

Pratylenchus zeae in maize: Current advances, economic impacts, and challenges for sustainable management

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Abstract

Maize (*Zea mays* L.) is one of the most important crops worldwide, playing a fundamental role in food security, animal nutrition, and industrial production. However, its productivity is frequently threatened by plant-parasitic nematodes, among which *Pratylenchus zeae* stands out as one of the most relevant species in tropical and subtropical production systems. This study aimed to conduct a narrative literature review on the impacts of *P. zeae* on maize, synthesizing scientific advances published between 2016 and 2025 and identifying current knowledge gaps related to its management. The review was based on a qualitative and descriptive approach, using scientific articles, theses, dissertations, technical documents, and review papers retrieved from SciELO, CAPES Periodicals Portal, Brazilian Digital Library of Theses and Dissertations (BDTD), Web of Science, and PubMed/MEDLINE databases. The available evidence indicates that *P. zeae* acts primarily within the root system, causing cortical lesions, impairing water and nutrient uptake, reducing plant vigor, and increasing susceptibility to abiotic and biotic stresses. The persistence and spread of the nematode are strongly influenced by continuous cultivation of susceptible hosts, inadequate crop rotation practices, weed reservoirs, and the use of highly susceptible genotypes. Current management strategies emphasize integrated approaches combining nematological diagnosis, population monitoring, crop rotation, cover crops, weed management, host resistance, biological control agents, and soil health improvement practices. Despite significant advances in understanding the biology and ecology of *P. zeae*, important gaps remain regarding economic damage thresholds, regionalized risk assessments, and the validation of management practices under commercial field conditions. Overall, sustainable management of *Pratylenchus zeae* requires an integrated systems-based approach supported by region-specific research capable of improving decision-making and reducing nematode-associated yield losses in maize production systems.

Keywords: *Pratylenchus zeae*, maize, root-lesion nematode, plant–nematode interaction, crop productivity.

Pratylenchus zeae na cultura do milho: Avanços atuais, impactos econômicos e desafios para o manejo sustentável

Resumo

O milho (*Zea mays* L.) constitui uma das culturas agrícolas mais importantes do mundo, desempenhando papel estratégico na segurança alimentar, na produção animal e em diversos setores industriais. Entretanto, sua produtividade pode ser significativamente comprometida por fitonematóides, destacando-se *P. zeae* como uma das espécies mais relevantes em sistemas agrícolas tropicais e subtropicais. Este estudo teve como objetivo

realizar uma revisão narrativa da literatura sobre os impactos de *P. zae* na cultura do milho, sintetizando os avanços científicos publicados entre 2016 e 2025 e identificando lacunas de conhecimento relacionadas ao seu manejo. A pesquisa foi conduzida por meio de abordagem qualitativa e descritiva, utilizando artigos científicos, dissertações, teses, documentos técnicos e revisões obtidos nas bases SciELO, Portal de Periódicos CAPES, Biblioteca Digital Brasileira de Teses e Dissertações (BDTD), Web of Science e PubMed/MEDLINE. As evidências disponíveis demonstram que *P. zae* atua predominantemente no sistema radicular, promovendo lesões necróticas, comprometendo a absorção de água e nutrientes, reduzindo o vigor vegetativo e aumentando a suscetibilidade das plantas a estresses bióticos e abióticos. A persistência e o aumento populacional do nematoide estão associados à sucessão de culturas hospedeiras, à presença de plantas daninhas, ao uso de genótipos suscetíveis e à ausência de monitoramento nematológico. As estratégias de manejo mais promissoras baseiam-se em abordagens integradas que incluem diagnóstico e monitoramento populacional, rotação de culturas, utilização de plantas de cobertura adequadas, manejo de plantas espontâneas, uso de genótipos menos favoráveis à reprodução do nematoide, controle biológico e práticas voltadas à melhoria da saúde do solo. Apesar dos avanços obtidos na compreensão da biologia, ecologia e interação patógeno-hospedeiro, ainda persistem lacunas relacionadas à definição de limiares de dano econômico, à quantificação regionalizada das perdas produtivas e à validação de estratégias de manejo em condições comerciais de cultivo. Conclui-se que o manejo sustentável de *Pratylenchus zae* depende da adoção de estratégias integradas e do fortalecimento de pesquisas aplicadas que subsidiem recomendações técnicas mais precisas para os sistemas de produção de milho.

Palavras-chave: *Pratylenchus zae*, milho, nematoide das lesões radiculares, interação patógeno-hospedeiro, produtividade agrícola.

1. Introduction

Maize (*Zea mays* L.) is one of the most important crops worldwide, playing a fundamental role in food security, animal production, and industrial supply chains. Globally, maize production for the 2024/25 growing season was estimated at approximately 1.217 billion tons, maintaining its position as the most widely produced cereal crop despite slight fluctuations in annual production volumes (FAO, 2024). In Brazil, maize occupies a strategic position within the agricultural sector, with an estimated production of 137 million tons for the 2024/25 season, consolidating the country among the world's leading producers and exporters (Bigo lin; Talamini, 2024; CONAB, 2025; EMBRAPA, 2024).

The expansion of maize cultivation, particularly in tropical regions, has been accompanied by increasing phytosanitary challenges capable of limiting crop productivity and profitability (Andrade-Piedra et al., 2025). Among these constraints, plant-parasitic nematodes have emerged as one of the most significant threats to sustainable crop production due to their wide distribution, cryptic nature, and ability to cause substantial yield losses before symptoms become readily apparent in the field (Sousa, 2018). Recent estimates indicate that nematode-associated damage to major Brazilian crops generates annual economic losses exceeding R\$ 65 billion, highlighting the growing importance of these pathogens within modern agricultural systems (Barros et al., 2022; Sociedade Brasileira de Nematologia; Agroconsult; Syngenta, 2022).

