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The effectiveness of acid-tolerant antagonists in the control of oil palm basal stem rot disease caused by *Ganoderma* sp. in peat soils

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Abstract. *Supriyanto, Purwanto, Poromarto SH, Supyani. 2024. The effectiveness of acid-tolerant antagonists in the control of oil palm basal stem rot disease caused by* Ganoderma *sp. in peat soils. Asian J Agric 8: 143-152.* Oil palm is one of the main contributors to global vegetable oil production. Some of the oil palm plantation areas are on peatlands. A serious problem of oil palm plantations in peatlands is the high incidence of Basal Stem Rot (BSR) disease caused by *Ganoderma* sp. Effective methods to control the oil palm BSR disease in peatlands have not been found. Biological control is an alternative control method that is currently the focus of development, however, the characteristics of tropical peatlands with ultra-low pH levels are an obstacle to its development. This research aimed to find the effective use of indigenous acid-tolerant antagonists and the effect of peat pH in the biological control of BSR disease in oil palm seedlings in peat soils. Research has been carried out in an experimental garden involving three fungi and two bacterial acid-tolerant antagonists from peatlands. The results showed that the effectiveness of acid-tolerant antagonists was 56.25% in reducing the symptoms of the disease. The difference in peat pH did not affect the effectiveness of control in hemic peat soil, however, it affected the effectiveness of disease control in sapric peat soil. This study indicates that acid-tolerant antagonists from West Kalimantan peatlands can potentially be used as biological control agents of *Ganoderma* in oil palms on peatlands.

Keywords: Acid-tolerant, antagonist, *Ganoderma* sp., oil palm, peatlands

Abbreviations : BSR: Basal Stem Rot, DMRT: Duncan's Multiple Ring Test, PDA: Potato Dextrose Agar

INTRODUCTION

Oil palm (*Elaeis guninensis* Jaqc.) is one of the main contributors to global vegetable oil production. Oil Palm has the highest productivity among oil-producing plants, so oil palm is estimated to be able to meet the increasing global demand for vegetable oil, which is estimated to reach 240 million tons in 2050 (Barcelos et al. 2015). Currently, palm oil makes up 35.7% (around 78 million tons) of the world's total vegetable oil in 2023 (USDA 2024), which is produced from around 30.02 million hectares of plantations, mainly in Southeast Asia (Ritchie 2021). However, limited fertile land forces palm oil-producing countries, especially Indonesia and Malaysia, to use peatlands as areas for oil palm plantations. As a result, today some of the oil palm plantation areas are in peatlands. In the world, the oil palm plantations in peatlands were 3.1 million ha in 2015. Indonesia, the largest palm oil-producing country in the world, has a large area of oil palm plantations in peatlands, which is 2.046 million ha, equivalent to 14.58% of the total area (Miettinen et al. 2016), which until 2022 was 14.95 million ha (Ritchie 2021). Apart from the low level of land fertility, a serious problem of oil palm plantations in peatlands is the high incidence of Basal Stem Rot (BSR) disease caused by *Ganoderma* sp. BSR disease is higher and appears earlier than in mineral soils (Rakib et al. 2017; Supriyanto et al. 2023). BSR disease causes palm death, thus shortening the production period. The intensity of BSR disease also always increases with age and oil palm plantation regeneration (Chong et al. 2017). In peatlands, BSR intensity can reach 70%, so oil palms generally have to be rejuvenated earlier, around 18 years of age (Supriyanto et al. 2020a). Nowadays, it is stated that BSR disease is the most devastating disease for the sustainability of oil palm plantations on peatlands due to its increasing intensity (Rakib et al. 2017; Supriyanto et al. 2020b). Thus, *Ganoderma* attacks that cause BSR on oil palms on peatlands are the main problem in cultivating oil palms on peatlands.

Many studies that have been conducted state that BSR is relatively difficult to control (Darlis et al. 2023). BSR was transmitted through contact between healthy roots and the source of *Ganoderma* inoculum, which was usually diseased plant parts or wood debris overgrown by *Ganoderma* (Rees et al. 2012). BSR disease generally develops relatively slowly and symptoms are usually difficult to observe. When symptoms appear on the leaves, the disease is usually severe and the plant cannot be saved (Siddiqui et al. 2021). Economically, in 2022, this disease causes significant losses, because it is estimated to have reduced production by 6.5 million tons of Crude Palm Oil or approximately $7.5 billion in Indonesia (Sipayung 2024). In Malaysia, BSR is estimated to cause significant losses, reaching $365 million per year (Olaniyi and Szulczyk 2021; Siddiqui et al. 2021).

