Impact of *Ganoderma boninense* Infection on The Abundance of Cellulolytic And Lignolytic Fungi In The Soil of Oil Palm In Pare-Pare Tengah Village, North Labuhanbatu

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Abstract.
Basal Stem Rot (BSR), caused by Ganoderma boninense, is the most destructive disease affecting oil palm (Elaeis guineensis) plantations in Southeast Asia, leading to severe yield losses and threatening the sustainability of the industry. Despite extensive studies on the pathogenicity of Ganoderma, its ecological impact on functional fungal communities in oil palm soils remains poorly understood. This study aimed to evaluate the effect of Ganoderma infection on the abundance of total fungi, cellulolytic fungi, and ligninolytic fungi in oil palm plantation soils in Pare-Pare Tengah Village, North Labuhanbatu, North Sumatra, Indonesia. Soil samples were collected from healthy and infected oil palm stands and analyzed using the Total Plate Count (TPC) method to quantify fungal populations. Statistical analysis using paired t-tests and effect size (Cohen's d) revealed significant differences between healthy and infected soils. Total fungal abundance decreased from 2.91×10^9 *CFU* g^{-1} *in healthy soils to* 2.16×10^9 *CFU* g^{-1} *in infected soils (Cohen's d = 19.15). Similarly, cellulolytic fungi declined from* 4.74×10^4 *CFU* g^{-1} *to* 2.51×10^4 *CFU* g^{-1} *(Cohen's d = 16.28). Unexpectedly, ligninolytic fungi also showed a marked reduction from* 2.22×10^3 *CFU* g^{-1} *in healthy soils to* 2.01×10^2 *CFU* g^{-1} *in infected soils (Cohen's d = 59.14). These findings indicate a substantial shift in soil fungal community structure associated with Ganoderma infection, suggesting complex ecological interactions and potential suppression of other lignocellulose degrading fungi. Understanding these microbial dynamics provides important insights for developing more sustainable and ecologically based management strategies for BSR disease in oil palm plantations.*

Keywords: *Basal Stem Rot, Ganoderma boninense, oil palm, soil fungi, cellulolytic fungi and ligninolytic fungi.*

I. INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important plantation crops in tropical regions and represents the largest source of vegetable oil in the global market. The rapid expansion of oil palm cultivation has played a significant role in supporting food industries, bioenergy production, and rural economic development. Indonesia is currently the world's largest producer of palm oil, accounting for more than 55% of global production [1, 2]. According to the *Indonesian Ministry of Agriculture*, the total oil palm plantation area in Indonesia exceeded 16.8 million hectares in 2023, producing more than 46 million tons of crude palm oil annually [3]. Among the major producing regions, *North Sumatra* is one of the key oil palm production centers, with plantation areas covering approximately 1.5–1.8 million hectares and contributing substantially to regional economic growth [4].

Despite its economic importance, the sustainability and productivity of oil palm plantations are increasingly threatened by several biotic stresses, among which Basal Stem Rot (BSR) is considered the most destructive disease. BSR is primarily caused by the soil-borne fungal pathogen *Ganoderma boninense*, which infects the root system and subsequently colonizes the basal stem tissues of oil palm trees [5]. The infection gradually leads to structural decay of plant tissues, disruption of water and nutrient transport, canopy collapse, and eventually plant death [6]. The pathogen can survive for long periods in soil and infected plant debris, making disease management particularly difficult in replanted oil palm areas [7, 5].

The economic impact of BSR disease is substantial. Several studies have reported that infection by *Ganoderma* can cause yield losses ranging from 50% to 80% in severely affected plantations [6]. In Indonesia, the disease has been reported in almost all major oil palm producing regions, including North Sumatra, where infection incidence can reach 10–30% in mature plantations and even higher in replanting areas [7]. The resulting economic losses are estimated to reach hundreds of millions of US dollars annually due to reduced productivity, premature plant mortality, and increased replanting costs [8].

The pathogenicity of *Ganoderma* species is closely associated with their ability to degrade lignocellulosic components of plant cell walls. As a white-rot fungus, *G. boninense* produces a complex extracellular enzymatic system capable of degrading lignin, cellulose, and hemicellulose [9]. These enzymatic activities involve ligninolytic enzymes such as laccase and manganese peroxidase, as well as cellulolytic enzymes that break down structural polysaccharides of plant tissues [10]. Through this mechanism, the pathogen can efficiently colonize host tissues and utilize plant biomass as a nutrient source. Transcriptomic studies have also revealed the upregulation of genes encoding carbohydrate-active enzymes (CAZymes) during infection, indicating the important role of lignocellulose degradation in the pathogenesis of *Ganoderma* [11].

