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ROOT DISEASES IN *HEVEA BRASILIENSIS*: CHALLENGES, STRATEGIES AND PATHWAYS TO SUSTAINABLE RUBBER CULTIVATION

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Global rubber cultivation is facing significant challenges due to root diseases that affect *Hevea brasiliensis*, commonly known as the rubber tree. Despite the negative impact of root diseases on tree health and latex yield, they often receive less attention than above-ground pests and diseases. Fungal pathogens such as *Rigidoporus lignosus*, *Ganoderma pseudoferreum* and *Phellinus noxius* are major contributors to root diseases in rubber trees, causing white root rot, red root disease and brown root disease respectively. Managing these diseases is a difficult task due to the lack of disease-resistant plant varieties, the ability of pathogens to remain in the soil for long periods, environmental factors and limited effectiveness of control methods. To tackle these challenges, it is suggested to adopt integrated disease management strategies that combine cultural, biological and chemical approaches. Cultural practices such as optimal site selection and sanitation, biological control using beneficial microorganisms and botanical control utilizing plant extracts offer sustainable alternatives to chemical fungicides. Although chemical control is commonly used, it should be integrated with other methods to minimize environmental impact and reduce the risk of resistance development. Moreover, the adoption of integrated approaches, early disease detection and resistant cultivars are essential for long-term disease management and sustainable rubber cultivation. Policymakers play a crucial role in promoting sustainable practices through funding support, extension services and regulations that incentivize environmentally friendly approaches. Collaboration among stakeholders is crucial for knowledge exchange, innovation and collective action towards a resilient rubber industry. Urgent action and collaboration are imperative to effectively manage root diseases, safeguard livelihoods and ensure sustainability of rubber cultivation.

Keywords: Disease management, *Hevea brasiliensis*, Integrated approaches, Root diseases, Sustainable rubber cultivation

INTRODUCTION

Hevea brasiliensis Muell. Arg., commonly known as the rubber tree, holds immense economic significance as the primary source of natural rubber, a crucial commodity in various industries worldwide. However, the sustainable cultivation of rubber faces significant challenges, particularly from root diseases that threaten tree health and latex yield. Despite severity of these diseases, they often receive insufficient

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attention compared to above-ground pests and diseases, underscoring the need for comprehensive reviews to highlight their importance (Omorusi, 2012).

Root diseases in *H. brasiliensis*, primarily caused by fungal pathogens, have been extensively studied due to their detrimental effects on tree health and productivity (Maiden *et al*., 2022). These diseases include white root rot caused by *Rigidoporus lignosus* (Klotzsch) Imazeki, red root disease caused by *Ganoderma pseudoferreum* (Wakef) Over. & Steinm. and brown root disease caused by *Phellinus noxius* (Corner) G. H. Cunn. These diseases pose significant threat to rubber plantations worldwide (Nandris *et al.,* 1987; Omorusi *et al*., 2014a; Liu *et al*., 2021). Understanding the mechanisms of infection and interactions between pathogens and host plants is essential for developing effective disease management strategies (Maiden *et al*., 2022).

Challenges in disease management further exacerbate the impact of root diseases on rubber cultivation. These challenges include limited access to disease-resistant cultivars, difficulties in early detection and increasing prevalence of pathogens due to climate change (Omorusi, 2012; Maiden *et al*., 2022). Overcoming these obstacles requires a concerted effort from researchers, farmers and policymakers to develop and implement sustainable disease management practices. Our specific aims include discussing the major fungal pathogens associated with root diseases, outlining challenges faced by farmers in disease management, evaluating existing control and management strategies and proposing recommendations for enhancing disease resilience and sustainable rubber cultivation.