Unfortunately, effective methods to control the oil palm BSR disease in peatlands have not been found until now. The results of some developed methods were still varied. For example, the use of the large planting hole method is only suitable for the replanting process and the results have not been tested (Priwiratama et al. 2014). Likewise, with the mounding method, stem surgery, and the use of fungicides, the results vary greatly so that they are not widely used (Muniroh et al. 2019; Ibrahim et al. 2020) Biological control is an alternative control method that is the focus of current development (Muniroh et al. 2019). Biological control is low-cost and safe for the environment so it complies with international certification standards. However, biological control of BSR disease in peatlands has not been widely reported. Its development is constrained by the characteristic of tropical peatlands which have ultra-low pH level. Tropical peatlands in the lowlands of Kalimantan have an average pH of 3.3-4.3 (Andriesse 1988). Allegedly, ultra-low soil pH causes the antagonist to be unable to develop or causes its functional ability as an antagonist not function properly (Supriyanto et al. 2023).

Recently, in the peatlands of West Kalimantan, it was discovered that several acid-tolerant fungi and bacteria could act as *Ganoderma* antagonists in vitro. Some fungi that have been isolated can grow at pH 2, although their functional ability as antagonists is only limited to pH 3-6 (Supriyanto et al. 2020a). Several bacteria have also been isolated and can grow at pH 2, although their growth rate has decreased significantly (Supriyanto et al. 2021). However, the effectiveness of these fungi and bacteria has not been tested in the field. This research objective is to determine the efficacy of indigenous acid-tolerant antagonists and the effect of peat pH and peat maturity in the biological control of BSR disease in oil palm seedlings in peat soils. The results of this study are important for the oil palm industry because they can form the basis for determining strategies to control the disease in peatlands.

MATERIALS AND METHODS

Experimental design

The research was conducted at the experimental garden, Faculty of Agriculture, Universitas Tanjungpura, Pontianak, West Kalimantan, Indonesia (0°3'27.875"N, 109°20'54.3"E). This research was designed to imitate the natural condition in the oil palm plantations.

The experiment was carried out in natural peat soil condition, sterile peat soil, peat soil that was pH-changing with the addition of dolomite ($CaMg(CO_3)_2$) at different doses, and mineral soil as a comparison. The peat soils used were hemic peat soil and sapric peat soil. Thus, four treatments of hemic peat soil, four treatments of sapric peat soil, and one treatment of mineral soil was obtained. The treatment of hemic peat soil, i.e. natural hemic soil, sterile hemic soil, and hemic peat soil with dolomite added at a dose of 12.5 g/kg and a dose of 25 g/kg. The treatment of sapric peat soil, i.e. natural sapric soil, sterile sapric soil, sapric peat soil with dolomite added at a dose of 12.5 g/kg and a dose of 25 g/kg.

A total of three isolates of *Ganoderma*-antagonistic fungi from West Kalimantan peatlands have been tested previously in the laboratory, namely isolates *Trichoderma harzianum* 13EJ15, *T. harzianum* B3J19, and *Trichoderma viride* E4J8 (Supriyanto et al. 2020a) and two isolates of *Ganoderma*-antagonistic bacteria, namely isolate *Pseudomonas* sp. E4B6 and isolate *Bacillus* sp. E2B12 (Supriyanto et al. 2021) were tested in this study. The treatments given were as follows. Each antagonist isolate was applied singly and mixed isolates so that eight antagonistic treatments were obtained. These treatments i.e. 3 treatments of single isolate antagonistic fungi (13EJ15, B3J19, E4J8), 2 single treatment of antagonistic bacteria isolates (E4B6 and E2B12), one treatment of mixed fungal isolate (a consortium of fungal isolate) antagonist (13EJ15 + B3J19 + E4J8), one treatment of antagonistic consortium bacterial isolates (E4B6 + E2B12), and one treatment of antagonistic consortium fungal and bacterial isolates (13EJ1 + B3J19 + E4J8 + E4B6 + E2B12). *Ganoderma* sp. from peatlands that had been isolated previously, namely *Ganoderma* G301 isolate was used as the test pathogen. *Ganoderma* was inoculated on oil palm seedlings in experimental pots. Positive and negative control treatments were used in this experiment as a comparison. Positive control was oil palm seedling which was inoculated with *Ganoderma* but not controlled with antagonists. The negative control was healthy oil palm seedling and not inoculated with *Ganoderma*. All treatments were arranged in a factorial completely randomized design and replicated three times.

Peat soil preparation

The soil was made friable, stirred, and sieved with a two cm-hole sieve to obtain a homogeneous aggregate size. Peat soil was weighed in air-drying condition, and as much as 5 kg of peat soil was placed in a 30 × 40 cm polyethylene bag (polybag). Mineral soils were measured by volume to equal the volume of peat soil in polybags in air-drying conditions due to the difference in their bulk density. Sterile peat soil was obtained by sterilization with the steaming method for 6 hours. The peat soil was added with dolomite at a dose of 12.5 g/kg and 25g/kg to obtain a different peat pH. Dolomite was mixed evenly onto the peat soil 3 weeks before planting oil palm seedlings and incubated under plastic sheeting to avoid direct sunlight. Soil pH was measured at the beginning of medium preparation, 2 weeks after liming by the dolomite, and at the end of the experiment.