Beyond its direct impact on the host plant, *Ganoderma* infection can also alter the structure and function of soil microbial communities in the oil palm rhizosphere. Soil microorganisms play a crucial role in nutrient cycling, organic matter decomposition, and plant health maintenance [12]. Changes in microbial community composition can influence ecosystem processes and may either suppress or facilitate disease development. Recent metagenomic analyses have shown significant differences in microbial diversity between healthy and *Ganoderma*-infected oil palm soils, suggesting that pathogen invasion may disrupt microbial ecological balance in the rhizosphere [12, 13, 14].

Among soil microorganisms, fungi involved in lignocellulose degradation are particularly important for ecosystem functioning. Cellulolytic fungi contribute to the decomposition of cellulose, the most abundant organic polymer in terrestrial ecosystems, while ligninolytic fungi are among the few organisms capable of breaking down lignin, a complex aromatic polymer that provides structural rigidity to plant cell walls and protects them from enzymatic degradation [9]. These functional groups play a critical role in regulating soil carbon cycling, nutrient availability, and organic matter turnover in agricultural ecosystems [10]. Considering that *G. boninense* itself is a ligninolytic fungus, its presence and activity in the soil may influence the abundance and ecological roles of other lignocellulose-degrading fungi.

Although numerous studies have investigated the pathogenic mechanisms and control strategies of *Ganoderma*, limited information is available regarding its ecological impact on functional fungal communities involved in lignocellulose decomposition in oil palm soils. Most previous studies have focused on pathogen detection, host resistance, or biological control agents, whereas the ecological consequences of pathogen invasion on cellulolytic and ligninolytic fungal populations remain poorly understood. Understanding these interactions is important for explaining the patoecology of BSR disease and its broader implications for soil ecosystem functioning. Therefore, this study aimed to quantitatively analyze the impact of *Ganoderma* infection on the abundance of total fungi, cellulolytic fungi, and ligninolytic fungi in soils of oil palm stands in Pare-Pare Tengah Village, North Labuhanbatu, North Sumatra, Indonesia. By investigating changes in functional fungal populations associated with pathogen infection, this research is expected to provide new insights into the microbial ecological dynamics of oil palm soils and contribute to the development of more sustainable management strategies for Basal Stem Rot disease.

II. METHODS

This research was conducted in an oil palm plantation located in Pare-Pare Tengah Village, Marbau Subdistrict, North Labuhanbatu Regency, North Sumatra. Soil samples were taken from two conditions of oil palm stands:

1. Healthy soil was taken from the rhizosphere of oil palm stands that did not show symptoms or infection of *Ganoderma* sp.

Fig 1. Location of sample from healthy soil

2. Infected soil was taken from the rhizosphere of oil palm stands that showed visual symptoms of *Ganoderma* sp. infection, namely the presence of *Ganoderma* fruiting bodies at the base of the trunk.

Fig 2. Location of sample from infected soil with fruiting bodies

Sample collection was carried out carefully to ensure representation of soil conditions. A total of 4 pairs of samples (4 healthy soil samples and 4 infected soil samples) were collected. The soil samples were then brought to the laboratory for further analysis. The abundance of fungi is analyzed using the Total Plate Count (TPC) method, which is a standard technique for estimating the number of viable microorganisms in soil samples. The fungal parameters tested include:

- Total Fungi: Measures the overall population of fungi.
- Cellulolytic Fungi: Measures the population of fungi capable of degrading cellulose.
- Ligninolytic Fungi: Measures the population of fungi capable of degrading lignin.

Appropriate selective media are used for each group of fungi, and incubation is carried out at optimal temperature and time. The results are expressed in Colony Forming Units per gram (CFU/g) of soil. Fungal abundance data from healthy and infected soil samples were analyzed using a paired two-sample t-test (Paired Two Sample for Means) to determine whether there is a statistically significant difference between the two conditions. The analysis was conducted with a significance level of $\alpha = 0.05$. Additionally, the effect size (Cohen's d) was calculated to measure the magnitude of the observed difference. Data visualization can be done using a scatter plot with connecting lines for each pair of observations to illustrate the changes in fungal abundance between healthy and infected conditions.