ROOT DISEASES OF *HEVEA BRASILIENSIS*

White root rot caused by the fungus *R. lignosus*, is one of the most destructive diseases affecting rubber plantations worldwide (Nandris *et al.,* 1987). This pathogen attacks the roots of rubber trees, leading to rotting and eventual death of the affected trees (Meenakshi and Mathivanan, 2012). Management of white root rot is challenging due to the longevity of the pathogen in the soil and its ability to survive adverse environmental conditions (Omorusi *et al*., 2014a). Studies in Nigeria have highlighted the severe economic impact of white root rot, with up to 94 per cent of root diseases attributed to this pathogen, leading to substantial tree mortality and financial losses (Omorusi *et al*., 2014a).

Red root disease caused by *G. pseudoferreum*, is another significant threat to rubber cultivation (Ogbebor *et al.,* 2013; Ann and Kuan, 2017; Liu *et al*., 2021). This pathogen infects roots of rubber trees, causing characteristic symptoms such as red discoloration and decay (Singh *et al*., 2002; Gafur, 2023). Red root disease can lead to extensive yield losses and even complete stand failures in severely affected plantations (Ann and Kuan, 2017; Mazlan *et al*., 2019).

Brown root disease caused by *P. noxius*, is also a devastating fungal disease of rubber trees (Liu *et al*., 2021). This pathogen infects the roots and lower trunk of rubber trees causing brown discoloration and decay. Brown root disease is particularly challenging to manage due to its rapid spread and lack of effective control measures.

In addition to these major pathogens, other fungi such as *Ustulina deusta* (Hoffm.

ex Fr.) Lind, *Poria hypobrunnea* Petch, *Sphaerostilbe repens* Berk. & Br., *Armillaria* spp. and *Helicobasidium compactum* Boedijn also contribute to root diseases in rubber trees, albeit to a lesser extent (Rao, 1975; Geiger *et al*., 1986). These pathogens originate from indigenous hosts in the jungle and persist in soil and timber, posing challenges for disease management in rubber plantations.

CHALLENGES IN MANAGING ROOT DISEASES

Managing root diseases in rubber trees presents numerous challenges for farmers, ranging from the complexity of disease dynamics to limitations in available control measures (Maiden *et al*., 2022). Some of the key challenges include:

Limited disease resistance: *H. brasiliensis* cultivars with adequate resistance to root diseases are scarce, exacerbating the vulnerability of rubber plantations to pathogen outbreaks (Le Guen *et al*., 2013).

Soil persistence of pathogens: Fungal pathogens causing root diseases in rubber trees often persist in the soil for extended periods (Omorusi *et al*., 2014a). Even after implementing control measures such as fungicide applications or crop rotation, pathogens may remain viable in the soil, posing a continued threat to plant health.

Environmental factors: Environmental conditions play a crucial role in the development and spread of root diseases in rubber trees (Liu *et al*., 2021). Factors such as temperature, humidity, and soil moisture influence the activity and proliferation of fungal pathogens.

Limited efficacy of control measures: Existing control measures for root diseases in rubber trees often yield limited efficacy, particularly in the case of widespread infections (Nandris *et al*., 1987). Chemical fungicides may offer temporary relief, but their effectiveness diminishes over time due to the development of resistance in pathogen populations. Moreover, fungicide application incurs additional costs and may have adverse environmental impacts.

Cost considerations: Implementing effective disease management strategies can impose a significant financial burden on rubber farmers (Saha *et al*., 2021). Smallholder farmers in particular may struggle to afford the necessary interventions.

To tackle the issue of root diseases affecting rubber tree cultivation, a comprehensive approach is necessary that combines cultural, biological and chemical control techniques while prioritizing sustainable practices. It is essential to foster collaborative research efforts among academia, government agencies and industry stakeholders to devise innovative solutions. Moreover, promoting awareness and providing farmers with extension services can increase their ability to implement effective disease management practices and ensure long-term sustainability of rubber production.