Preparation of oil palm seedlings

This research used commercial oil palm seeds of Marihat D×P 239 variety from PPKS Medan, Indonesia. Oil palm seeds were grown in 10 × 20 cm polybags containing a mixture of peat and mineral soil in a 1:1 ratio. The soil mixture was homogenized by making it friable and sieving with a 2 cm-hole sieve. The medium was sterilized by steaming for 6 hours before it was used. Seedlings were cultivated for two months under 50% shade.

Inoculum preparation and inoculation of oil palm seedlings with *Ganoderma*

Ganoderma inoculum preparation followed the method of Rakib et al. (2015) with modifications. The *Ganoderma* inoculum was prepared by growing the *Ganoderma* isolate G301 onto 6×6×12 cm rubber woodblocks. Before it was used, the rubber woodblocks were soaked in tap water for a night, thoroughly washed and wrapped in an autoclaved-resistant plastic bag, sterilized in an autoclave for one hour, cooled overnight, and then re-sterilized in the same way. After that, 10 ml of liquid Potato Dextrose Agar (PDA) was added to the plastic and flattened over the entire surface of the rubber wood block. After the PDA achieved room temperature, aseptically, a quarter part of 1 Petri culture of seven days-age *Ganoderma* isolate was put on the surface of rubberwood, and then closed again and incubated for two months. The inoculum was ready to use after the mycelium had covered all the rubber woodblock surfaces.

Ganoderma inoculation of oil palm seedlings follow the method of Supriyanto et al. (2023). The rubber woodblocks (covered by *Ganoderma*) were buried in the soil in polybags one week before the oil palm seedlings were planted at a depth of 10 cm. The 2-month-old oil palm seedling was planted on the medium, and placed on a rubber woodblock and the main root was made sure to sit on the rubber wood block, and then backfilled. Oil palm seedling was then cultivated for 24 weeks. The growing medium humidity was maintained in a condition of field capacity.

Preparation and inoculation of antagonists onto peat soil medium

Three isolates of antagonistic fungi and two isolates of antagonistic bacteria were rejuvenated. The antagonistic fungal inoculum was prepared in a corn-water medium (1:1 ratio) for two weeks. The bacterial inoculum was prepared in a bacterial suspension with a minimum density of about 10^8 CFU/mL. The antagonist inoculum was given into the medium according to the predetermined treatment. As much as 30 g of corn-water inoculum was used for single fungal antagonist treatment, while for the fungal consortium treatment 10 g of corn-water medium inoculum was used for each isolate so that for each treatment 30 g of the antagonist was obtained. Isolates were buried and mixed into the planting medium three days after *Ganoderma* inoculation. The polybags were incubated under plastic sheeting to sunlight avoided. Antagonistic bacteria were given in a bacterial suspension by soil drenching. For antagonistic bacteria, a suspension with a density of 10^8 CFU/mL was used, with a dose of 30 ml for a single treatment, while for the consortium treatment a suspension of 15 ml was used for each isolate. Thus, each treatment was obtained 30 ml of the bacterial suspension. The bacterial suspension was splashed evenly onto the surface of the planting medium and then incubated a day before planting oil palm seedlings.

BSR disease severity observation

Observation of the disease was carried out every 4 weeks for 24 weeks, by observing the symptoms on the shoot of oil palm seedlings. Observation of disease intensity was carried out using two scoring criteria, i.e. disease symptom scoring of the shoot and the root necrotic of the oil palm seedling at the end of the experiment. The disease symptom scoring criteria used was shown in Table 1.

Disease severity was calculated using the formula of Arwiyanto et al. (1994):

$$DS = \frac{\sum_{i=1} k \times nk}{Z \times N} \times 100\%$$

Where:
DS: Disease severity
Nk: Number of plants with a score of k (k=0,1,2,3,4,5)
K: Score used
Z: Highest score
N: Number of plants observed

The growth of oil palm seedlings observation

Growth of oil palm seedlings was observed every 4 weeks with parameters of plant height and number of frond leaves. At the end of the observation, the volume of the root and dry weight of the oil palm seedlings were observed.

Statistical analysis

Data on disease severity, in the form of a scoring number, were calculated using the formula of Arwiyanto et al. (1994) to determine the success rate of disease control. The growth parameter data i.e. increase in plant height, number of frond leaves, the volume of the roots, and dry weight were analyzed statistically with Analysis of Variance (ANOVA) to determine the effect of acid-tolerant antagonists and treatment of growth medium on oil palm seedlings growth. If there was a significant difference, it was carried out by further testing using Duncan's Multiple Ring Test (DMRT) to determine the distance between treatments.

