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REVIEW PAPER

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Basal stem rot of oil palm in Africa: Emerging epidemiology, pathogen diversity and future management challenges

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ABSTRACT

Basal stem rot (BSR) is one of the most destructive diseases affecting oil palm (*Elaeis guineensis* Jacq.), causing severe yield losses, economic damage, and premature palm mortality in affected plantations. The disease is primarily associated with fungal pathogens belonging to genus *Ganoderma*. While BSR has been extensively studied in Southeast Asia, little attention has been given to the disease in Africa despite the crops' origin on the continent. Recent reports from several African countries suggest that BSR incidence may be increasing, raising concerns regarding its potential impact on the sustainability of oil palm production systems. This review synthesizes current knowledge on BSR of oil palm in Africa with emphasis on pathogen diversity, epidemiology, and management strategies. Available evidence indicates that multiple *Ganoderma* species are associated with BSR in Africa, with *Ganoderma ryvardenii* identified as one of the principal causal agents. However, the diversity, distribution, and population structure of African *Ganoderma* species remain poorly understood due to limited molecular studies. The epidemiology of BSR in African plantations is influenced by multiple interacting factors including plantation age, soil conditions, environmental variables, and management practices. Current management approaches rely largely on cultural practices, although these measures often provide only short-term control. Emerging strategies including biological control, host resistance breeding, and early detection technologies offer promising paths for sustainable disease management. However, limited research and majority plantations under smallholders significantly contribute to knowledge gaps elucidated regarding BSR in Africa. Addressing these gaps are essential for safeguarding the future oil palm production in Africa.

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the most economically important perennial oil crops globally, providing more than one-third of the world's vegetable oil supply despite occupying less area than other major oilseed crops (Alhaji *et al*., 2024; Ostfeld and Reiner, 2024) . The crop is native to Africa and thrives in wild and semi-wild palm groves across the tropical rainforest of West and Central Africa. However, its perennial nature and habitat make it more vulnerable to various tropical tree diseases, which threatens rural livelihoods, food security, and agro-industrial development across the African societies (Adusei-Fosu *et al*., 2025; Alhaji *et al*., 2024; Descals *et al*., 2024). In recent decades, expansion of commercial plantations and intensification of smallholder production systems have significantly increased the importance of oil palm as a strategic agricultural commodity in Africa (Duguma *et al*., 2021; Ordway *et al*., 2019; Uzonmwanne *et al*., 2023). However, the sustainability of oil palm production is increasingly threatened by various biotic stresses, among which basal stem rot (BSR) has emerged as one of the most destructive diseases.

BSR is primarily caused by fungi belonging to the genus *Ganoderma* (Basidiomycota: Polyporales), a group of wood-decaying pathogens capable of infecting a wide range of woody hosts (Castillo *et al*., 2022; Khoo and Chong, 2023). The disease attacks the basal stem tissues and root system of oil palm, leading to progressive internal decay, structural weakening, reduced productivity, and eventual palm death. In heavily affected plantations, BSR can cause substantial yield losses and significantly shorten the economic lifespan of oil palm stands (Ezrin *et al*., 2026; Murphy *et al*., 2021; Zakaria, 2023). The disease has been extensively studied in Southeast Asia, particularly in Indonesia, Malaysia and Thailand where it represents the most serious pathological constraints to oil palm cultivation. In these regions, BSR incidence can exceed 50% in replanted fields, leading to considerable economic losses and long-term management challenges (Ibrahim *et al*., 2020).

