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Effect of potential peat-derived bacteria and ameliorants for soil fertility improvement and oil palm seedling growth in *Ganoderma boninense* infected peat media

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ABSTRACT

The development of oil palm on peatlands presents significant problems and challenges. The prolonged process of oil palm cultivation, accompanied by the continuous use of chemical fertilizers and pesticides, puts the land at risk of degradation. Land degradation indeed risks reducing productivity, especially on land that has been infected with *Ganoderma boninense*. The problem is increasingly complex and challenging to solve. The use of biological agents and ameliorants to enhance productivity on degraded land should be implemented. This study aimed to evaluate the effectiveness of applying potential bacteria as biofertilizers and biocontrols, along with ameliorants, on improving soil fertility and the growth of oil palm seedlings in peat media infected with *G. boninense*. Therefore, in this study, an effectiveness test was carried out on the application of ameliorants (biochar from palm shell (A1); ash from oil palm empty bunch (A2); and cocopeat (A3)) and potential bacteria that play a role as biocontrol biofertilizers (S2A, H5, and F2 isolates). This study employed a completely randomized design with three replicates, conducted in a greenhouse on 2-month-old DxP oil palm seedlings planted in hemic peat without dolomite. The application of ameliorants and bacteria that act as biocontrol biofertilizers in *G. boninense*-infected peat media influences soil chemistry and oil palm seedling growth. S2A isolates show the best adaptation in growth in propagation media, while H5 and F2 isolates show similar growth trends. Ash is the best treatment on its own in terms of soil pH parameters and leaf count. The best interaction between the ameliorant and bacteria was observed in the combination of ash (A2) and S2A (B1) isolate, which affected the parameters of total Nitrogen (N), available Phosphorus (P), and total Potassium (K) in the soil, as well as plant height and root length of oil palm seedlings after 10 weeks of application. The use of ameliorants and bacteria as biofertilizers and biocontrol agents can be a way to address soil fertility issues and soil-borne diseases, particularly in oil palm plantations on peatlands.

Keywords: sustainable agriculture, organic, bacteria, *Bacillus*.

INTRODUCTION

Oil palm cultivation offers excellent prospects, with rapid growth, and is expected to continue contributing to the global market. Oil palm productivity in Indonesia in 2023 increased from the previous year, with privately owned and smallholder plantations accounting for 22.66 and 16.22 million tons, respectively. Cultivation practices were primarily carried out on peatlands, particularly in the provinces of Riau, Central Kalimantan, and West Kalimantan (Indonesian Oil Palm Statistic, 2024). The development of oil palm on peatlands presents significant problems and challenges. Peatlands naturally have low fertility and nutrient availability, as well as high acidity, which makes cultivation require higher clearing and maintenance costs, including more intensive amelioration and fertilization requirements. In addition, based on the function of the national peat ecosystem, as outlined by the Minister of Environment and Forestry of the Republic of Indonesia in 2019, there are two functions of peat: the protection function (which must be protected) and the cultivation function/allowed for cultivation/agriculture. To maintain sustainability and not exploit peat, it is necessary to carry out optimal oil palm cultivation efforts only on land with cultivation functions (not using land with a protective function).

The lengthy process of oil palm cultivation, which can span up to 20 years, puts the land at risk of degradation. Land degradation indeed risks reducing productivity. Especially on land infected with *Ganoderma boninense*, the problem is becoming increasingly complex and challenging to solve. Given the complexity between economic potential and environmental risks, oil palm management on peatlands requires a balance between production and ecosystem conservation, prioritizing development on degraded lands. Governance of degraded peatlands can be achieved by implementing effective water management, reducing the excessive use of synthetic fertilizers and pesticides, and utilizing biological agents and ameliorants to enhance productivity on degraded land. Research Huang et al. (2019) reports that the combined application of ameliorant and biofertilizer can control the wilting disease *Fusarium* and play a role in changing soil properties and the growth of banana plants. Through the mechanism of increasing soil pH, the toxic effects of antagonists on pathogens, and the regulation of soil properties and microbial communities to improve the condition of soil fungal infections. This makes a combination of amelioran and biofertilizer the right choice.