Table 1. Criteria for scoring symptoms of the disease on oil palm seedling (Ilias 2000)

Score	Disease symptoms
0	Healthy plants, green leaves, not any fungal mass on the seedlings.
1	1-3 chlorotic leaves without showing any fungal mass on the seedlings
2	Seedlings reveal a mass of fungi in any part
3	More than 3 chlorotic leaves, necrotic leaves with or without fungal mass on seedlings
4	At least 50% of leaves have chlorosis and necrosis with or without a fungal mass on the seedlings
5	Dead seedlings with or without the appearance of a fungal mass on the seedlings

RESULTS AND DISCUSSION

Peat soils pH

During 24 weeks of observation, the peat soil showed some changes. Visually, the visible change was subsidence in the surface of the peat in the polybags, causing some of the roots of the oil palm seedlings to be exposed and leaning of some of the oil palm seedlings. Another change was the change of the peat soil pH to be higher than the pH at the beginning of the observation (Table 3).

These results indicate that the peat soil was relatively unstable. However, the addition of dolomite was generally able to maintain the peat soil pH until the end of the observation. These changes did not occur in the mineral soil. The volume of mineral soils was relatively constant, as was the pH from the beginning to the end of the observation. This was according to the characteristics of the peat soil which was very unstable and prone to disturbance (Andriesse 1988). The increase in peat pH was thought to be caused by cultivation activities during the experiment (Yondra and Wawan 2017).

Effect of acid-tolerant antagonists on the intensity of disease symptoms

The disease symptoms in oil palm seedlings just appeared in week 14. The initial symptoms observed were wilting on some of the lower frond leaves. Some oil palm seedlings also show symptoms of necrosis and chlorosis (changes in leaf color to bright yellow) on some of the lower fronds. This symptom is a common symptom of *Ganoderma* attack on the oil palm seedlings as described by Rakib et. al. (2015). The effect of acid-tolerant antagonists in controlling *Ganoderma* in this experiment varies. In the hemic peat soil, the intensity of the symptoms ranged from 8.33% to 41.67%. Except for the single antagonist treatment of fungal isolate E4J8 and bacterial isolate E4B6, all antagonist treatments reduced the disease symptom intensity in various hemic peat soil conditions. The lowest symptom intensity in hemic peat soil was obtained from the treatment of bacterial antagonist consortium, and the highest intensity occurred in the single antagonist of the E4J8 fungal isolate treatment. There was a trend that the intensity of disease symptoms on the application of antagonists from the fungal group increased with increasing soil pH. Contrarily, there was a decrease in the intensity of disease symptoms as the pH of the medium increased in the treatment of antagonists from the bacterial group (Figure 1). This is consistent with the results of laboratory studies where the fungal isolates used were acid-tolerant, and the bacteria used their growth decreased significantly as the pH of the medium decreased (Supriyanto et al. 2020a). In the sapric peat soil, the disease symptom intensity varied from 8.33% to 50%.

A certain pattern can be observed based on the average symptom intensity of each medium treatment. In the first pattern, the average disease symptom intensity on peat soils is higher than on mineral soils. This pattern is the same as the results of previous studies as disease intensity on peat soils is relatively higher than on mineral soils (Parthiban et al. 2016). In the second pattern, the average intensity of disease symptoms in the antagonist treatment increased with the increasing pH of the medium, both in hemic and sapric peat soil. Meanwhile, the symptom intensity in the positive control treatment (without antagonist) was relatively the same even though the medium was treated differently. This suggests that the difference in intensity of the symptoms observed was an involvement result of the acid-tolerant antagonist.

Table 2. Results of the peat soils pH measuring at the beginning and the end of observation

Treatment of the medium	Initial pH	2 weeks after liming pH	At the end of observation pH
Natural hemic peat	2.9	-	3.5
Sterile hemic peat	2.9	-	3.3
Hemic peat + dolomite 12.5 g/kg	2.9	4.1	5.3
Hemic peat + dolomite 25 g/kg	2.9	6.4	6.3
Natural sapric peat	2.7	-	3.4
Sterile sapric peat	2.7	-	4.5
Sapric peat + 12.5 g/kg	2.7	5.7	5.5
Sapric peat + 25 g/kg	2.7	6.2	6.4
Mineral Soil	4.0	-	4.0

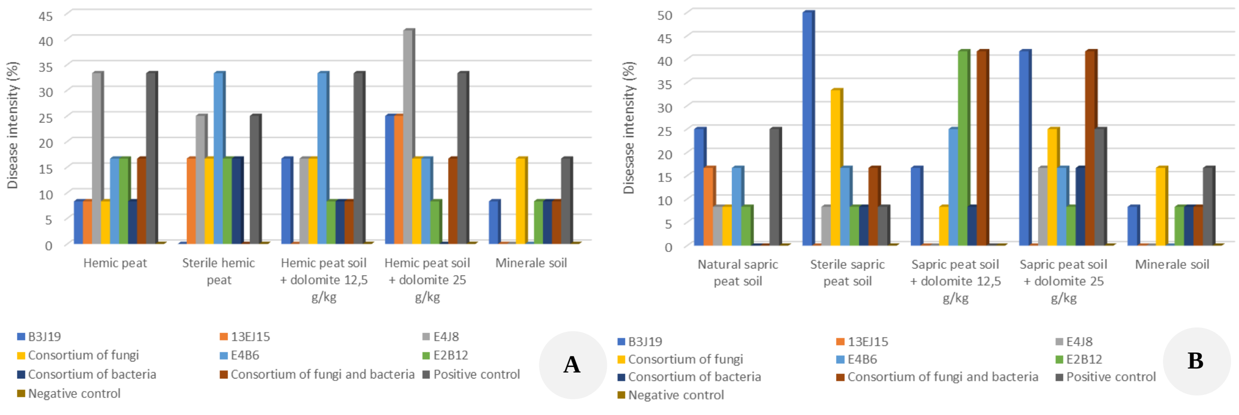

Figure 1. The effect of acid-tolerant antagonists on disease intensity in oil palm seedlings on A. Hemic peat soil and B. Sapric peat soil