III. RESULT AND DISCUSSION

Recent advances in plant microbe interaction research highlight the important role of the soil microbiome in maintaining plant health and suppressing soil-borne pathogens. The rhizosphere microbiome, which consists of complex microbial communities surrounding plant roots, can influence plant resistance through several mechanisms, including nutrient competition, production of antimicrobial metabolites, and induction of plant defense responses [15, 16]. The results of this study clearly demonstrate that infection by *Ganoderma boninense* significantly alters the soil microbial ecology of oil palm plantations in Pare-Pare Tengah Village, North Labuhanbatu. These changes are characterized by a drastic decrease in the total of fungi (Figure 3), total cellulolytic fungi (Figure 4), and total lignolytic fungi (Figure 5) in the infected soil.

a. Total of fungi

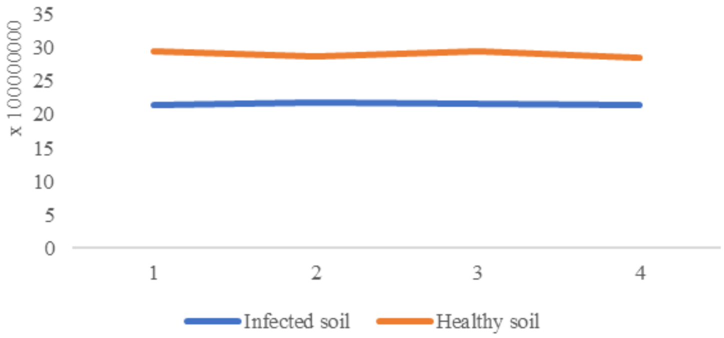

Fig 3. Total of fungi in healthy soil and infected soil

Paired t-tests showed a highly significant difference in total fungal abundance between healthy and infected soils (t = -25.98, df = 3, p = 0.000125). The mean total fungal abundance in infected soil (2.16 × 10^9 CFU/g) was significantly lower compared to healthy soil (2.91 × 10^9 CFU/g). The effect size, Cohen's d, was 19.15, indicating a very large difference. The decline in total fungal abundance in infected soil (t = -25.98, p < 0.001, Cohen's d = 19.15) suggests that the presence of *Ganoderma* sp. and the conditions it causes (e.g., stress on the host plant, changes in soil chemistry, or production of antimicrobial compounds by the pathogen) are overall unfavorable for the soil fungal community. This may imply that *Ganoderma* is not only a pathogen but also a disruptive agent that generally suppresses other fungal populations.

The results of this study demonstrate that infection by *Ganoderma boninense* significantly alters fungal community abundance in soils associated with oil palm (*Elaeis guineensis*) plantations. The decline in total fungal abundance observed in infected soils suggests that the presence of this pathogen may disrupt microbial ecological balance in the rhizosphere. Soil fungi play critical roles in nutrient cycling, organic matter decomposition, and ecosystem stability; therefore, disturbances in fungal populations can affect soil functionality and plantation productivity. Previous microbiome studies have shown that *Ganoderma* infection significantly modifies microbial community structures in oil palm soils and roots, often leading to shifts in microbial composition and ecological interactions [6, 12, 13]. Metagenomic studies have shown that the composition and diversity of the rhizosphere microbiome can significantly change when oil palm is exposed to *G. boninense*. A recent study by [17] demonstrated that asymptomatic oil palm seedlings exposed to the pathogen exhibited enrichment of microbial taxa belonging to Actinobacteriota and Ascomycota, which were identified as key microbial groups associated with disease suppression. These microorganisms are known to produce bioactive compounds and extracellular enzymes capable of inhibiting fungal pathogens, suggesting their potential role in natural disease suppression within the rhizosphere.