The intensification of agricultural production in the Brazilian Cerrado, characterized by large-scale monoculture systems and continuous succession of susceptible host crops, has created favorable conditions for the establishment and population increase of several phytoparasitic nematode species (Carvalho et al., 2025). Among the most economically important groups reported in Brazil are root-knot nematodes (*Meloidogyne* spp.), cyst nematodes (*Heterodera* spp.), reniform nematodes (*Rotylenchulus* spp.), and root-lesion nematodes (*Pratylenchus* spp.) (EMBRAPA, 2013). The latter deserves particular attention because of its broad host range, migratory endoparasitic habit, and capacity to cause extensive root damage in economically important crops.

Within the genus *Pratylenchus*, *Pratylenchus zae* Graham, 1951 has been increasingly reported in maize-growing regions throughout Brazil, including the states of Goiás, Mato Grosso, Maranhão, and Paraná (Sousa, 2018). This migratory endoparasite penetrates root tissues and moves through the cortical region, causing necrotic lesions that impair water and nutrient uptake, ultimately reducing plant vigor and yield potential (Abreu, 2018). In addition to direct damage, root injuries created by *P. zae* may predispose plants to secondary infections by soilborne pathogens, further aggravating productivity losses.

Recent surveys conducted in the Brazilian Cerrado have confirmed the occurrence of *P. zae* in commercial fields of sweet corn and green maize, reinforcing concerns regarding its widespread distribution and economic relevance under tropical production conditions (Carvalho et al., 2025). Nevertheless, despite increasing reports of its occurrence, substantial knowledge gaps remain regarding the epidemiological behavior of this nematode,

regional economic damage thresholds, host-parasite interactions, and the long-term effectiveness of available management strategies (Tiwari et al., 2024). Furthermore, studies evaluating the host suitability of commercial maize hybrids suggest that most currently cultivated genotypes are susceptible to *P. zeae*, increasing the risk of population build-up in infested areas (Araújo et al., 2025; Procópio, 2023).

Although considerable advances have been achieved in the understanding of plant-parasitic nematodes over recent decades, information regarding the impact of *P. zeae* on maize remains fragmented across isolated studies conducted under distinct environmental and production conditions. Consequently, a comprehensive synthesis of current knowledge is necessary to support future research efforts and improve integrated management programs.

Therefore, this study aimed to provide a narrative review of the scientific literature on the impact of *Pratylenchus zeae* on maize cultivation, emphasizing advances reported between 2016 and 2026 and identifying the principal knowledge gaps that continue to limit the development of effective and sustainable management strategies.

2. Materials and Methods

This study was conducted as a narrative literature review with a qualitative and descriptive approach, aiming to synthesize and critically discuss the scientific knowledge available on the impacts of *Pratylenchus zeae* on maize (*Zea mays* L.) and the management strategies currently employed for its control. Narrative reviews are particularly suitable for providing a comprehensive understanding of a given subject, allowing the integration of theoretical, conceptual, and empirical evidence from different sources without the restrictions imposed by systematic review protocols (Rother, 2007). This approach is especially relevant for emerging or multidisciplinary topics in which scientific information remains fragmented across distinct areas of knowledge.

The review was guided by the following research question: What are the main impacts of *P. zeae* on maize production, and which management strategies have been investigated and validated by the scientific community?

To address this question, a comprehensive literature search was conducted between March 05 and April 28, 2026, using the following electronic databases: SciELO, Web of Science, PubMed/MEDLINE, Portal de Periódicos CAPES, and the Brazilian Digital Library of Theses and Dissertations (BDTD). Searches were performed using isolated and combined descriptors in English and Portuguese, including: "*Pratylenchus zeae*", "maize lesion nematode", "root lesion nematode", "nematode das lesões radiculares", "maize nematode", "*Zea mays* nematode", "nematode management", "biological control of nematodes", and "maize phytopathogenic nematodes". Boolean operators (AND, OR) were used to refine and expand the search strategy according to the indexing characteristics of each database.

The principal search strategies included:

Web of Science

- TS = ("*Pratylenchus zeae*") AND TS = (maize OR "*Zea mays*")
- TS = ("root lesion nematode") AND TS = (maize) AND TS = (management)

PubMed/MEDLINE

- ("*Pratylenchus zeae*") AND ("*Zea mays*")
- ("root lesion nematode") AND maize AND management

SciELO

- ("*Pratylenchus zeae*") AND (milho OR maize)
- ("nematode das lesões radiculares") AND milho

Portal de Periódicos CAPES

- ("*Pratylenchus zeae*") AND maize
- ("plant-parasitic nematodes") AND maize AND management
- Brazilian Digital Library of Theses and Dissertations (BDTD)
- "*Pratylenchus zeae*"
- "nematode das lesões radiculares"
- milho AND nematodes

The temporal scope included publications from 2008 to 2026. Eligible documents comprised original research articles, review papers, theses, dissertations, book chapters, and technical-scientific publications written in English, Portuguese, or Spanish that addressed the biology, ecology, pathogenicity, diagnosis, monitoring, economic impact, or management of *P. zae* in maize production systems. Duplicate records, publications lacking scientific or technical support, documents without clearly identified authorship, commercial dissemination materials, and studies not directly related to the proposed topic were excluded.

Reference management and duplicate screening were performed using Mendeley Reference Manager (Elsevier). After duplicate removal, publications were screened based on titles and abstracts, followed by full-text evaluation of studies considered relevant to the objectives of this review. The final selection prioritized studies presenting consistent scientific evidence regarding the biology, epidemiology, host-pathogen interaction, economic importance, diagnosis, and management of *P. zae* in maize.

