (Islam et al., 2012).

From a biological perspective, the primary survival structure of the fungus is the microsclerotium. These structures consist of compact aggregates of melanized hyphae with a dark coloration resulting from melanin deposition in their cell walls. Melanization protects against solar radiation, desiccation, and other adverse environmental factors, enabling microsclerotia to remain viable in soil for several years, even in the absence of susceptible hosts (Gupta et al., 2012). In infested agricultural fields, microsclerotia serve as the main source of inoculum for new disease cycles (Lodha; Mawar, 2019).

The life cycle of *M. phaseolina* begins with the germination of microsclerotia in response to root exudates released by host plants. Following germination, the fungus colonizes root tissues and the stem base, producing hydrolytic enzymes such as cellulases, pectinases, and ligninases that degrade plant cell walls. This process facilitates tissue invasion and subsequent colonization of the vascular system, impairing water and nutrient transport within the plant (Kaur et al., 2012; Marquez et al., 2021).

Environmental conditions strongly influence disease development. High temperatures, generally ranging from 30 to 35 °C, combined with periods of water deficit, favor both microsclerotia germination and tissue colonization. Under these conditions, plants become more susceptible to infection, resulting in increased symptom severity and greater yield losses. Consequently, root rot caused by *M.*

phaseolina is frequently associated with regions exposed to climatic stress, particularly under scenarios of global climate change (Farag et al., 2025; Marquez et al., 2021).

Another important aspect of the fungus's biology is its ability to produce a wide variety of metabolites and virulence factors. Genomic studies have identified genes associated with the production of plant cell wall-degrading enzymes, pathogenicity-related proteins, and mechanisms of tolerance to environmental stress. These characteristics partially explain the pathogen's high destructive potential and its ability to infect diverse plant species (Islam et al., 2012; Sinha et al., 2022).

Therefore, understanding the taxonomic, biological, and ecological aspects of *M. phaseolina* is essential for comprehending its epidemiology and for developing effective integrated disease management strategies aimed at reducing the economic impacts caused by this pathogen in agricultural systems (Kaur et al., 2011; Lodha; Mawar, 2019).

3.2. Infection and colonization process of *Macrophomina phaseolina*

The infection process of *M. phaseolina* primarily begins from microsclerotia present in the soil, which serve as the main survival and dissemination structures of the pathogen. Under favorable environmental conditions, particularly temperatures ranging from 30 to 35 °C and low soil moisture, microsclerotia germinate and produce infective hyphae capable of recognizing and responding to root exudates released by host plants (Gupta et al., 2012; Marquez et al., 2021).

Following germination, the fungus penetrates root tissues either directly or through natural openings and wounds caused by environmental stress, insects, or nematodes. Initial colonization occurs in the root cortex and is followed by invasion of vascular tissues, particularly the xylem, impairing the transport of water and nutrients to the aerial parts of the plant. During this process, *M. phaseolina* produces hydrolytic enzymes, including cellulases, hemicellulases, and pectinases, which degrade plant cell walls and facilitate the rapid spread of infection throughout host tissues (Kaur et al., 2012).

The colonization capacity of the fungus is closely associated with the production of virulence factors and phytotoxic metabolites that promote cell death and tissue necrosis. Consequently, characteristic symptoms develop, including root darkening, cortical necrosis, lesions at the stem base, reduced plant growth, leaf chlorosis, wilting, and premature plant death under severe infections (Marquez et al., 2021).

Infection by *M. phaseolina* is of major concern in

numerous crops due to its broad host range and destructive impact on plant health and productivity. In soybean (*G. max*), the pathogen causes charcoal rot, resulting in substantial yield losses, particularly under drought stress conditions. In maize (*Z. mays*), colonization of the root system impairs water and nutrient uptake, increasing susceptibility to lodging and negatively affecting grain development. Similarly, in common bean (*P. vulgaris*), cotton (*G. hirsutum*), sorghum (*S. bicolor*), and sunflower (*H. annuus*), the disease is commonly associated with reduced plant vigor, lower productivity, and diminished crop quality (Gupta et al., 2012).