The interaction between oil palm roots, soil microorganisms, and pathogens reflects a complex ecological network in the rhizosphere. In many agricultural systems, soils with high microbial diversity are often associated with disease-suppressive soils, where naturally occurring microbial communities inhibit pathogen development [16, 18]. Enhancing microbial diversity and activity in oil palm soils may therefore provide a promising strategy to reduce the incidence of basal stem rot. However, soil physicochemical properties also influence microbial community composition and disease development. Previous studies have shown that certain soil nutrient conditions, particularly high phosphorus levels, may increase plant susceptibility to *G. boninense* infection [19]. These findings indicate that soil management practices, including balanced fertilization and organic amendments, may play an important role in shaping the soil microbiome and improving plant resilience against soil-borne pathogens. Overall, the integration of soil microbiome management into oil palm disease control strategies represents a promising and environmentally sustainable approach.

b. Total of Cellulolytic Fungi

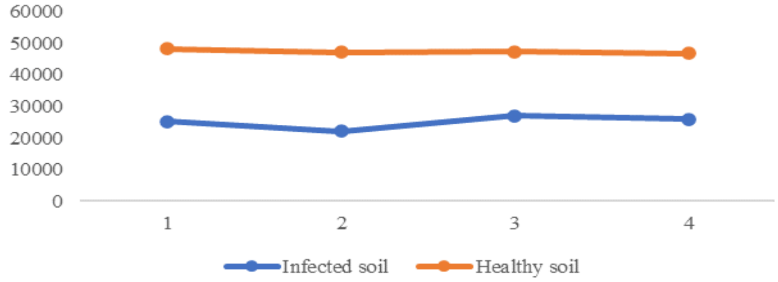

Fig 4. Total of cellulolytic fungi in healthy soil and infected soil

Paired t-tests showed a highly significant difference in the abundance of cellulolytic fungi between healthy and infected soils (t = -20.84, df = 3, p = 0.00024). The average abundance of cellulolytic fungi in infected soil (2.51×10^4 CFU/g) was significantly lower compared to healthy soil (4.74×10^4 CFU/g). The effect size, Cohen's d, was 16.28, indicating a very large difference. The significant decrease in the abundance of cellulolytic fungi in infected soil ($t = -20.84$, $p < 0.001$, Cohen's $d = 16.28$) indicates that *Ganoderma* infection creates an environment that is not conducive to the growth of other cellulolytic fungi. Although *Ganoderma* itself has cellulolytic capability, its dominance may suppress more diverse populations of other cellulolytic fungi. Competition for substrates or the production of allelopathic compounds by *Ganoderma* may be contributing factors to this decline [20].

The reduction in total fungal abundance observed in this study may also be related to competitive interactions between *Ganoderma* and other soil fungi. As a highly aggressive white-rot fungus, *G. boninense* possesses strong enzymatic capabilities for degrading lignocellulosic substrates, allowing it to efficiently colonize plant residues and organic matter in soil environments [10, 17]. Such ecological dominance may limit resource availability for other fungal taxa, thereby suppressing overall fungal population growth. Similar competitive exclusion phenomena have been reported in pathogen-dominated microbial ecosystems, where the establishment of a dominant pathogenic species reduces microbial diversity and abundance [21].

The significant reduction in cellulolytic fungi observed in infected soils indicates potential disruption of soil carbon cycling processes. Cellulolytic fungi are essential decomposers responsible for converting cellulose into simpler compounds that can be utilized by other soil microorganisms. Reduced abundance of cellulolytic fungi may slow organic matter decomposition and nutrient release, potentially affecting soil fertility and ecosystem productivity in oil palm plantations [22]. Studies examining microbial community responses to plant pathogens have reported similar decreases in decomposer microbial populations following disease outbreaks. Additionally, changes in soil fertility and microbial activity have been associated with the development and spread of basal stem rot disease in oil palm plantations [15, 16].

c. Total of Ligninolytic Fungi

Paired t-test showed a highly significant difference in the abundance of ligninolytic fungi between healthy and infected soils (t = -101.64, df = 4, p = 5.62E-08). The mean abundance of ligninolytic fungi in infected soil (2.01×10^2 CFU/g) was significantly lower compared to healthy soil (2.22×10^3 CFU/g). The effect size, Cohen's d, was 59.14, indicating a very large difference. The most striking finding that requires special attention is the decrease in the abundance of ligninolytic fungi in infected soil ($t = -101.64$, $p < 0.001$, Cohen's $d = 59.14$). In general, *Ganoderma* sp. is known as a white rot fungus that is highly active in degrading lignin [17, 9].