Following study selection, the retrieved information was subjected to qualitative content analysis. To facilitate interpretation and synthesis, the selected literature was organized into five thematic categories: (i) biology and ecology of *P. zae*; (ii) damage and economic impacts on maize; (iii) diagnosis and population monitoring; (iv) management and control strategies; and (v) scientific gaps and future research perspectives. This thematic organization enabled the identification of convergences, divergences, and emerging trends within the available scientific literature.

Finally, evidence was synthesized through critical and interpretative analysis, emphasizing the relationships among biological, agronomic, and phytosanitary factors associated with *P. zae* and their implications for maize production under tropical agricultural conditions.

3. Biology and ecology of *Pratylenchus zae*

The genus *Pratylenchus* comprises a group of plant-parasitic nematodes commonly known as root-lesion nematodes; a designation associated with the characteristic necrotic lesions formed in infected root tissues (Wanjau et al., 2024). Among the species within this genus, *Pratylenchus zae* Graham, 1951 stands out as one of the most important pathogens affecting maize under tropical and subtropical conditions due to its wide distribution, broad host range, and capacity to cause significant damage to root systems (Abreu, 2018; Espada et al., 2025; Goulart, 2008; Pires et al., 2022) (Figure 1).

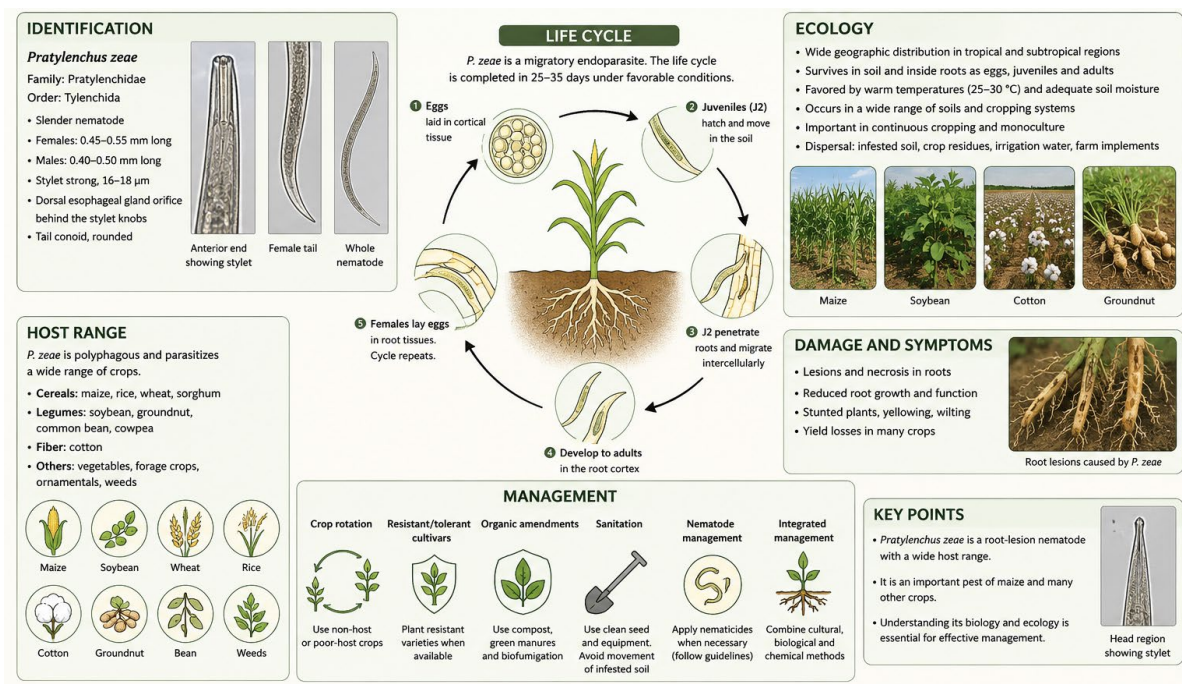


Figure 1. Biology and ecology of *Pratylenchus zae*. The infographic summarizes the main biological and ecological characteristics of *P. zae*, a migratory endoparasitic root-lesion nematode of major agricultural importance. It illustrates the nematode's morphological features, life cycle, host range, ecological requirements,

and dispersal pathways, as well as the typical symptoms caused by root infection, including cortical lesions, root necrosis, reduced root development, plant stunting, and yield losses. The figure also highlights the broad host spectrum of *P. zae*, including cereals, legumes, fiber crops, and several other cultivated species, together with integrated management strategies such as crop rotation, resistant cultivars, soil sanitation, organic amendments, and the judicious use of nematicides. Understanding these biological and ecological aspects is essential for developing sustainable management practices and minimizing the economic impact of this nematode in agricultural production systems. Source: Authors, 2026, by ChatGPT (2026).

Unlike sedentary endoparasitic nematodes, *P. zae* exhibits a migratory endoparasitic lifestyle, allowing individuals to penetrate, feed, and move continuously within root tissues throughout their life cycle. This behavior results in extensive cellular disruption within the cortical region, leading to the formation of elongated necrotic lesions that may coalesce as nematode populations increase. The continuous migration of the nematode through root tissues intensifies structural damage and compromises root functionality (Abreu, 2018; Goulart, 2008; Miedaner; Garbelotto, 2024).

The lesions caused by *P. zae* extend beyond visible anatomical alterations, as they directly affect physiological processes associated with water and nutrient absorption. The destruction of cortical cells and feeder roots reduces the efficiency of the root system, increasing plant susceptibility to drought stress, nutrient deficiencies, and other adverse environmental conditions. Consequently, infected plants frequently exhibit reduced vigor and lower productive potential, particularly when exposed to high nematode population densities (Abreu, 2018; Gorný; Cox, 2021).