Kaur et al. (2023) reported the occurrence of *M. phaseolina* infecting mung bean (*Vigna radiata*), further highlighting the pathogen's adaptability to diverse hosts. More recently, Ranjan et al. (2024) and Mmbaga et al. (2018) emphasized the extensive host range of *M. phaseolina*, which includes more than 100 plant species of agricultural and floricultural importance, reinforcing its status as one of the most economically significant soilborne fungal pathogens worldwide.

Beyond field infections, studies have demonstrated that *M. phaseolina* can survive in crop residues, infected seeds, and stored plant materials. The presence of the fungus in seeds represents an important pathway for dissemination into new production areas, contributing to the establishment of the pathogen in previously non-infested regions. In stored grains, fungal colonization may result in tissue deterioration, reduced seed physiological quality, and economic losses during storage (Kaur et al., 2012).

Another relevant aspect of the infection process is the close relationship between disease severity and environmental factors. Water stress, high temperatures, low soil fertility, and soil compaction favor root rot development by reducing the plant's ability to respond to infection. For this reason, the disease is often considered a pathosystem strongly influenced by the interaction among pathogen, host, and environment, with outbreaks becoming more severe under unfavorable climatic conditions (Marquez et al., 2021).

Therefore, a detailed understanding of the infection and colonization mechanisms of *M. phaseolina* is essential for the development of more effective disease management strategies, allowing reductions in pathogen survival in soil, minimization of crop damage, and improved sustainability of agricultural production systems (Lodha; Mawar, 2019; Marquez et al., 2021).

3.3. Worldwide distribution of *Macrophomina phaseolina*

Macrophomina phaseolina is considered one of the most widely distributed phytopathogenic fungi

worldwide, occurring on nearly all continents where susceptible host species are cultivated (Farr; Rossman, 2024). Its broad distribution is associated with the remarkable survival capacity of microsclerotia in soil, its extensive host range, and its dissemination through infected seeds, crop residues, and contaminated agricultural equipment (Gupta et al., 2012; Kaur et al., 2012; Pedroncelli et al., 2025).

The pathogen is most frequently found in tropical and subtropical regions characterized by high temperatures and periods of water deficit. Under these conditions, the fungus encounters a highly favorable environment for germination, colonization, and disease development, resulting in increased incidence and severity. Countries such as Brazil, India, the United States, Argentina, Mexico, China, Pakistan, Australia, and several African nations have consistently reported outbreaks of root rot and charcoal rot caused by *M. phaseolina* (Castro-Diego et al., 2026; Marquez et al., 2021) and Türkiye (Canpolat et al., 2022).

India is considered one of the regions most severely affected by the pathogen, where the disease represents a major limiting factor for the production of legumes, oilseed crops, and other food crops. In the United States, *M. phaseolina* is widely distributed across major soybean and maize-producing regions, particularly in states experiencing high temperatures during the reproductive stages of crop development. In South America, the disease has been frequently reported in soybean-producing areas of Brazil, Argentina, and Paraguay, where climatic conditions strongly favor fungal development (Elez et al., 2023; Gupta et al., 2012).

In Brazil, the presence of *M. phaseolina* has been reported in virtually all major agricultural regions. The expansion of soybean, maize, and cotton cultivation areas, combined with the occurrence of prolonged drought periods and irregular rainfall patterns, has contributed to the increasing incidence of the disease in recent decades. In the Brazilian Cerrado, characterized by high temperatures and seasonal water stress, the pathogen finds ideal conditions for survival and multiplication, becoming a significant phytosanitary challenge for agricultural production (da Costa et al., 2023; Dilkin et al., 2022; Morais et al., 2022).

The worldwide distribution of *M. phaseolina* is also closely linked to its ability to infect more than 500 plant species. The presence of alternative hosts, including weeds and spontaneous vegetation, contributes to the maintenance of inoculum sources in the environment and complicates eradication efforts. Furthermore, the long-term persistence of microsclerotia in soil allows infested fields to remain potential sources of infection for several years, even after crop rotation practices have been

implemented (Kaur et al., 2012).