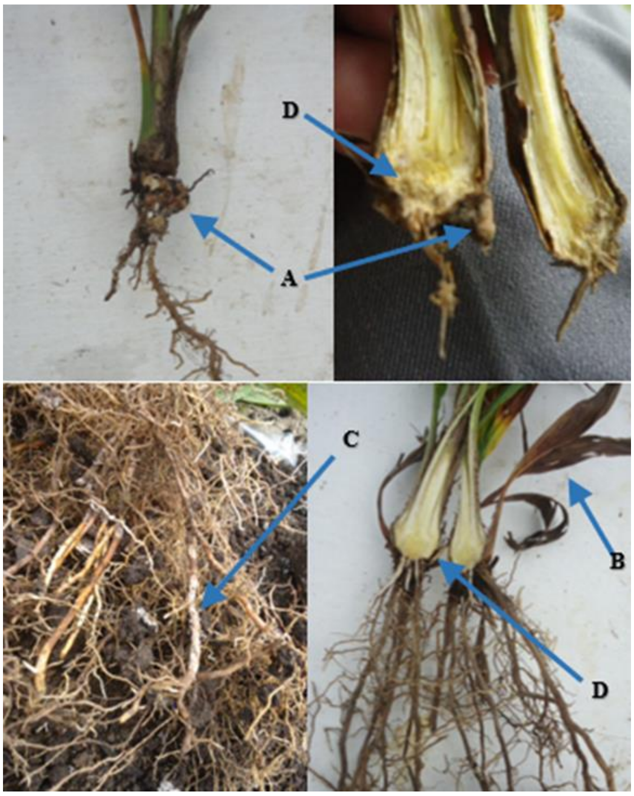

Figure 2. Infection does not cause basal stem rot disease in oil palm seedlings. A. *Ganoderma* infection has formed fruit bodies at the base of the seedling roots, B. Symptoms of leaf necrosis, C. Symptoms of root necrosis, D. but does not cause stem rot on the seedlings

The symptom intensity which ranges from 8.33% to 50%, was a relatively low. This may be related to the research site which was not provided with shade. Research by Rees et al. (2007) concluded that the intensity of *Ganoderma* attacks on the oil palm seedling without shade occurs more slowly. The condition without shade was thought to cause the development of *Ganoderma* infection relatively slowly due to direct sunlight. At the last week of observation, the base of the oil palm seedling not showed rotting even though the plant was showing symptoms on the leaves. The infection has only causing necrosis and rotting to the base of the roots (Figure 2).

There is no clear pattern of each acid-tolerant antagonist treatment in response to differences in the pH of both hemic and sapric peat. These results indicate that there possibly environmental specificities for optimal growth in each antagonist. For example, the B3J19 isolate fungus which caused the lowest intensity (symptoms on roots and leaves) only on hemic peat soil, but did not work on sapric peat, even though with almost the same pH. This is consistent with previous studies where antagonistic agents are generally location specific and narrow spectrum (Peng et al. 2022).

The roots of healthy oil palm seedlings were generally yellowish-white when young and turn brownish when they were old. Root necrosis generally causes a blackish discoloration of the roots. Cross-section and longitudinal incisions demonstrated that the inner healthy roots were bright-white and dense. While the diseased roots were generally dark brown to blackish and were cavity due to the loss of cortical tissue, leaving only the central cylinder (Figure 3). This symptom was the same as described by Rees et al. (2009). In the active infections, the necrotic roots turned white due to the growth of *Ganoderma* mycelium after incubation for at least 48 hours (Figure 3). Observations on the roots also demonstrated that root infection by pathogenic *Gamoderma* only occurred in secondary roots. *Ganoderma* forming an active white and thick mycelium complex around the infected roots. From infection in the area of this active mycelium complex, mycelium spreads to the primary roots of oil palm seedlings. This could be observed through the presence of white-mycelium on the root surface (Figure 4). These results are different from those reported by Rees et al. (2009) where the infection occurred at the primary root. This is presumed to be related to differences in the aggressiveness of the *Ganoderma* used in this experiment. *Ganoderma* was known to have different levels of aggressiveness (Goh et al. 2014; Rakib et al. 2015) and just a weak parasitic fungus (Paterson 2007).