Morphologically, *P. zae* possesses a vermiform body typical of root-lesion nematodes and completes its life cycle through egg, juvenile, and adult stages. Its development occurs both within host roots and in the surrounding rhizosphere, where a portion of the population may survive between cropping cycles, contributing to the persistence of infestations in agricultural soils (Chapagain et al., 2025; Sousa, 2018; Yigit; Akyazi, 2024).

Environmental and agronomic factors strongly influence the population dynamics of *P. zae*. Temperature, soil moisture, texture, host availability, and cropping history are among the principal determinants of nematode reproduction and survival (Goulart, 2008). In tropical regions, where favorable climatic conditions often prevail throughout the year, the continuous presence of susceptible hosts may sustain nematode populations and minimize periods of natural population decline (Araújo et al., 2025; Benjamin et al., 2024; EMBRAPA, 2013; Sousa, 2018).

The ecology of *P. zae* is closely linked to agricultural management practices. Production systems characterized by low crop diversity, intensive monoculture, and successive cultivation of susceptible hosts tend to favor the establishment and multiplication of root-lesion nematodes. Conversely, diversified cropping systems and well-planned crop rotation programs may contribute to suppressing population growth and reducing infestation levels over time (EMBRAPA, 2013).

Field surveys conducted in the Brazilian Cerrado have demonstrated the widespread occurrence of *Pratylenchus* spp. across different agricultural production systems, highlighting the remarkable ecological adaptability of these nematodes under intensive farming conditions (Costa et al., 2019; Sousa, 2018). Studies performed in southern Goiás have further confirmed the occurrence of *Pratylenchus* populations in sweet corn and green maize production areas, indicating that the problem extends beyond large-scale grain production systems and affects diverse maize production chains (Carvalho et al., 2025).

Another factor contributing to the epidemiological importance of *P. zae* is the difficulty of early detection under field conditions. Because initial damage occurs predominantly belowground, symptoms in the aerial portion of the plant often become evident only after substantial root deterioration has already occurred. By the time aboveground symptoms are observed, nematode populations may be well established in the soil, limiting the effectiveness of corrective management measures and reinforcing the importance of preventive diagnosis and monitoring programs (Gorný; Cox, 2021; Grabau; Vann, 2024).

The combination of a migratory endoparasitic habit, survival capacity in the rhizosphere, broad host range, and adaptation to tropical agricultural systems makes *P. zae* a particularly challenging pathogen to manage. Therefore, a comprehensive understanding of its biology and ecology is essential for interpreting its effects on maize productivity and for supporting the development of effective and sustainable integrated management strategies (Abreu, 2018; Grabau; Vann, 2024).

4. Pathogen–host interaction in maize

The interaction between *Pratylenchus zae* and maize (Figure 2) occurs predominantly within the root system, where the nematode penetrates, migrates, and feeds on cortical cells throughout its life cycle (Abreu, 2018; Gorný; Cox, 2021). As a migratory endoparasite, *P. zae* causes continuous mechanical disruption of root tissues during feeding and movement, resulting in the formation of necrotic lesions that compromise root integrity and functionality (Abreu, 2018; Goulart, 2008; Lu et al., 2024).

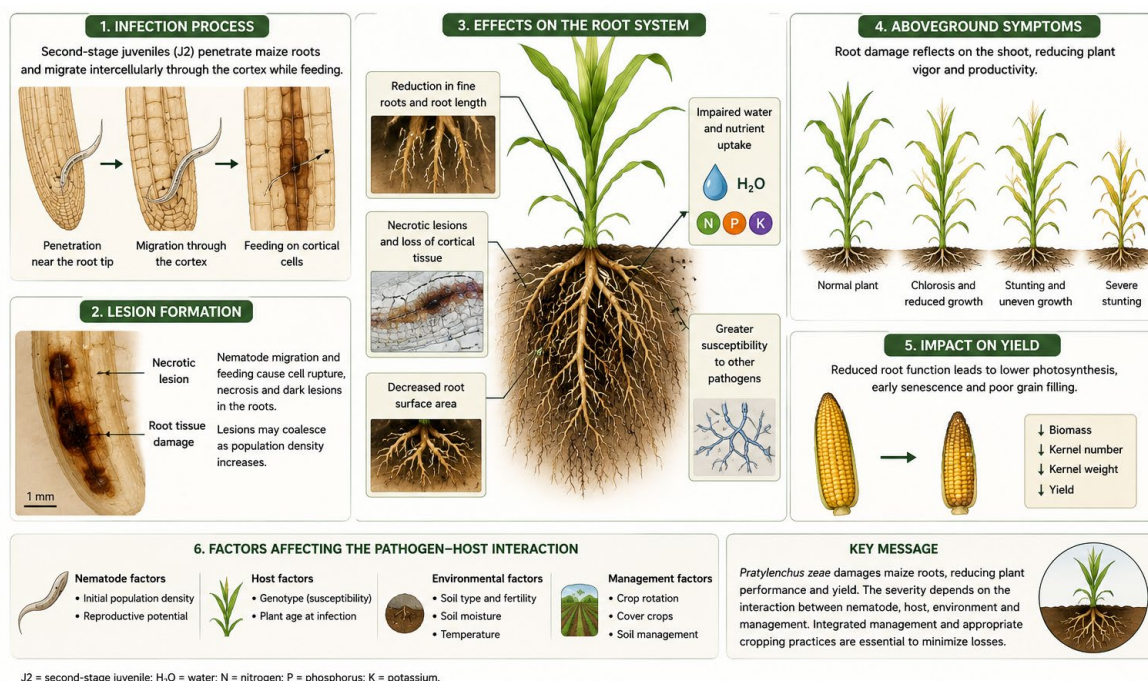


Figure 2. Schematic representation of the pathogen–host interaction between *Pratylenchus zae* and maize (*Zea mays*). After penetrating the root cortex, the nematode migrates through root tissues, inducing cell destruction and necrotic lesions that impair root functionality. The resulting reduction in water and nutrient absorption negatively affects plant vigor, growth, and yield performance. Source: Authors, 2026, by ChatGPT (2026).