In contrast, the epidemiology and management of BSR in African oil palm belt, particularly in Nigeria, Côte d'Ivoire, Cameroon, Tanzania, Democratic Republic of Congo (DRC), Benin, Ghana, Burundi, Angola and Uganda remain comparatively understudied despite the crop's African origin. Early observations of BSR symptoms in African oil palm plantations date back several decades, yet the disease has historically received less attention than other major oil palm diseases, such as Fusarium wilt caused by *Fusarium oxysporum* f. sp. *elaeidis* (Flood *et al*., 2022; Zakaria, 2023). As a result, information regarding the diversity of *Ganoderma* species, their distribution, epidemiology, and management strategies in African oil palm system remains fragmented and limited (Murphy *et al*., 2021; Zakaria, 2023). Recent reports from several African countries suggests that BSR incidence may be increasing, for example, In Cameroon, BSR incidence ranging from 5.4% to 39.0 % were reported in Mungo and Bota regions, respectively (Mih and Kinge, 2015). Similarly, Ghana and Côte d'Ivoire recorded an average BSR incidence of 3.5% in both industrial and village plantations (Abraham *et al*., 2023; Lekete-Lawson *et al*., 2024). Recently, an average BSR incidence of 55.8% has been recorded in oil palm plantations in Tanzania (Mabula *et al*., 2025). This raises concerns about its potential to become a major constraint to future oil palm expansion across the continent.

The epidemiology of BSR in Africa appears to be shaped by the interaction of multiple factors, including pathogen diversity, plantation management practices, and environmental conditions.

Unlike Southeast Asia, where large monoculture plantations dominate, African oil palm production is largely dominated by smallholder farming systems characterized by heterogenous plantation ages, limited sanitations practices, and diverse host reservoir (Sultan *et al*., 2025).

These factors may significantly influence emergence, persistence, and spread of *Ganoderma* population in

African agroecosystem and later the effectiveness of existing management strategies. Therefore, available information suggests that the emergence of BSR disease in Africa is driven not only by pathogen introduction, but also by ecological changes and shifts in management practices. Understanding these regional dynamics is essential for developing context-specific approaches to BSR management.

Despite growing recognition of BSR as a potential threat to African oil palm production, comprehensive syntheses of available knowledge on the disease in African remain scarce. Most existing studies focus on Southeast Asian production systems, leaving substantial knowledge gaps regarding the African patho-system. A systematic evaluation of current knowledge is therefore necessary to identify research priorities and guide future disease management strategies.

This review aims to synthesize the available literature on basal stem rot of oil palm in Africa, with particular emphasis on pathogen diversity, epidemiology, and management challenges.

Specifically, the review (i) examines the diversity and phylogenetic relationships of Ganoderma species associated with BSR in Africa, (ii) discusses the epidemiological factors influencing disease occurrence and spread across different agroecological zones, and (iii) evaluates current and potential management strategies within the context of African oil palm production systems.

By integrating available evidence and identifying key knowledge gaps, this review provides a framework for future research and supports the development of sustainable BSR management strategies for the African oil palm sector.

Pathogen diversity associated with BSR in Africa

Species belonging to the genus *Ganoderma* are widely distributed wood-decaying fungi capable of colonizing numerous woody plant hosts (Kinge and Mih, 2015; Mawar *et al.*, 2020; Morera *et al.*, 2022; Tchotet Tchoumi *et al.*, 2019). Several species within this genus have been implicated in basal stem rot disease of oil palm across the world, with differences in pathogenic aggressiveness (Table 1)(Castillo *et al.*, 2022; Lekete-lawson *et al.*, 2025; Wong *et al.*, 2012) .

In Southeast Asia, *Ganoderma boninense* is widely recognized as the primary causal agent of BSR. However, studies conducted in Africa indicate that different *Ganoderma* species may be involved in disease development (Kinge and Mih, 2014, 2015; Ndeh *et al.*, 2024). Among the species reported in African oil palm systems, *Ganoderma ryvardenii* (*G. ryvardenii*) has been identified as one of the main pathogens associated with BSR. Molecular identification using internal transcribed spacer (ITS) sequencing and phylogenetic analysis has confirmed the presence of this specie in infected oil palm tissues in Ghana and Cameroon (Lekete-lawson *et al.*, 2025; Kinge and Mih, 2011). The identification of *G. ryvardenii* highlights the possibility that African BSR patho-systems may differ from those in Southeast Asia in term of pathogen composition and evolutionary history.