Recent studies suggest that global climate change may further expand the distribution and economic importance of *M. phaseolina*. Rising average temperatures and the increasing frequency of drought events are expected to favor pathogen development while simultaneously increasing host susceptibility. Consequently, the disease is increasingly recognized as an emerging threat to agricultural production systems, particularly in regions prone to water stress (Marquez et al., 2021).

Under highly favorable conditions for pathogen development, yield losses may exceed 50% in susceptible crops, depending on cultivar susceptibility, plant growth stage, and the intensity of environmental stress. These impacts highlight the importance of phytosanitary monitoring and the implementation of integrated disease management strategies to reduce the economic losses associated with this pathogen across different agricultural regions worldwide (Gupta et al., 2012).

3.4. Chemical and biological control and integrated management of *Macrophomina phaseolina*

The management of *M. phaseolina* remains one of the greatest challenges in plant pathology due to the pathogen's broad host range, high genetic variability, and, most importantly, its ability to survive in soil for extended periods through microsclerotia. These resistant structures can remain viable for several years, making pathogen eradication difficult and reducing the effectiveness of individual control measures. Consequently, integrated disease management strategies are considered the most effective approach for minimizing disease-related losses (Gupta et al., 2012; Marquez et al., 2021).

Chemical control has shown variable results and, in many cases, limited effectiveness when used alone. Several fungicides, biological agents, and β -glucosidases have been evaluated for their ability to reduce microsclerotia germination and fungal mycelial growth, including active ingredients such as carbendazim, thiophanate-methyl, azoxystrobin, fludioxonil, tebuconazole, and pyraclostrobin (Abo-Elyousr et al., 2026; Degani et al., 2024; Khalili et al., 2026). Although some of these compounds exhibit fungistatic effects or reduce disease severity, their efficacy depends on environmental conditions, soil inoculum density, crop growth stage, and the sensitivity of pathogen populations to the active ingredients applied (Degani et al., 2023; Marquez et al., 2021).

Seed treatment has been widely adopted as a complementary management practice, protecting seedlings during the early stages of plant development. However, due to the predominantly soilborne nature of

the disease and the long-term survival of the pathogen in soil, seed treatment alone has limited effects on established infestations and should be integrated with additional control measures (Sagarika et al., 2023).

Among cultural practices, crop rotation is an important tool for reducing inoculum pressure in the soil. However, the broad host range of *M. phaseolina* limits the effectiveness of this strategy when susceptible species are included in cropping sequences. Therefore, the use of less susceptible or non-host crops is recommended, together with proper soil fertility management, maintenance of soil organic matter, and the reduction of factors that increase plant stress (Gupta et al., 2012; Rajendra Prasad et al., 2022).

The use of resistant or tolerant cultivars represents one of the most promising approaches for sustainable disease management. Although high levels of genetic resistance are still limited in many crops, breeding programs have identified genotypes with improved tolerance to the pathogen, reducing infection-related damage and contributing to greater production stability (Kaur et al., 2012).

In recent years, biological control has gained increasing attention as a key component of integrated management programs for *M. phaseolina* (Jaber; Fayyadh, 2019; Villavicencio-Vásquez et al., 2025). Antagonistic microorganisms, particularly species belonging to the genera *Trichoderma*, *Bacillus*, and others, have demonstrated substantial potential to reduce microsclerotia germination, inhibit mycelial growth, and stimulate plant defense mechanisms (Pandit et al., 2022). Species such as *Trichoderma harzianum*, *Trichoderma asperellum*, *Bacillus subtilis*, and *Bacillus amyloliquefaciens* are among the most extensively studied biological agents for controlling this pathogen (Marquez et al., 2021).