Figure 3. Necrosis of oil palm roots. A. Longitudinal section of healthy and diseased oil palm roots, B. The roots of diseased oil palm seedlings give white mycelium after being incubated for 2 days

Table 3. Effect of peat soils treatment on the effectiveness average of acid-tolerant antagonists in control the BSR control

Growth medium	pH medium	Effectiveness of disease controls (%)
Mineral soil	4.0	62.52
Natural hemic peat soil	2.9-3.5	56.25
Hemic peat soil + dolomite 12,5 g/kg	4.1-5,3	59.5
Hemic peat soil + dolomite 25 g/kg	6.4-6.3	43.7
Sterile hemic peat soil	2.9-3.3	37.5
Natural sapric peat soil	2.7-3.4	58.34
Sapric peat soil + dolomite 12,5 g/kg	5.7-5.5	0
Sapric peat soil + dolomite 25 g/kg	6.2-6.4	16.66
Sterile sapric peat soil	2.7-3.4	0

Figure 4. Initial infection of the roots of oil palm seedlings by *Ganoderma*. The infection starts from the secondary root. A. The active mycelium complex was the starting point of infection, B. Mycelium spreads from the center of infection through secondary roots

Effect of the peat soils pH and maturity on the acid-tolerant antagonists effectiveness

On average, the acid-tolerant fungi and bacteria treatment was 56.25% effective in reducing disease symptoms. The maturity of peat does not affect the effectiveness of disease symptom reduction. The difference in peat pH also did not affect the effectiveness of control in hemic peat soil. However, the difference in peat pH affects the disease control effectiveness in sapric peat soil (Table 3).

In this experiment, *Ganoderma*-antagonistic fungi isolates from West Kalimantan peatlands have different effectiveness. The B3J19 isolate was only relatively effective on hemic peat soils, and increasing the pH caused a decrease in the effectiveness. The 13EJ15 isolate was relatively effective in almost all medium conditions. Meanwhile, E4J8 isolate was only effective on natural sapric peat. The consortium of isolates used also did not affect the effectiveness compared to single isolates. In general, these results are thought to be related to the origin environment of the antagonist isolates. In natural conditions, hemic and sapric peat soil were relatively similar in characteristics. Antagonistic isolates originating from hemic peat soils are thought to be easily adapted in sapric peat soil environments. Thus, the functional role as an antagonist to *Ganoderma* has kept it running. The difference in pH of hemic peat soil which also did not affect the effectiveness of disease control was thought to be related to the ability of its acid-tolerant character. Based on the in vitro test results, most of the antagonistic fungi and bacteria from West Kalimantan peatlands can grow on a medium with a pH spectrum of 3-6 (Supriyanto et al. 2020a). In this experiment, the dolomite addition to hemic peat soil resulted in a pH ranging from 4.1 to 6.4. This pH range is thought to be tolerated by the antagonists, although the higher the resulting pH causes a decrease in its ability.

In sapric peat soil, differences in pH affect the effectiveness of control, which is thought to be related to differences in the chemical properties of the soil. In sapric peat soil, the organic matter rate of decomposition was higher than in hemic peat, so the dolomite addition in the same amount may have a different impact. The pH level after the incubation period which tends to be higher in sapric peat soil than in hemic peat soil is evidence of this (Table 2). This difference is thought to cause changes in chemical composition which are also different. The added dolomite contributes Ca^{2+} base cations (or Ca^{2+} and Mg^{2+}) to the soil and could replace the position of H^{+} and Al^{3+} ions in the soil absorption complex. A decrease in the concentration of H^{+} ions increases OH^{-} ions which causes an increase in soil pH and soil saturation increase (Prihantoro et al. 2023). However, peat pH that is too high will cause the decomposition process to be too fast (Widiarso et al. 2020). A peat pH that is close to neutral can damage the natural properties of peat and change chemical reactions and the availability of nutrients in the soil (Arabia et al. 2020; Wijayanti et al. 2023). The addition of excessive dolomite can stimulate the decomposition of lignin in peat and produce acidic phenolic, humic, and fulvic acids (Kang et al. 2018).

Phenolic acid was allelopathic for plants (Fu et al. 2019) by inhibiting plant root development and nutrient supply in the soil (Misra et al. 2023). Free phenolic acid could accumulate in the rhizosphere, thereby affecting nutrient availability in the soil and nutrient cycling rate, both of which in the end affect plant growth. Generally, the impact is also accumulative. The higher the phenolic acid content in the soil, the more inhibitory it is (Ladhari et al. 2020). The relatively lower oil palm seedling growth parameters in plants treated with the addition of dolomite at a dose of 25 g/kg in this experiment are a strong indication of this (Table 5).