The diversity of *Ganoderma* species in Africa remains poorly understood due to limited molecular characterization studies. Many earlier reports relied primarily on morphological identification, which is often insufficient for distinguishing closely related species within the genus (Kinge and Mih, 2014, 2015; Wakefield, 1920). Also, existence of many *Ganoderma* species across the African forest ecosystems provides the shift possibility to oil palm ecosystems which may form a unique phylogeographic lineage (Ndeh *et al.*, 2024; Tchotet Tchoumi *et al.*, 2019; Xing *et al.*, 2016). Advances in molecular phylogenetics and DNA sequencing have improved the accuracy of *Ganoderma* identification and genetic diversity studies worldwide.

Given that oil palm is indigenous to Africa, it is possible that African *Ganoderma* populations represent ancestral lineages that have co-evolved with native palm species and forest hosts (Kinge and Mih, 2015; Ndeh *et al.*, 2024; Tchotet Tchoumi *et al.*, 2019). Hence, BSR in Africa may involve different pathogenic species than Southeast Asia, despite the possibility of the present *Ganoderma* species may be either cryptic or non-pathogenic species (Kinge and Mih, 2015). Understanding the genetic diversity and population structure of these pathogens through multilocus phylogeny and population genomics studies will be important for elucidating disease epidemiology and developing effective management strategies.

Table 1. *Ganoderma* species associated with basal stem rot (BSR) disease of oil palm and their pathogenic characteristics

Ganoderma species	Region	Pathogenicity Reported (virulence, infection mode, decay type, host interaction)	References
Ganoderma ryvardenii	Africa	Pathogenicity not fully elucidated; associated with BSR symptoms. Likely root/contact infection; white rot fungus degrading lignin. Presumed low–moderate virulence based on limited reports.	(Lekete-Lawson *et al.*, 2025)
Ganoderma boninense	Southeast Asia	Highly virulent primary BSR pathogen. Infects via root contact and basidiospores; extensive colonization of basal stem tissues. Causes white rot through ligninolytic enzymes (laccases, peroxidases). Leads to severe structural decay, palm collapse, and significant yield loss. Broad host interaction within oil palm plantations.	(Wong *et al.*, 2012)
Ganoderma zonatum	South America	Moderately to highly pathogenic; causes basal stem and butt rot. Infection primarily via roots and wounds. White rot decay of lignified tissues. Virulence influenced by environmental conditions and host susceptibility.	(Castillo *et al.*, 2022)
	Africa	Pathogenic; associated with BSR-like symptoms. Likely similar infection biology (root contact, wood decay). Virulence not well quantified.	(Kinge and Mih, 2015)
	Southeast Asia	Present but generally less aggressive than G. boninense. Causes white rot; contributes to disease under conducive conditions.	(Wong *et al.*, 2012)
Ganoderma miniatotinctum	Southeast Asia	Weak to moderate pathogen. Occasionally isolated from diseased palms. Likely opportunistic; root-based infection and white rot activity reported. Limited capacity for severe disease compared to dominant pathogens.	(Wong *et al.*, 2012)

Epidemiology of basal stem rot

The development of BSR is influenced by complex interaction among host plants, pathogen populations, and environmental conditions (Jazuli *et al.*, 2022; Naher *et al.*, 2013; Rees *et al.*, 2009). The epidemiology of the disease can be understood within the framework of the plant disease triangle, in which disease occurrence depends on the simultaneous presence of a susceptible host, a virulent pathogen, and favorable environmental conditions (Agrios, 2005).