CONTROL AND MANAGEMENT STRATEGIES

Effective control and management strategies are crucial for mitigating the impact of root diseases in rubber trees and sustaining rubber production. Drawing from integrated pest management principles, a combination of cultural, biological and chemical approaches can help address the complex challenges associated with these diseases. Some key strategies include:

Cultural practices

Optimal site selection and soil management practices can help minimize the risk of root diseases in rubber plantations

(Saha *et al*., 2021). Selecting well-drained sites with good soil structure and fertility can reduce waterlogging and create conditions less favourable for pathogen proliferation. Implementing strict sanitation measures, such as removing and destroying infected plant material can help prevent spread of root diseases within rubber plantations (Meenakshi and Mathivanan, 2012).

Biological control

Biological control agents such as beneficial fungi and bacteria, can be applied to suppress growth and activity of root pathogens (Saha *et al*., 2021). Several biocontrol agents, including *Trichoderma* spp., *Bacillus* spp. and *Chaetomium cupreum* have shown potential for controlling root diseases in rubber trees by competing with pathogens for resources or producing antifungal compounds (Jayasuriya and Thennakoon, 2007; Meenakshi and Mathivanan, 2012; Soytong and Kaewchai, 2014; Li *et al*., 2015; Ogbebor *et al*., 2015a; Go *et al*., 2023).

Inoculating rubber seedlings with mycorrhizal fungi could enhance root development and improve resistance to soil-borne pathogens as has been demonstrated in other crops (Marx, 1972; Dehne, 1982; Ramaraj *et al*., 1988; Mohammad, 2019). Mycorrhizal associations not only enhance nutrient uptake but also trigger systemic resistance mechanisms in the host plant.

Botanical control

Botanical control involves the use of plant-derived substances or extracts to suppress growth and activity of root pathogens in rubber trees. Several studies have examined the potential of extracts from various plant species such as garlic (*Allium sativum* Linn.), neem (*Azadirachta indica* A. Juss.), aloe vera (*Aloe barbadensis*), eucalyptus (*Eucalyptus* spp.) and *Thonningia sanquinea* Vahl., in treating fungal diseases (Ogbebor *et al*., 2015b; Omorusi *et al*., 2014b; Adekunle *et al*., 2021). One of the studies (Ogbebor *et al*., 2015b) showed that extracts from *A. sativum* and *T. sanquinea* were effective in managing the disease in both *in vitro* and *in vivo*. The study recommends that botanical fungicides are more effective when applied before the onset of the infection as a preventive measure.

Chemical control

The application of fungicides remains a common practice for managing root diseases in rubber trees, especially during periods of high disease pressure (Gohet *et al*., 1991; Meenakshi and Mathivanan, 2012; Omorusi *et al*., 2014a; Ogbebor *et al*., 2015c). Fungicides such as Tridemorph, pentachloronitrobenzene (PCNB), Benomyl and Bayfidan are commonly used to control root diseases in *Hevea*. Gohet *et al*. (1991) found that triazole-based compounds showed high efficacy in both *in vitro* and small-scale experiments, suggesting their practical use to control white root disease in *H. brasiliensis* plantations. Omorusi *et al*. (2014a) suggested use of powdered sulfur during the process of transplanting rubber plants to prevent white root disease. Additionally, the use of fungicides such as calixin (*i.e.* Tridemorph) and pentachloronitrobenzene (PCNB) was recommended for treatment of the disease in plantations. Ogbebor *et al*. (2015c) evaluated *in vitro* and *in vivo* Tridemorph, Benomyl and Bayfidan on *R. microporus* on rubber seedlings and demonstrated that Tridemorph was the most effective as it exhibited higher mycelial percentage inhibition. However, indiscriminate use

of chemical agents raises concerns about environmental contamination, development of resistance in pathogens and negative impacts on non-target organisms (Saha *et al*., 2021). Therefore, chemical control should be integrated with other management strategies and used judiciously. Treating rubber seeds with fungicides before planting can help protect seedlings from soil-borne pathogens and improve establishment success.