The effect of phenolic acid was thought have impact on the severity of disease in oil palm seedlings caused by *Ganoderma*. The effect of phenolic acid, in this case, could occur through two mechanisms. First, the phenolic acid which inhibits the growth of the oil palm seedlings has become a predisposing factor for *Ganoderma* attack on oil palm seedling roots. Several similar cases have long been reported in which phenolic acid allelochemistry could affect plant disease resistance. The effect of phenolic acid on the relationship between plants and pathogens occurs through several mechanisms (Misra et al. 2023). Second, phenolic acid influences antagonistic activity. Different phenolic acid groups were known to exhibit broad-spectrum antimicrobial activity against various microorganisms (Siqueira et al. 1991). As known, phenolic acid released in the peat decomposition process was inhibit the growth of fungi and bacteria (Yule et al. 2018; Cory et al. 2022). Its effect was presumed also include its functional activity as a *Ganoderma* antagonist because phenolic acid could affect the activity of the enzymes *β*-glucosidase, phosphatase, sulfatase, chitinase, and xylosidase (Min et al. 2015). The phenolic acid released and accumulated in the rhizosphere of oil palm seedling influences its antagonistic activity through several mechanisms. For example, through its influence on the growth and development of mycelium, inhibiting conidial germination, and respiration of the fungi (Leontopoulos et al. 2015). Likewise, the effects of phenolic acid on bacteria were very heterogeneous, ranging from stimulation of bacterial growth to antibacterial activity, and depending on the bacterial strain (Chibane et al. 2019).

On the other hand, increasing the pH of peat is thought to have a positive effect on the growth of *Ganoderma*. *Ganoderma* is one of the white-rot fungi that can degrade lignin into CO_2 and water, resulting in white cellulose that can be utilized by the fungus (Paterson 2007). Together with the other Basidiomicetae fungi groups that were dominant in peatlands (Kusai et al. 2018), *Ganoderma* was presumed to be more active because the environmental situation became more supportive. G. boninense has an ideal growing range at pH 3.7-5 (Nawawi and Ho 1990). Increasing the pH of peat soil causes lignin decomposition enzymes such as lignin peroxidase and phenol oxidase produced by *Ganoderma* to be more effective. The faster development of *Ganoderma*, allows the fungus to survive and compete with antagonists in peatlands. In this study, amelioration with dolomite caused a rapid increase in sapric peat soil pH and is thought to have accelerated the decomposition process so that the peat soil released more phenolic acid. The case is not the same for hemic peat soil because the decomposition rate of hemic peat soil was lower than that of sapric peat soil. The organic matter in hemic peat soil was more complex, so it took longer to decompose than in sapric peat soil. Thus, the difference in pH in hemic and sapric peat soil has a different effect on the effectiveness of *Ganoderma* control by Indigenous acid-tolerant antagonists.

The decomposition of organic matter in sapric peat soil is more advanced than in hemic peat soil, therefore the level of nutrient availability and supporting capacity for plants is higher (Arabia et al. 2020). Better plant growth causes plants to be relatively more resistant to *Ganoderma* infection (Susanto et al. 2013). On the other hand, on the sapric peat soil medium, *Ganoderma* was thought to develop more slowly because of less aeration than in hemic peat soil. Sapric peat soil porosity was lower than that of hemic peat soil because there was more distribution of fine particles so it was more compressed (Wawan et al. 2019). *Ganoderma* develops faster on soils that contain lots of sand with high porosity than on soils that contain lots of loam with low porosity (Susanto et al. 2013).

The effect of acid-tolerant antagonists on oil palm seedling growth

Based on the analysis of variance, the acid-tolerant antagonist treatment had a significant effect only on the plant dry weight parameter. In contrast, other parameters observed i.e. the increase in plant height, the number of fronds leaves increase, and the roots volume did not show any significant differences between the antagonistic treatments. The highest dry weight was obtained from negative control treatment, i.e. oil palm seedlings were not inoculated with *Ganoderma* and were not given an antagonist. The lowest dry weight was observed in oil palm seedlings treated with *Ganoderma* inoculation and control with a consortium of bacterial antagonists (Table 4). On average, the result of oil palm seedling dry weight of all acid-tolerant antagonists treatments, both in hemic and sapric peat soil (except for 13EJ15 isolate treatment on sapric peat soil) was lower than those that were not treated with antagonists. These results indicate two possibilities. First, the acid-tolerant antagonist not only affects the growth of the pathogen but also affects plant growth. It is believed that in an environment with an extremely low pH such as peat soils, microorganism's presence could be a competitor for plants to compete for essential micronutrients. In this environment, micronutrients such as Fe, Cu, Mg, B, and Mn, although present in the medium, cannot be absorbed by plant roots. In low-pH soils, soil particles generally strongly bound micronutrients, making it difficult for plant roots to absorb them (Ferrarezi et al. 2022). In addition, plant roots also have varying charges, but in general, the higher the soil pH, the more negative the charge tends to be, so the absorption capacity of nutrient molecules also increases (Lu et al. 2020; Barrow and Hartemink 2023). Thus, the lower the soil pH, the lower the absorption capacity.The existence of microorganisms that also need essential elements for their growth further reduces the availability of these elements, therefore plants suffer micronutrient deficiency, which causes stunted plant growth. In environments with specific conditions, it was often found that microorganisms can chelate micro essential nutrients such as siderophore-producing bacteria which were able to bind Fe in a Fe-deficient environment (Murdoch and Skaar et al. 2022).