Understanding the epidemiology of BSR in African oil palm system is essential for predicting disease spread and developing effective management strategies. Although extensive epidemiological studies have been conducted in southeast Asia (Flood *et al.*, 2005, 2022; Jazuli *et al.*, 2022), knowledge regarding the dynamic of BSR in African plantations remain limited. Visually, BSR disease in Africa manifests as wilting and yellowing of fronds followed by the appearance of *Ganoderma* basidiocarp prior to the collapse of the palm tree (Fig. 1), as is observed in Southeast Asia. Nevertheless, available studies and field observations suggest that disease development in Africa follows patterns broadly consistent with the classical plant disease triangle, where host susceptibility, pathogen virulence, and environmental conditions collectively determine disease occurrence and severity (Abraham *et al.*, 2023; Lekete-Lawson *et al.*, 2024; Mih and Kinge, 2015).

Pathogen factor and disease transmission

The presence of multiple *Ganoderma* species within African ecosystem suggests a potentially large pathogen reservoir with diverse ecological adaptations (Ndeh *et al.*, 2024; Tchotet Tchoumi *et al.*, 2019; Xing *et al.*, 2016). Although the pathogenic roles on BSR for many species reported in Africa remain unclear. In addition, based on the ITS analyses, many *Ganoderma* isolates from African oil palm plantations cluster closely with G. *ryvardenii* reference sequences, suggesting a relatively conserved lineage associated with BSR (Lekete-lawson *et al*., 2025). This evidence suggests that *Ganoderma* population in Africa may exhibit moderate to high genetic diversity due to the reproductive biology of the fungus, which favors outcrossing through basidiospores dispersal and promotes genetic recombination resulting to the emergence of new pathogenic strains (Mawar *et al*., 2020; Tchotet Tchoumi *et al*., 2019).

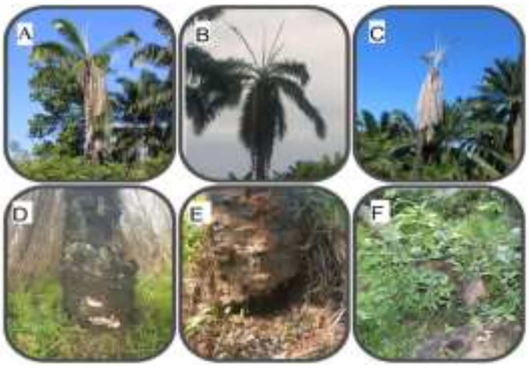

Fig. 1. Progressions of basal stem rot symptoms in oil palm. (A) Chlorosis of oil palm fronds. (B) Numerous unopened spear leaves. (C) A ring of dead fronds hanging around the crown. (D) Appearance of *Ganoderma* fruiting bodies on the trunk. (E) Basal rotting due to *Ganoderma*. (F) Dead and fallen oil palms

The primary source of inoculum for BSR is *Ganoderma*-infected wood debris and root systems that remain in the soil after diseased palms die or are removed. BSR disease cycle involves the presence of an infection or inoculum source, followed by pathogen penetration of the host roots.

The pathogen then transitions from a biotrophic to a necrotrophic phase, ultimately leading to palm death and the persistence of the pathogen in plant and soil residues (Fig. 2). *Ganoderma* species can survive for extended periods as saprophytic mycelia within colonized plant residues, serving as reservoirs of infection for subsequent planting cycle (Flood *et al*., 2005). Root-to-root contact between healthy palms and infected residues is widely recognized as the main mechanism of pathogen transmission within plantations (Rees *et al*., 2009; Zakaria, 2023). As roots grow and expand through the soil, they may encounter infected debris, allowing fungal hyphae to colonize the root tissues of healthy palms.

Fig. 2. Epidemiological cycle of basal stem rot disease caused by *Ganoderma* species in oil palm plantations

In addition to root contact transmission, *Ganoderma* fruiting bodies produce large number of airborne basidiospores. These spores may contribute to the long-distance dispersal of the pathogen and the establishment of new infection foci (Pilotti *et al*., 2018; Sanderson, 2005).

Although the epidemiological importance of basidiospore infection remains debated, several studies suggest that spore-mediated infection could play a role in disease spread, particularly in plantations with high inoculum pressure.