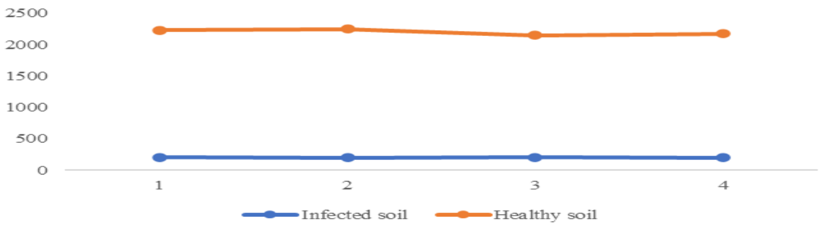

Fig 5. Total of ligninolytic fungi in healthy soil and infected soil

Interestingly, this study also found a substantial decline in ligninolytic fungi in infected soils, despite the fact that *G. boninense* itself is a ligninolytic fungus. One possible explanation is that the pathogen dominates the lignocellulose-degrading ecological niche, thereby suppressing other ligninolytic organisms that would otherwise compete for lignin substrates. White-rot fungi such as *Ganoderma* possess highly efficient ligninolytic enzyme systems, including laccase, manganese peroxidase, and lignin peroxidase, enabling them to rapidly colonize woody plant tissues and degrade complex aromatic polymers [9].

Another possible explanation involves chemical changes in the soil environment caused by pathogen activity. During the decomposition of infected plant tissues, *Ganoderma* may produce phenolic compounds or other secondary metabolites that inhibit competing microorganisms. Such biochemical interactions have been widely reported in fungal ecological studies, where dominant fungal species produce inhibitory compounds to maintain ecological advantage. In addition, pathogen-induced stress may reduce root exudation by infected oil palm plants, limiting the availability of organic substrates that support microbial growth in the rhizosphere [6].

Recent studies have also highlighted the importance of beneficial microorganisms in suppressing *Ganoderma* infection and maintaining microbial balance in oil palm soils. For example, several rhizosphere bacteria and fungi have demonstrated antagonistic activity against *G. boninense*, including species capable of producing antifungal metabolites and cell wall-degrading enzymes. Experimental studies have shown that rhizosphere bacteria such as *Burkholderia* spp. can inhibit *Ganoderma* growth through antifungal compounds and chitinase production, suggesting that microbial antagonism plays a key role in disease suppression [14].

Similarly, beneficial fungi such as *Trichoderma* spp. have been widely reported as biological control agents against *Ganoderma*. Indigenous *Trichoderma* isolates from oil palm rhizosphere soils have demonstrated strong antagonistic activity against *G. boninense* through mechanisms such as mycoparasitism, enzyme production, and competition for nutrients [23]. Recent studies in North Sumatra have also identified rhizosphere-derived *Trichoderma* isolates capable of reducing *Ganoderma* infection in oil palm seedlings, highlighting the ecological importance of beneficial fungi in maintaining soil microbial balance [24, 25].

The extremely large effect sizes observed in this study further confirm that *Ganoderma* infection strongly influences fungal population dynamics in oil palm plantation soils. These results suggest that pathogen invasion not only affects plant health but also triggers substantial ecological shifts in soil microbial communities. Such microbial alterations may influence decomposition processes, nutrient cycling, and overall soil ecosystem stability. Overall, these findings highlight the importance of considering soil microbial ecology in the management of Basal Stem Rot disease. Conventional management strategies have primarily focused on pathogen detection, sanitation, and biological control. However, increasing evidence suggests that maintaining a diverse and balanced soil microbiome may be crucial for enhancing natural disease suppression and sustaining long-term productivity in oil palm plantations.

The decline in cellulolytic and ligninolytic fungi suggests that *Ganoderma* infection may disrupt key processes involved in lignocellulose decomposition and carbon cycling in plantation soils. Such ecological changes may ultimately influence soil fertility, nutrient availability, and the sustainability of oil palm production systems. Understanding the interactions between plant pathogens and soil microbial communities is essential for developing more effective and sustainable disease management strategies. Future studies integrating microbial ecology, molecular approaches, and soil health indicators will be important for identifying beneficial microorganisms capable of restoring microbial balance and enhancing natural disease suppression in oil palm plantations.

IV. CONCLUSION

This study demonstrates that infection by *Ganoderma boninense* significantly affects the abundance of soil fungal communities in oil palm (*Elaeis guineensis*) plantations. Infected soils showed substantial declines in total fungal abundance, cellulolytic fungi, and ligninolytic fungi compared with healthy soils. These findings indicate that pathogen invasion not only damages host plant tissues but also alters the ecological structure and functional composition of soil microbial communities.

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