Root damage caused by *P. zae* directly affects the plant's ability to absorb water and nutrients by reducing the quantity of functional root tissue available for resource uptake. Consequently, infected maize plants frequently exhibit impaired early growth, reduced vegetative vigor, and decreased tolerance to abiotic stresses, particularly drought and nutrient deficiency (Abreu, 2018; Gorný; Cox, 2021; Kim; Lee, 2023; Njeru et al., 2023). The severity of these effects is often associated with the extent of root colonization and the density of nematode populations present in the rhizosphere.

The physiological consequences of root parasitism are frequently expressed in the aerial portion of the plant through symptoms such as stunting, chlorosis, uneven plant development, and the formation of irregular patches within fields. However, these symptoms are not exclusive to nematode infection and may also arise from nutrient imbalances, soil compaction, water stress, or infections caused by other root-associated pathogens (Gorný; Cox, 2021; Grabau; Vann, 2024). This lack of symptom specificity represents a major challenge for field diagnosis and often delays the implementation of effective management measures.

Because visual symptoms alone are insufficient for reliable diagnosis, nematological analyses of soil and root samples are essential for confirming the presence of *P. zae*, identifying the species involved, and estimating population densities. Accurate diagnosis is a critical component of integrated nematode management programs, particularly in areas with a history of infestation (Grabau; Vann, 2024).

Beyond direct feeding damage, the lesions created by nematode migration may serve as entry points for opportunistic microorganisms naturally present in the soil. This interaction can intensify root deterioration and amplify yield losses through disease complexes involving fungi, bacteria, and other soilborne pathogens. As a

result, the negative effects observed in infected plants often reflect not only nematode parasitism but also the combined impact of secondary infections and physiological stress (Goulart, 2008; Gorný; Cox, 2021; Lamichhane et al., 2024).

Maize plays a dual role in the epidemiology of *P. zae*, acting both as a susceptible crop and as a host capable of supporting nematode reproduction and population growth. Studies evaluating host suitability among commercial maize genotypes have demonstrated significant differences in nematode reproduction rates, indicating that genetic variability among cultivars can influence population dynamics and disease severity (Procópio, 2023).

The cultivation of highly susceptible genotypes in infested areas may contribute to substantial increases in nematode populations during the cropping season. Consequently, residual populations remaining in the soil after harvest may pose a significant risk to subsequent crops, particularly in production systems characterized by continuous cultivation of susceptible hosts and limited crop diversification (EMBRAPA, 2013; Procópio, 2023).

The outcome of the pathogen–host interaction is influenced by multiple factors, including the initial nematode population density, host genotype, soil characteristics, environmental conditions, and phytosanitary history of the field. While low infestation levels may result in limited economic damage, fields with established nematode populations frequently experience greater productivity losses, especially when preventive monitoring and crop rotation strategies are absent (Abreu, 2018; Grabau; Vann, 2024).

Plant developmental stage at the time of infection also plays a crucial role in determining disease severity. Young maize plants, whose root systems are still developing, tend to be more vulnerable to nematode attack because early root damage can compromise subsequent growth stages and limit the plant's capacity to recover throughout the production cycle (Abreu, 2018; Araújo et al., 2023; Gorný; Cox, 2021; Rutter et al., 2022).

Recent reports of *Pratylenchus* spp. in sweet corn production areas in southern Goiás further emphasize the importance of understanding pathogen–host interactions under regional production conditions. These findings indicate that the impact of *P. zae* should be evaluated according to cropping system characteristics, maize type, management practices, and local soil-use history (Carvalho et al., 2025).

Overall, understanding the interaction between *P. zae* and maize is fundamental for interpreting the epidemiology of the pathogen in agricultural systems. When susceptible cultivars are grown in infested areas without prior diagnosis and adequate management, maize may contribute not only to yield reduction but also to the maintenance and amplification of nematode populations, increasing the risk of damage in subsequent production cycles (Procópio, 2023; Grabau; Vann, 2024; Pfordt; Paulus, 2024; Xing et al., 2023).

5. Economic and productive impacts of *Pratylenchus zae* on maize

The economic significance of *P. zae* in maize production is primarily associated with its capacity to impair root system functionality, thereby reducing the plant's ability to absorb water and nutrients efficiently (Goulart, 2008; Abreu, 2018; Lopez-Nicora et al., 2023) (Figure 3). As a migratory endoparasite, the nematode causes extensive cortical tissue damage through feeding and movement within roots, resulting in necrotic lesions that compromise root architecture and physiological performance (Chapagain et al., 2025; Gorný; Cox, 2021). Consequently, infected plants frequently exhibit reduced growth, lower biomass accumulation, and diminished yield potential.