Host susceptibility and plantation age

Host factors play a critical role in determining the severity and progression of BSR. Oil palm susceptibility to *Ganoderma* infection is influenced by several factors including palm age, genetic background, and physiological condition (Jazuli *et al*., 2022; Mih and Kinge, 2015; Naher *et al*., 2013). Older palms generally exhibit higher disease incidence due to prolonged exposure to soilborne inoculum and accumulated root injuries that facilitate pathogen entry (Lekete-Lawson *et al*., 2024; Mabula *et al*., 2025). Replanting areas are particularly vulnerable, as residual infected debris from previous planting cycles often serves as a persistent inoculum source

(Ibrahim *et al.*, 2020). Genetic variation among oil palm varieties may also influence disease susceptibility, however, to-date BSR reported to affect all oil palm genotypes. Although complete resistance to BSR has not yet been identified, several breeding programs have reported partial resistance or tolerance among certain genetic lines (Idris *et al.*, 2004). The incorporation of resistance or tolerance varieties into breeding programs represents a promising strategy for long-term disease management. Despite the positive impact of oil palm root system growing deeper with adequate rooting volume in terms of nutrient and water uptake, it is also significantly influencing the emergence and spread of BSR disease within the plantations (Intara *et al.*, 2018; Rees *et al.*, 2009). Long-time established oil palm plantations and palm groves along river basins in Africa, exhibit high root system interaction which favor for rapid BSR spread particularly in plantations with poor planting spacing (Abraham *et al.*, 2023; Lekete-Lawson *et al.*, 2024; Mabula *et al.*, 2025).

Environmental and soil factors

Environmental conditions strongly influence the development and spread of BSR (Hao *et al.*, 2019). Soil characteristics such as soil texture, drainage, organic matter content, and moisture levels may affect both pathogen survival and host susceptibility (Anothai and Chairin, 2020; Chen *et al.*, 2017). Poorly drained soils and areas with high soil moisture levels may favor fungal growth and root infection. Similarly, soil disturbances during plantation establishment or replanting may facilitate spread of *Ganoderma* by exposing roots to infection sites (Ramdan *et al.*, 2024; Virdiana *et al.*, 2024). Climatic factors such as temperature and rainfall may also influence the epidemiology of BSR by affecting fungal growth, sporulation, and host stress (Paterson *et al.*, 2013). Tropical climates characterized by warm temperatures and high humidity provide favorable conditions for development of *Ganoderma* species (Paterson *et al.*, 2013).

However, the specific climatic thresholds influencing disease development in African oil palm systems remain poorly understood and require further investigation.

Plantation management and disease dynamics

Plantation management practices significantly influence BSR epidemiology. Practices such as inadequate removal of infected palms, improper sanitation during replanting, and poor field hygiene can increase inoculum levels and accelerate disease spread (Abraham *et al.*, 2023; Lekete-Lawson *et al.*, 2024; Mih and Kinge, 2015). In many African production systems, particularly smallholder plantations, limited access to disease management resources may exacerbate disease incidence (Iyabanoa *et al.*, 2014; Sultan *et al.*, 2025). The transition from traditional mixed cropping systems to monoculture oil palm plantations may also contribute to increasing BSR risk (Ordway *et al.*, 2019; Pirker *et al.*, 2016). Monoculture systems can facilitate pathogen buildup in soils over successive planting cycles, thereby increasing disease pressure over time. A comparative analysis between African and Southeast Asia oil palm production systems shows significance differences, as described in (Table 2). These differences highlight potential threats to the future of African oil palm industry under current practices, particularly with the increasing emergence of BSR.