Furthermore, practices aimed at reducing plant water stress can significantly contribute to lowering disease severity. Proper irrigation management, soil moisture conservation, and the adoption of cropping systems that promote soil health help reduce conditions favorable to infection and pathogen development (Singh et al., 2024). This approach is particularly relevant given projections of increasing frequency and intensity of extreme climatic events associated with global climate change (Farag et al., 2025; Ranjan et al., 2024).

Therefore, the integrated management of *M. phaseolina* should be based on the combination of multiple control strategies, including cultural practices, resistant cultivars, seed treatment, biological control, and, when necessary, the judicious use of fungicides (Khaskheli et al., 2025). The integration of these measures contributes to reducing pathogen populations in the

environment, minimizing disease-related damage, and promoting the sustainability of agricultural production systems (Awoke et al., 2025).

3.5. Epidemiology and dissemination of *Macrophomina phaseolina*

The epidemiology of the phytopathogenic fungus *M. phaseolina* is strictly associated with specific climatic conditions, being predominantly favored by hot and dry environments (Lodha; Mawar, 2019). This climatic scenario stimulates both microesclerotia germination and subsequent root infection in host plants. With a broad geographical distribution, it is believed that the global dissemination of the pathogen has occurred mainly through the transport of contaminated seeds, crop residues, and infected soil (Ghosh et al., 2018; Pandey; Basandrai, 2020). In Brazil, the relevance of this disease grew significantly with the expansion of soybean and corn crops into tropical climate regions. Locally, the fungus can also be spread via agricultural implements, irrigation water, and contaminated plant debris (Gupta et al., 2012; Júnior et al., 2020; Negreiros et al., 2019).

3.6. Symptomatology and economic impact

Classic symptoms observed in plants infected by *M. phaseolina* include:

- Root system necrosis;
- Progressive stem discoloration;
- Generalized wilting;
- Premature maturation (which compromises grain filling).

In economic terms, yield losses in crops are variable and fluctuate according to seasonal weather conditions, the susceptibility level of the cultivars used, and the initial infection intensity caused by the pathogen (Gupta et al., 2012; Kaur et al., 2011; Mendes et al., 2015).

4. Conclusion

Macrophomina phaseolina stands out as one of the most complex phytopathological challenges for contemporary agriculture in tropical and subtropical regions. The fungus's robust survival capacity in the soil via microsclerotia—accentuated by increasingly frequent scenarios of drought stress and high temperatures—not only accelerates the dissemination of charcoal rot but also severely restricts the efficacy of isolated control interventions.

Given this complexity, mitigating economic damage

strictly depends on the consolidation of Integrated Disease Management (IDM). Strategies that combine crop rotation with non-host species, genetic improvement focused on resilient cultivars, biological control, and conservation practices that enhance soil bio-structure are no longer optional, but fundamental prerequisites for yield stability. In short, successfully addressing the threat of *Macrophomina phaseolina* requires continuous advancements in elucidating its epidemiological dynamics and molecular infection mechanisms. Only by bridging the gap between scientific research and practical field management will it be possible to design sustainable agricultural systems capable of safeguarding crop yield potential and ensuring food security in the face of global climate change.

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The authors declare that they have no conflicts of interest.

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Author's Contributions

Diuly Morgana Matias Araujo: study conceptualization, research coordination, main drafting of the manuscript, development of the integrative literature review, scientific review, and general organization of the article. *Gabriel Ribeiro dos Santos*: literature review, analysis of scientific information, and textual review. *Guilherme Rafael do Prado*: bibliographic research, assistance with the scientific discussion, and review of technical content. *Heric Santos Souza*: gathering of scientific data, bibliographic research, and assistance with article structuring. *Humberto Bispo da Silva*: methodological analysis, organization of bibliographical references, and academic review. *Juliana Araújo Rocha*: scientific advising, research supervision, and final review of the manuscript. *Maxsuel Lucas da Silva*: methodology development, literature review, and textual correction. *Porshia Sharma*: english language editing and final proofreading for publication. *Carlos Frederico de Souza Castro*: final corrections and scientific writing. *Natália Melo Martins*: assistance with scientific data interpretation, review of academic standards, and article formatting.

Ethics