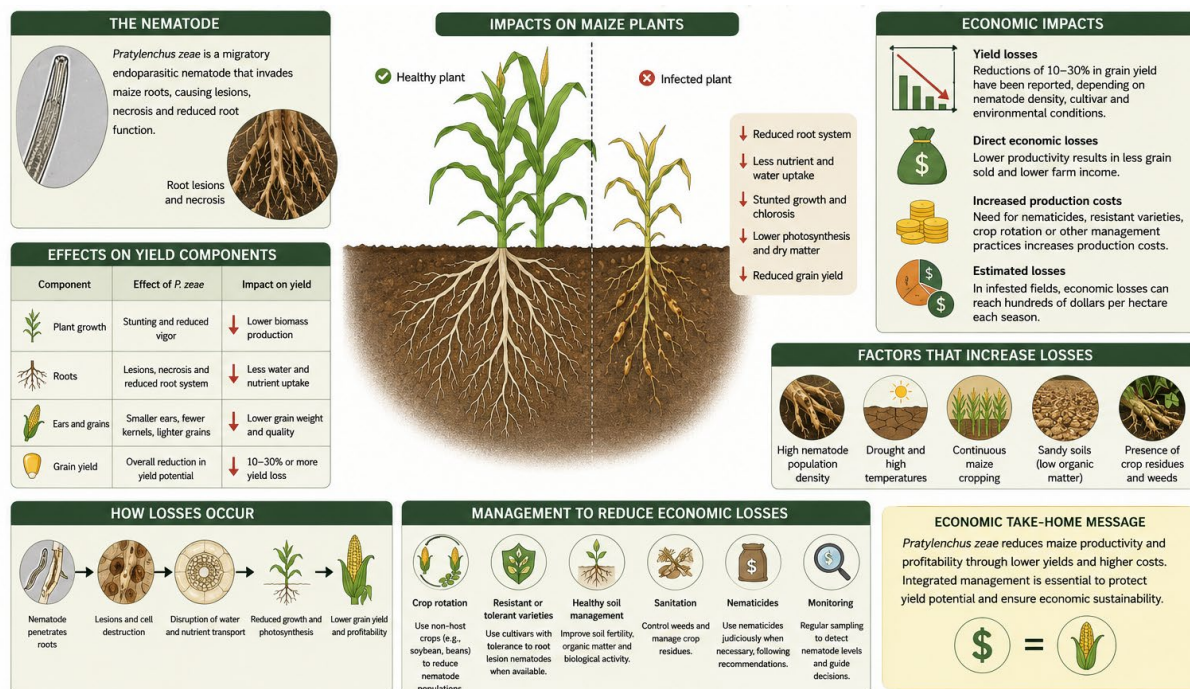


Figure 3. Economic and productive impacts of *Pratylenchus zeae* on maize production. Source: Authors, 2026, by ChatGPT (2026).

The reduction in functional root area directly affects crop establishment, vegetative development, and reproductive performance. Under field conditions, the impact of *P. zeae* is often intensified by environmental stresses such as drought, low soil fertility, and soil compaction, which further restrict root activity and exacerbate productivity losses (Abreu, 2018; Grabau; Vann, 2024). Thus, the effects of nematode parasitism should not be interpreted in isolation but rather as part of a complex interaction involving biotic and abiotic stress factors that collectively influence crop performance.

Yield losses associated with *P. zeae* are highly variable and depend on several interacting factors, including initial nematode population density, host susceptibility, soil characteristics, climatic conditions, and management practices adopted within the production system (Chadfield et al., 2022; Grabau; Vann, 2024; Procópio, 2023). Consequently, fields infested by the same nematode species may exhibit markedly different levels of damage depending on local environmental conditions and crop management history.

Given the strategic importance of maize for global food security, animal nutrition, and industrial production, any factor capable of reducing crop productivity deserves considerable attention. In Brazil, maize is among the most economically important crops, playing a fundamental role in domestic supply chains and international grain markets (CONAB, 2025; EMBRAPA, 2024). Therefore, yield reductions associated with phytoparasitic nematodes represent not only agronomic challenges but also potential economic losses for producers and the agricultural sector as a whole.

The economic burden imposed by plant-parasitic nematodes in Brazil has been increasingly recognized over recent years. Estimates generated through collaborative studies involving the Brazilian Society of Nematology, Agroconsult, and Syngenta indicate that nematodes and associated soilborne diseases are responsible for billions of reais in annual losses across major crops, highlighting their relevance within tropical production systems (Sociedade Brasileira de Nematologia; Agroconsult; Syngenta, 2022).

Despite the recognized importance of *P. zeae*, quantitative information regarding its specific impact on maize yield remains limited. Most available studies focus on species occurrence, host suitability, root damage characterization, or population dynamics, whereas relatively few investigations have established direct relationships between nematode population densities and grain yield reductions under commercial field

conditions (Abreu, 2018; Procópio, 2023; Carvalho et al., 2025). This limitation hinders the development of more precise risk assessment models and management recommendations.

One of the principal challenges in managing *P. zeae* is the absence of well-defined economic damage thresholds. Effective decision-making requires reliable parameters indicating the population levels at which intervention becomes economically justified. However, these thresholds are likely to vary according to environmental conditions, soil properties, cropping systems, maize genotype, and regional production characteristics (Grabau; Vann, 2024; Procópio, 2023).

The lack of region-specific damage thresholds also complicates the interpretation of nematological reports. Although species identification and population quantification are essential components of diagnosis, management decisions should additionally consider field history, cultivar susceptibility, environmental conditions, and the overall production context (Alisaac; Mahlein, 2023; Gorný; Cox, 2021; Grabau; Vann, 2024).

Host suitability studies have demonstrated that maize genotypes differ in their capacity to support the reproduction of *P. zeae*. Procópio (2023) reported significant variation among maize and sorghum genotypes, suggesting that productivity losses should be evaluated not only according to nematode presence but also according to the reproductive potential of the pathogen within each host genotype. Such findings reinforce the importance of incorporating host response into integrated nematode management programs.

Another factor complicating economic assessments is the frequent coexistence of nematode infestations with other yield-limiting factors, including nutrient deficiencies, water stress, soil compaction, and root diseases. Because these constraints often occur simultaneously, distinguishing the specific contribution of *P. zeae* to productivity losses can be challenging under field conditions (Gorný; Cox, 2021; Grabau; Vann, 2024).

Recent reports documenting the occurrence of *Pratylenchus* spp. in sweet corn production systems in southern Goiás further highlight the need for regional studies linking nematode population density, crop performance, and economic outcomes. Although these surveys confirm the presence of the pathogen, accurate quantification of losses requires long-term field experiments conducted under diverse environmental conditions, production systems, and management strategies (Carvalho et al., 2025).