Management strategies for basal stem rot in Africa

Effective management of BSR remains one of the greatest challenges in oil palm production due to the persistence nature of *Ganoderma* pathogens in soil and plant residues and the absence of curative treatments for infected palms (Chong *et al.*, 2017; Chung, 2011; Hushiarian *et al.*, 2013; Khoo and Chong, 2023). Most current management strategies aim to reduce inoculum levels, delay disease progression, and minimize the spread of infection within plantations. In Africa, farmers manage BSR through field sanitation where infected palm trees and *Ganoderma* basidiocarps are removed from the field. Also, trenching practice which consists of trenches digging around the infected palm tree are frequently used to prevent root-to-root contact within the plantation (Lekete-Lawson *et al.*, 2024). However, the implementation of BSR management practices is often constrained by limited research, resource availability, and the predominance of smallholder production systems (Iyabanoa *et al.*, 2014; Lekete-Lawson *et al.*, 2024; Sultan *et al.*, 2025). Hence, direct transfer of BSR management technologies from Southeast Asia to Africa may be ineffective without considering differences in production systems.

Table 2. Comparative analysis of basal stem rot (BSR) in African and Southeast Asian oil palm production systems

Aspect	Africa	Southeast Asia
Primary pathogen	*Ganoderma ryvardenii* (emerging, less characterized)	*Ganoderma boninense* (well-characterized, highly aggressive)
Secondary *Ganoderma* spp.	High diversity; several uncharacterized species	Low diversities; largely dominated by *G. boninense*
Plantation type	Predominantly smallholder-based system	Both smallholder and industrial estates
Disease prevalence	Low to moderate; localized and likely underreported	High; widespread reaching up to 80% in replanted areas
Historical prevalence	Previously overlooked; currently emerging and increasing	Long-established major production constraint
Management strategies	Mainly cultural practices with limited integration of other methods	Integrated disease management (IDM) combining chemical, biological and cultural approaches
Early detection tools	Rarely applied	Increasingly adopted and implemented
Diagnosis and monitoring	Limited; primarily visual inspection with minimal infrastructure	Advanced systems including molecular tools and remote sensing
Farmers awareness	Relatively low to moderate	High
Research intensity	Limited and fragmented; constrained funding	Extensive and continuous; well-funded research programs
Source of infection	Forest reservoirs and infected residues	Infected debris and soil inoculum
Replanting system	Irregular and less structured; manual with limited sanitation	Systematic (25–30 years cycle); mechanized with sanitation protocol
Economic impact	Emerging threat; limited loss data available	Major constraint; severe yield losses reported up to 80% in high-risk areas

Cultural and sanitation practices

Cultural practices and sanitation represent the most widely implemented approaches for managing BSR in oil palm plantations. These strategies focus on reducing inoculum sources and limiting pathogen spread (Hushiarian *et al.*, 2013; Priwiratama *et al.*, 2020; Zakaria, 2023). Key practices include the removal of infected palms, destruction of diseased plant residues, trenching to prevent root contact between infected and healthy palms, and soil mounding to improve drainage around palm bases (Chong *et al.*, 2017; Chung, 2011). A study by Judijanto, (2026) reported that, with consistent implementation and favorable environmental conditions, cultural practices can significantly reduce BSR incidence by approximately 30-50% under field conditions. However, in African oil palm system, strict adoption of these practices may reduce disease incidence by only 3-8% and does not fully prevent reinfections due to the multiple survival structures of *Ganoderma* (Khoo and Chong, 2023). Despite their widespread use, these methods often provide only temporary relief and may extend the productive lifespan of infected palms rather than eliminate the disease (Bharudin *et al.*, 2022; Chong *et al.*, 2017). In many cases, infected woody debris remains in the soil and continues to serve as a reservoir for future infections.

Biological control

Biological control has emerged as a promising strategy for suppressing *Ganoderma* infections, particularly using various antagonistic microorganisms. For instance, Musa *et al.* (2018) reported that the application of *Trichoderma* spp. significantly reduced BSR incidence by colonizing the root zone and directly competing with the *Ganoderma* pathogen, thereby suppressing its growth.