Table 4. The effect of acid-tolerant antagonists on the oil palm seedling growth

Antagonists' treatment	Increase in plant height (cm) Sig: 0.42	Increase in the number of leaves Sig: 0.057	Dry weight (gr) Sig: 0.015	The volume of the roots (mL) Sig: 0.2
Single fungal treatment				
B3J19	33.09a*	8.41a*	36.51a*	26.64a*
13EJ15	34.48a	8.48a	41.47abc	31.49a
E4J8	30.59a	8.67a	37.86ab	31.38a
Single bacterial treatment				
E4B6	31.81a	8,70a	39.91ab	35.33a
E2B12	33.98a	8,70a	38.28ab	36.55a
Consortium treatment				
Consortium of fungi	35.20a	8.93a	42.26abc	38.22a
Consortium of bacteria	31.79a	7.93a	35.84a	38.14a
Consortium of fungi and bacteria	32.76a	9.11a	36.64a	35.95a
Positive control	34.76a	8.78a	47.15bc	36.10a
Negative control	35.24a	9.19a	50.21c	39.82a

Note: *The same letter which follows the numbers in the same column shows no significant difference in the DMRT test at 5% level

Table 5. Effect of the medium on the growth of oil palm seedlings

Medium treatment	Increase in plant height (cm) Sig: 0.00	Increase in the number of leaves Sig: 0.50	Dry weight (g) Sig: 0.00	The volume of the roots (ml) Sig: 0.00
Natural hemic peat soil	33.43abcd*	8.60a*	39.08a*	38.99b*
Sterile hemic peat soil	37.48d	9.43b	50.38b	56.53c
Hemic peat soil + dolomite 12.5 g/kg	35.41cd	8.53a	39.40a	29.81a
Hemic peat soil + dolomite 12.5 g/kg	28.80a	8.50a	32.58a	26.11a
Natural sapric peat soil	32.98bcd	8.93ab	40.22a	39.65b
Sterile sapric peat soil	37.15d	8.90ab	54.87b	45.92b
Sapric peat soil + dolomite 12.5 g/kg	33.60bcd	8.60a	37.53a	23.12a
Sapric peat soil + dolomite 12.5 g/kg	29.18ab	8.50a	33.90a	26.93a
Mineral soil	32.30abc	8.20a	37.58a	27.59a

Note: *The same letter which follows the numbers in the same column shows no significant difference in the DMRT test at 5% level

The second possibility, the biological agents provided in this study are capable of a plant growth promoter in oil palm seedlings, however, in sterile peat soil conditions only (there were no competitors). The higher dry weight of E4B6 isolate bacterial treatment on sterile peat soil compared to negative control treatment suggests that this mechanism may have occurred in this study. There is a possibility that these bacteria are plant growth-promoting bacteria. The presumption of this mechanism in this study is supported by evidence that in sterile peat soil, both hemic and sapric, the dry weight obtained in the antagonist treatment was significantly higher on average than in the medium with natural conditions (Table 5). In previous studies, it was found that the antagonistic fungi and bacteria tested in this study were not dominant species in their native environment therefore they were thought to be less able to compete in normal situations (Supriyanto et al. 2020b). Table 5 shows clearly that differences in growing media conditions cause significant differences in the growth rate of oil palm seedlings. Sterile peat soil resulted in the highest parameters of vegetative growth rates, even compared to mineral soils.

These results suggest that the biological factors of the peat soil are an important factor affecting plant growth. Based on plant growth parameters, the effect of differences in soil biological conditions appears to be more significant than differences in the pH of the peat soil. This phenomenon may occur because in a sterile medium whose less competition, the antagonist's ability to work more effectively so that the impact is more visible on the experimental plants.

In conclusion, in this study, the acid-tolerant antagonists tested were on average effective in controlling *Ganoderma* in oil palm seedlings on peat soil. Its effectiveness 56.25% in reducing the symptoms of the disease. The maturity and differences in peat pH did not affect the effectiveness in reducing disease symptoms. However, there are exceptions, the difference in peat pH affects the acid-tolerant antagonists' effectiveness in disease control in sapric peat soil. Interestingly in this study, in the use of acid-tolerant antagonists, it turned out that disease symptoms increased with increasing pH on sapric peat soil. Thus, in oil palm cultivation on peat soil, this acid-tolerant antagonist can be used on natural peat soil without requiring soil pH increase treatment, hence reducing farming input costs. This study indicates that acid-tolerant antagonists from West Kalimantan peatlands can potentially be used as biological control agents of *Ganoderma* in oil palms on peatlands. Further studies are required to determine environmental factors in peat soil other than pH that affect the effectiveness of control by acid-tolerant antagonists. Field studies are also suggested to strengthen further the use of these acid-tolerant antagonists in controlling BSR in oil palms on peatlands.

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