Overall, current evidence indicates that *P. zeae* significantly compromises root system performance and may reduce maize productivity under a wide range of production conditions (Baloch, 2025). Nevertheless, important knowledge gaps remain regarding the quantification of economic losses, the establishment of regional damage thresholds, and the development of predictive tools capable of supporting more effective and economically viable management decisions.

Although precise estimates of yield losses caused exclusively by *Pratylenchus zeae* remain limited, available evidence consistently indicates that lesion nematodes are among the most economically important plant-parasitic nematodes affecting maize worldwide. Yield reductions are highly dependent on initial nematode population density, cultivar susceptibility, soil characteristics, water availability, and interactions with other biotic and abiotic stressors. Consequently, economic damage varies considerably among production systems, making universal damage thresholds difficult to establish (Lopez-Nicora et al., 2023).

Experimental studies have demonstrated that *P. zeae* infection reduces root biomass, shoot biomass, plant height, chlorophyll concentration, and overall plant vigor, ultimately decreasing grain yield. In heavily infested fields, root lesions impair water and nutrient uptake, resulting in poor crop establishment and increased susceptibility to drought stress. Because aboveground symptoms are often nonspecific, yield reductions may occur before growers recognize nematode infestations, leading to underestimation of their economic importance (Khan; Quintanilla, 2023).

At the global scale, plant-parasitic nematodes are estimated to cause annual crop losses exceeding USD 125 billion, with maize representing one of the most affected cereal crops. In tropical and subtropical regions, where *Pratylenchus* species complete multiple life cycles during a single growing season, economic losses may be amplified by continuous host availability and favorable environmental conditions. Studies conducted in Africa have reported maize yield reductions ranging from 20% to 28.5% due to plant-parasitic nematodes, while root-lesion nematodes have been associated with production declines of approximately 27% in some production areas (Benjamin et al., 2024).

The economic burden of *P. zeae* extends beyond direct yield reduction. Infested fields frequently require additional investments in nematode diagnosis, soil sampling, seed treatments, biological products, nematicides, crop rotation, and cover crops. Furthermore, root injuries caused by lesion nematodes facilitate secondary infections by soilborne fungi and bacteria, increasing disease severity and further elevating production costs.

These indirect losses may substantially reduce farm profitability even when visible yield reductions appear moderate (Quintanilla; Fazlabadi, 2023).

Current evidence also indicates that economic losses cannot be explained solely by nematode population density. Crop response depends on the interaction among nematode pressure, soil fertility, irrigation, environmental stress, hybrid susceptibility, and management practices. Consequently, integrated nematode management programs combining accurate diagnosis, resistant or less susceptible hybrids, crop rotation, biological control, and appropriate chemical interventions generally provide greater economic returns than reliance on a single management strategy (Grabau et al., 2017; Lopez-Nicora et al., 2023; Sikora et al., 2023).

6. Management strategies for *Pratylenchus zae* in maize production systems

The management of *P. zae* in maize production systems requires an integrated and preventive approach, as complete eradication of the nematode from infested agricultural soils is rarely achievable under commercial conditions (Abd-Elgawad, 2024). Consequently, management strategies should focus on reducing initial population densities, limiting nematode reproduction during the crop cycle, and minimizing the negative effects of parasitism on plant growth and productivity (Goulart, 2008; Grabau; Vann, 2024).

Accurate diagnosis represents the foundation of any effective nematode management program. The symptoms associated with root-lesion nematodes are generally nonspecific and may include stunting, chlorosis, reduced vigor, and irregular patches within the field. However, these manifestations are frequently confused with nutrient deficiencies, water stress, soil compaction, and other root diseases, making visual diagnosis unreliable (Gomý; Cox, 2021; Grabau; Vann, 2024). Therefore, nematological analyses of soil and root samples are essential to confirm the presence of *P. zae*, determine population densities, and support decision-making processes (Thiruchelvan et al., 2024). Furthermore, periodic monitoring enables the assessment of population fluctuations over time and the effectiveness of implemented management practices.

Among cultural control practices, crop rotation remains one of the most widely recommended strategies for suppressing phytoparasitic nematodes. Nevertheless, its effectiveness depends largely on the selection of appropriate rotation species. When susceptible or highly favorable hosts are included in the production system, nematode populations may be maintained or even increased, reducing the benefits of crop diversification (EMBRAPA, 2013; Santana-Gomes et al., 2019). Consequently, the success of rotation programs depends on a detailed understanding of host suitability and nematode reproductive potential across different plant species.

Cover crops may also play an important role in integrated nematode management. Studies evaluating the reproduction of *P. zae* and related species in cover crops have demonstrated substantial variation among plant species regarding their capacity to support nematode multiplication (Santana-Gomes et al., 2019). While poor hosts may contribute to gradual population decline, highly susceptible cover crops may inadvertently increase infestation levels before maize establishment. Therefore, cover crop selection should be based on both agronomic benefits and nematological considerations.

Host resistance and reduced host suitability constitute additional components of sustainable nematode management. The use of maize genotypes that restrict nematode reproduction can decrease direct crop damage and reduce residual populations remaining in the soil after harvest (Procópio, 2023). However, the adoption of resistant or less susceptible cultivars is still constrained by limited information regarding the response of commercially available hybrids under diverse environmental conditions. Because genotype performance may vary according to soil characteristics, climate, cropping system, and initial nematode density, further regional evaluations are required to support cultivar recommendations (Carvalho et al., 2025).