Similarly, Puspita *et al.* (2020) explored the role of *Bacillus* spp. as biocontrol agents against BSR and found that these bacteria suppress disease development through the production of metabolites, such as lipopeptides, which inhibit *Ganoderma* growth. Additionally, these microorganisms can exhibit strong antibiosis and mycoparasitism against the pathogen (Chong *et al.*, 2017; Musa *et al.*, 2018). Furthermore, *Trichoderma* sp. and *Bacillus* sp. have shown significant potential to induce systemic resistance in the host by stimulating defense-related enzymes, thereby reducing disease severity over time. Although the use of beneficial soil microorganisms to enhance soil health and suppress pathogenic fungi is gaining increasing attention, the effectiveness of biological control agents may vary depending on environmental conditions and application methods (Musa *et al.*, 2018; Puspita *et al.*, 2020). Therefore, further research is needed to optimize their application under African plantation conditions.

Host resistance and breeding

Developing oil palm varieties with improved tolerance or resistance to BSR represents a key long-term strategy for sustainable disease management. However, African oil palm (*Elaeis guineensis*) exhibits considerable variability in susceptibility to BSR, and several breeding programs have identified progenies that show partial resistance to *Ganoderma* infection (Godswill *et al.*, 2016; Idris *et al.*, 2004; Soh, 2017).

A notable example of applied breeding innovation is the development of *Ganoderma*-tolerant variety, such as the 'Yangambi *Ganoderma*-tolerant 1' line, whose genetic base originates from Central Africa (Khoo and Chong, 2023). Nevertheless, many studies indicate that resistance in oil palm is quantitative (polygenic) rather than controlled by a single gene, making breeding program complex and time-consuming. Recently, there has been increasing focus on molecular and genomic approaches, which facilitate the identification of specific biochemical markers associated with resistant oil palm genotypes, thereby accelerating selection in breeding programs (Daval *et al.*, 2021; Nugroho *et al.*, 2025). Although complete resistance has not yet been achieved, incorporating tolerant genotypes into breeding programs could significantly reduce disease impact in future plantations. Given the high genetic diversity of oil palms in Africa, there is considerable potential for identifying locally adapted germplasm with enhanced disease tolerance (Godswill *et al.*, 2016; Ngando-Ebongue *et al.*, 2011; Soh, 2017). With growing recognition of this potential, African research institutions and governments could further strengthen this effort by investing in local breeding programs, conserving genetic resources, and fostering collaboration with international oil palm research centers.

Early detection and monitoring: evidence from Southeast Asia and research gaps for Africa

Early detection of BSR is critical for preventing disease spreading within plantations. Traditional detection methods rely on visible symptoms such as foliar yellowing, wilting, canopy collapse, and the presence of *Ganoderma* fruiting bodies at the palm base (Amrutha *et al.*, 2024; Chong *et al.*, 2017; Hushiarian *et al.*, 2013). However, these symptoms typically appear at advanced stages of infection, when internal tissue damage is already extensive (Amrutha *et al.*, 2024; Chong *et al.*, 2017). This challenge is even more pronounced in Africa, where *G. ryvardenii* is relatively new and diagnostic frameworks remain underdeveloped.

Evidence from Southeast Asia indicates that advances in molecular diagnostics, remote sensing technologies, and spectral imaging offer new opportunities for early disease detection and management, as shown in Table 3 (Ahmadi *et al.*, 2022; Hailini *et al.*, 2022; Kwang *et al.*, 2025b; Muniroh *et al.*, 2014; Zairun *et al.*, 2018). The integrating of remote sensing, machine learning, geospatial, and sensor-based approaches such as hyperspectral imaging, unmanned aerial vehicles (UAVs), and terrestrial laser scanning enables the detection of *Ganoderma* infection before visible symptoms appear, with high accuracy (Baharim *et al.*, 2022).