Integrated approaches

Integrating multiple control methods, including cultural, biological and chemical approaches can enhance the effectiveness of disease management strategies (Saha *et al*., 2021). It is crucial to regularly monitor rubber plantations for any indications of disease and to promptly detect outbreaks. Studies have shown that early detection and intervention can prevent the spread of diseases (Omorusi, 2012; Maiden *et al*., 2022). To successfully implement integrated management strategies for rubber production, it is essential to have collaboration between researchers, extension services and rubber industry stakeholders. This collaboration should focus on developing and disseminating best practices that are tailored to local conditions. Additionally, ongoing research into new control technologies and cultivars with improved disease resistance is crucial for ensuring the long-term sustainability of rubber production.

LIMITATIONS OF CONTROL MEASURES

While various control strategies exist for managing root diseases in rubber trees, they are not without limitations. Understanding these limitations is crucial for devising effective disease management strategies. Some key constraints include:

Environmental factors

The efficacy of control measures may vary depending on climatic conditions, with certain strategies being more effective in specific environments (Saha *et al*., 2021). Environmental factors such as temperature, humidity and rainfall can influence the activity of pathogens and the effectiveness of fungicides. Soil properties such as texture, pH and organic matter content can impact the effectiveness of control measures by influencing pathogen survival and activity (Meenakshi and Mathivanan, 2012). Strategies that rely on soil amendments or microbial inoculants may be less effective in soils with unfavourable conditions.

Resistance development

Prolonged use of fungicides can lead to development of resistance in target pathogens, reducing the efficacy of chemical control measures (Wastie, 1975; Meenakshi and Mathivanan, 2012; Kumar *et al*., 2018; Saha *et al*., 2021). Developing new cultivars with improved resistance to root diseases requires extensive breeding efforts and may take years to achieve. Currently, the varietal type in rubber comprises of clonal trees that are budded onto unselected heterogeneous seedling rootstocks.

Cost and labour intensity

Implementing certain control measures such as fungicide applications or biological treatments and sanitation can be costly for smallholder rubber farmers (Chong *et al*., 2019; Hoffner, 2021; Saha *et al*., 2021). Scaling up these practices across large plantations

can be challenging to implement and may necessitate changes in farming practices and management approaches.

Long-term sustainability

The use of chemical control measures can have negative environmental impacts, including contamination of soil and water resources (Wastie, 1975; Meenakshi and Mathivanan, 2012; Raguraman and Kannan, 2014; Saha *et al*., 2021). Overreliance on fungicides may disrupt natural ecosystems and harm non-target organisms, contributing to long-term ecological imbalances (Raguraman and Kannan, 2014; Saha *et al*., 2021). Rubber farmers must cultivate resilience and adaptability to combat dynamic root diseases. This includes regularly assessing disease prevalence, adjusting management strategies and investing in long-term solutions to enhance sustainability of rubber cultivation (Chong *et al*., 2019; Esekhade *et al*., 2021).

RECOMMENDATIONS AND THE WAY FORWARD

Integrated Disease Management (IDM)

Continued investment in research and development is essential for identifying and developing effective IDM strategies tailored to the specific needs of rubber farming systems (Narayanan and Mydin, 2012). This includes exploring synergistic effects of combining cultural, biological and chemical control methods to enhance disease suppression while minimizing environmental impact. Extension programs should be strengthened to disseminate knowledge and best practices in disease management to rubber farmers, particularly in regions where access to information and technical support is limited (Adesemoye and Eskalen, 2010; Sriprasert and Lumyong, 2012; Deguine *et al*., 2021; Saha *et al*., 2021; Velten *et al*., 2021). Training programs and farmer field schools can empower growers with the skills and tools needed to implement IDM practices effectively.