Biological control has emerged as a promising complementary strategy within integrated management programs. Microbial agents capable of suppressing nematode populations have received increasing attention due to their potential compatibility with sustainable agricultural systems. Studies involving seed treatment with *Pasteuria thornei* have demonstrated promising results for the suppression of *P. zae* populations in maize, highlighting the potential of biological tools as components of integrated nematode management (Confort; Inomoto, 2023). Nevertheless, the effectiveness of biological control agents may be influenced by environmental conditions, soil microbiota composition, product formulation, and interactions with other agronomic inputs.

Chemical control, including the use of nematicides and seed treatments, may also contribute to population suppression when applied according to technical recommendations. However, chemical interventions should not be viewed as standalone solutions. Their effectiveness depends on factors such as application technology, environmental conditions, nematode population density, and integration with complementary management

practices (Grabau; Vann, 2024). Consequently, the greatest benefits are generally obtained when chemical tools are incorporated into broader integrated management programs.

Soil management practices likewise influence crop tolerance to nematode infection. Well-structured soils with adequate fertility, balanced nutrient availability, and low levels of compaction promote vigorous root development and may partially mitigate the effects of parasitism (EMBRAPA, 2013; Gorný; Cox, 2021). Improvements in soil health can enhance plant resilience and contribute to more stable crop performance even under moderate nematode pressure.

Overall, the integration of diagnostic procedures, crop rotation, cover crop management, host resistance, biological control, chemical treatments, and soil health practices represents the most robust strategy for reducing the impact of *P. zae* in maize production systems. Isolated measures often provide limited and temporary benefits when the production system continues to favor nematode survival and reproduction. Therefore, sustainable management depends on combining multiple complementary tactics tailored to local production conditions (Artega-Ojeda et al., 2026; Liang et al., 2025).

Recent reports of *Pratylenchus* spp. in sweet corn production areas of southern Goiás further emphasize the need for region-specific research capable of translating scientific advances into practical recommendations. Future progress in nematode management will depend on the development of integrated decision-support strategies that consider nematode species, initial population densities, crop succession schemes, cultivar selection, environmental conditions, and field history, thereby enabling more effective and economically sustainable management programs (Carvalho et al., 2025; Grabau; Vann, 2024).

7. Conclusions

This review highlights the importance of *Pratylenchus zae* as one of the principal plant-parasitic nematodes associated with maize production systems in tropical and subtropical regions. Due to its migratory endoparasitic habit, the species causes significant damage to root tissues, compromising water and nutrient uptake and negatively affecting plant growth, physiological performance, and yield potential. The impacts of infection are frequently intensified by adverse environmental conditions, including water deficit, soil compaction, and nutritional limitations, which collectively increase crop vulnerability and amplify productivity losses.

The available scientific evidence demonstrates that the severity of damage caused by *P. zae* results from a complex interaction among nematode population density, host susceptibility, environmental conditions, and crop management practices. Furthermore, maize plays a dual role in this pathosystem, acting not only as a susceptible crop but also as a host capable of sustaining and increasing nematode populations, thereby influencing infestation levels in subsequent cropping cycles.

Current management strategies indicate that no single control measure is sufficient to provide long-term suppression of *P. zae*. Sustainable management therefore depends on the integration of preventive and complementary approaches, including accurate diagnosis, periodic nematological monitoring, crop rotation with non-host species, appropriate cover crop selection, use of less susceptible genotypes, biological control agents, chemical treatments when technically justified, and practices aimed at improving soil health and root development. The effectiveness of these strategies is maximized when implemented within an integrated nematode management framework adapted to local production conditions.

Despite significant advances in the understanding of *P. zae* biology, ecology, and host interactions, important knowledge gaps remain. Future research should prioritize the establishment of economic damage thresholds under Brazilian production conditions, the quantification of yield losses across different environments and maize genotypes, the identification of resistance sources in commercial germplasm, and the validation of biological and integrated management strategies under field conditions. Additionally, the development of predictive models incorporating environmental, agronomic, and nematological variables may contribute to more accurate risk assessment and decision-making.

In conclusion, effective management of *Pratylenchus zae* requires a systems-based perspective that integrates pathogen biology, crop management, and soil health. Expanding applied research and translating scientific knowledge into region-specific recommendations will be essential for reducing nematode-related losses, improving maize productivity, and promoting the long-term sustainability of agricultural systems.

8. Authors' Contributions

Izadora Marques Galvão: conceptualization, methodology, investigation, data curation, writing – original draft. *Welber Cabral Bueno*: supervision, methodology, validation, writing – review & editing. *Fabiula Barbosa de Souza*: investigation, data curation, formal analysis, writing – review & editing. *Gabriel Henrique dos Santos Cardoso*: literature search, data curation, visualization, writing – original draft. *Hiago Medeiros dos Santos*: investigation, formal analysis, validation, writing – review & editing. *Juliana Araújo Rocha*: literature search, data curation, visualization, writing – original draft. *Francisco Rafael Santos Conceição*: literature search, data curation, visualization, writing – original draft. *Porshia Sharma*: literature search, data curation, visualization, writing – original draft, and translation. *Janslei Andrade da Silva*: conceptualization, supervision, project administration, resources, writing – review & editing. *Aurelio Ferreira Melo*: conceptualization, supervision, project administration, resources, writing – review & editing

9. Conflicts of Interest

No conflicts of interest.

10. Ethics Approval

Not applicable.

11. Artificial Intelligence Statement: Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

Generative artificial intelligence (AI) was used exclusively for the creation of the figures included in this manuscript and the graphical abstract. The AI-generated visual materials were reviewed, verified, and, when necessary, edited by the authors to ensure their scientific accuracy, consistency, and suitability for publication. No AI tools were used to generate, analyze, interpret, or modify the scientific data or conclusions presented in this study. The authors assume full responsibility for the accuracy, integrity, and final content of all figures and the graphical abstract. The use of AI has been disclosed in the corresponding figure legends, including the name of the AI tool and the year of use. AI tools are not authors and bear no responsibility for the content of this manuscript.

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