Table 3. Evidence from Southeast Asia on the effectiveness of advanced *Ganoderma* early detection approaches applied in oil palm plantations

Detection method	Principles	Application stage	Reported accuracy	Reference
Hyperspectral Imaging + SVM	Detects spectral changes in oil palm tissues (VIS-NIR)	Nursery and field (asymptomatic stage)	Up to 100% (controlled)	(Azmi *et al.*, 2020; Kwang *et al.*, 2025a)
Spectral indices (Remote sensing)	Uses reflectance differences to identify stress signatures	Seedling stage	Up to 80%	(Izzuddin *et al.*, 2017)
Hyper-and multi-spectral (Remote sensing)	Discern leaf spectral radiance	Field	Up to 85%	(Malinee *et al.*, 2021)
Artificial Neural Network (ANN) + Spectroscopy	Classifies infection levels using spectral derivatives	Early infection stage	Up to 100% (depending on wavelength/frond)	(Bharudin *et al.*, 2022)
UAV/multispectral Imaging	Large-scale canopy monitoring	Plantation level	Up to 97%	(Ahmadi *et al.*, 2022, 2023)
PCR/ELISA/culture-based methods	Detect pathogen DNA or protein directly	Confirmatory (lab-based)	High specificity (qualitative)	(Hailini *et al.*, 2022)

For example, recent studies on combining UAV-based hyperspectral imaging with machine learning and artificial intelligence (AI) such as Support Vector Machine (SVM), have demonstrated near-perfect accuracy, sensitivity, and specificity in detection *Ganoderma* infection at asymptomatic stage in oil palm plantations (Kwang, 2025a; Kwang, Razak, *et al.*, 2025). Similarly, Izzuddin *et al.* (2017) showed that physiological changes in infected oil palm can be detected earlier than morphological symptoms using spectral indices derived from reflectance data at seedling stage. These technologies could enable plantation managers to identify infected palms before visible symptoms develop, thereby improving disease management outcomes.

Integrated disease management

Given the complex nature of BSR, no single control strategy is sufficient for effective disease management. Instead, integrated disease management IDM approaches that combine cultural practices, biological control, resistant varieties, and early detection technologies are likely to be effective (Alexander and Phin, 2014; Khoo and Chong, 2023; Musa *et al.*, 2018). For example, in Africa, field sanitation and cleaning can be integrated with application of antagonistic microorganisms, such as *Trichoderma* spp., which are commercially available (Khoo and Chong, 2023). Additionally, investment in early detection methods in African oil palm plantations could further enhance the effectiveness of these integrated strategies for BSR management. Furthermore, developing region-specific IDM strategies tailored to African oil palm production systems will be essential for mitigating the long-term impact of BSR.

FUTURE RESEARCH PRIORITIES

Despite increasing recognition of BSR in African oil palm system, several critical knowledge gaps remain. Comprehensive surveys of *Ganoderma* diversity across African oil palm-growing regions are still lacking, limited population genetic studies to understand pathogen evolution and spread, epidemiological modeling of disease dynamics, development of early detection technologies, breeding programs targeting BSR resistance, and evaluation of integrated disease management strategies under African conditions. Future research should prioritize large-scale epidemiological surveys, molecular characterization of pathogen populations, and the development of early detection tools. Additionally, breeding programs aimed at improving oil palm tolerance to *Ganoderma* infection will be essential for sustainable disease management.

CONCLUSION

Basal stem rot is increasingly recognized as a potential threat to oil palm production in Africa.

Although the disease has been extensively studied in Southeast Asia, knowledge regarding pathogen diversity, epidemiology, and management in African oil palm systems remain limited.

Available evidence suggests that several Ganoderma species are associated with BSR in Africa, with *G. ryvardenii* playing an important role in disease development. The persistence of the pathogen in soil and plant residues, combined with limited management options, makes BSR particularly difficult to control. Sustainable management will likely require integrated approaches combining improved sanitation practices, biological control strategies, resistant planting materials, and early detection technologies. Addressing existing knowledge gaps through coordinated research efforts will be essential for developing effective disease management strategies and ensuring the long-term sustainability of oil palm production across Africa.

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