Breeding for resistance

Efforts to develop rubber tree cultivars with enhanced resistance to root diseases should be accelerated through breeding programs and biotechnological approaches (Narayanan and Mydin, 2012; Le Guen *et al*., 2013). Emphasizing traits such as tolerance to pathogen infection, root vigour and symbiotic associations with beneficial microorganisms can contribute to the development of resilient cultivars.

Sustainable agricultural practices

Promoting agroecological principles such as crop diversification, organic soil amendments and conservation tillage can enhance soil health and resilience to root diseases in rubber plantations (Chong *et al*., 2019; Esekhade *et al*., 2021). Integrating rubber cultivation with other compatible crops or agroforestry systems can help break disease cycles and improve overall farm sustainability. Recognizing the role of natural enemies and beneficial microorganisms in suppressing root pathogens and conservation of ecosystem services should be prioritized through habitat preservation and restoration efforts (Chong *et al*., 2019; Esekhade *et al*., 2021). Protecting biodiversity within rubber landscapes can enhance biological control and reduce reliance on external inputs.

Policy support and capacity building for promoting sustainable rubber cultivation

Policymakers play a vital role in promoting sustainable rubber cultivation. They provide support and establish frameworks that incentivize research, enhance extension services and enforce regulations to encourage environmentally friendly practices. The policymakers should allocate sufficient funds and research grants, promote collaborative research, improve extension support for farmers, provide training, create platforms such as online portals, mobile applications and farmer cooperatives. Providing subsidized loans, grants or input vouchers for purchasing disease-resistant seedlings, biocontrol agents, organic fertilizers and other inputs needed for sustainable rubber cultivation are other methods of support. Setting up monitoring frameworks, collecting data on key performance indicators and conducting periodic evaluations to measure the effectiveness of policy measures and identify areas for improvement are required for addressing sustainable root disease management in rubber plantations.

CONCLUSION

Root diseases in rubber trees are a significant threat to the sustainability of rubber cultivation worldwide. They endanger livelihoods of millions of people and undermine the economic viability of rubber plantations. Despite years of research and interventions, these diseases continue to create havoc, highlighting the critical need for immediate and concerted action from all stakeholders involved in the rubber industry. To combat root diseases and ensure long-term viability of rubber cultivation, stakeholders must work together to find innovative solutions and sustainable practices. This task is urgent and a clear roadmap for future research and action is imperative.

Firstly, researchers should prioritize investigations into the mechanisms of root disease infection, host-pathogen interactions and environmental factors that influence disease development. This research should inform the development of disease-resistant cultivars, novel disease management strategies and environmentally friendly agricultural practices tailored to the unique challenges faced by rubber farmers. Secondly, policymakers must enact supportive policies and provide financial incentives to promote sustainable rubber cultivation practices. This includes funding research and development initiatives, expanding extension services and implementing regulations to encourage adoption of environmentally friendly practices. By creating an enabling environment for innovation and sustainability, policymakers can empower rubber farmers to effectively manage root diseases while safeguarding the environment and their livelihoods. Rubber farmers themselves play a crucial role in implementing sustainable practices and adopting integrated disease management strategies. By embracing agroecological principles, practicing good soil management and actively participating in extension programs, farmers can enhance resilience of their plantations and minimize the impact of root diseases on their yield and income. Finally, collaboration and knowledge exchange among stakeholders is essential for sharing best practices, fostering innovation and driving collective action towards sustainable rubber cultivation. Industry associations, research institutions, government agencies and farmer

cooperatives must come together to share insights, resources and expertise, fostering a culture of collaboration and collective responsibility for addressing root diseases.

In conclusion, root diseases in rubber trees represent a pressing challenge that demands urgent attention and concerted efforts from all stakeholders involved. By prioritizing research, enacting supportive policies, empowering farmers and fostering collaboration, we can overcome the threat posed by root diseases and ensure long-term sustainability of the rubber industry. We should seize this opportunity to build a resilient and thriving future for rubber cultivation, one where root diseases are effectively managed and rubber farmers thrive in harmony with the environment.

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