Many bacteria have been identified as biological agents with a single ability, either as biofertilizers or biocontrol agents. However, in the case of land or plants infected with diseases, the use of bacteria as biofertilizers without biocontrol capabilities will not be able to replace the use of synthetic pesticides, and, of course, will interfere with the performance of these bacteria as biofertilizers if applied in conjunction with pesticides. Therefore, it is necessary to find biological agents that can exhibit both performances. Of course, this is much more effective, highly desirable for the agricultural industry because it is more profitable and can contribute to creating sustainable agriculture. The discovery of bacteria as biological agents in these two areas continues to be pursued and has yielded practical results. Bacteria *Bacillus* sp. LB14, which has been isolated from Tidal flat sediment, is known to be able to produce siderophores and dissolve P as well as produce chitinase and protease enzymes, and this isolate has been shown to reduce the occurrence of anthracnose symptoms in plants *Capsicum annuum* L. by 97.6% and helps increase growth (Han et al., 2015). Another study, isolating *Pseudomonas aeruginosa* from healthy oil palm root tissue, has shown potential to inhibit the spread of *G. boninense* by 76% and also enhances the vegetative growth of oil palm seedlings. (Sapak et al., 2008). Single-use and consortiums of fungi and antagonist bacterial isolates have also been carried out on infected oil palm nurseries, using *G. boninense* in peat media of sapric and hemic types, which are treated with dolomite. The results showed that the effect of fungi and antagonist bacteria reduced the symptoms of stem base rot in seedlings by 56.2% and had a noticeable impact on dry weight and root volume, but did not affect plant height or the number of leaves (Supriyanto et al., 2024). Research on the application of biological agents with biofertilizer and biocontrol capabilities on peatlands is still needed to achieve a more effective impact on plant growth in disease-infected areas.

MATERIALS AND METHODS

Research time and location

This research was conducted in the Plantation Plant Science laboratory and the Greenhouse of the Pontianak State Polytechnic, Pontianak, Indonesia, and chemical testing was performed at the Soil Laboratory of Tanjungpura University, Pontianak, Indonesia. The implementation consists of 4 main activities, namely: (1) preparing S2A, H5, and F2 bacterial isolate cultures; (2) preparing *Ganoderma boninense inoculants*; (3) preparing planting materials and media; and (4) effectiveness tests on oil palm seedlings. This series of activities has been carried out from July to December 2024.

Materials

The bacteria used amounted to 3 isolates that had been characterized and identified in previous studies. These bacterial isolates come from peatlands in Teluk Bakung Village, Sungai

Ambawang District, Kubu Raya Regency, West Kalimantan Province, Indonesia, with different levels of peat maturity, namely S2A isolates from sapric peat (mature), H5 isolates from hemic peat (semi-mature), and F2 isolates from fibric peat (raw). All three have been identified as having a close affinity to the genus *Bacillus* sp. and have been tested for their ability to act as biofertilizers and biocontrol agents against *Ganoderma boninense* in vitro. To prepare bacterial cultures, Nutrient broth (NB) media is used, which consists of 5.0 g/L pepton, 3.0 g/L yeast extract, and 5.0 g/L NaCl. The isolates of *G. boninense* used are a collection of isolates from the Plantation Plant Science laboratory of the Pontianak State Polytechnic. Propagation and inoculation *of G. boninense* using the following materials: Potato dextrose broth media, heat-resistant plastic, and rubber wood.

The ameliorants used are biochar from palm shells, ash from oil palm empty bunch, and cocopeat from coconut fibers. The oil palm sprouts used are the DxP variety, which is a cross between Dura Deli and Pisifera, from the Oil Palm Research Center (PPKS) in Medan. Sprouts are selected that have grown their plumula and radicula. The peat medium used for planting media is hemic peat. The pot used is made of plastic with a diameter of 30 cm.

Research design and procedure

This research was conducted using a completely randomized design, with three replicates. The treatment factors that have been used are: (1) variation in the type of ameliorant (A0= no ameliorant; A1= biochar; A2= ash; A3= cocopeat); (2) variation in the type of potential bacterial isolates (B0= no bacteria; B1= S2A isolate; B2= H5 isolate; B3= F2 isolate). The experiment treatments are shown in Table 1. The study was conducted under the stress of infection with *G. boninense,* which is deliberately introduced into the planting medium around the roots of oil palm seedlings.

Bacterial proliferation

A total of 1 bacterial strain was inoculated on the media and incubated at a temperature of 37 °C. The bacteria cultured for 24 hours are inoculated at a concentration of log10 CFU/mL into NB liquid medium in an Erlenmeyer flask and then incubated in a rotary shaker at 120 rpm. Bacterial growth was observed by measuring OD at a wavelength of 600 nm using a UV-Vis spectrophotometer, and its density was calculated using the Total Plate Count method.

Table 1. List of experiment treatments

Ameliorant treatment (A)	Bacteria treatment (B)	Code
No ameliorant (A0)	No Bacteria (B0)	A0B0
	S2A isolate (B1)	A0B1
	H5 isolate (B2)	A0B2
	F2 isolate (B3)	A0B3
Biochar (A1)	No Bacteria (B0)	A1B0
	S2A isolate (B1)	A1B1
	H5 isolate (B2)	A1B2
	F2 isolate (B3)	A1B3
Ash (A2)	No Bacteria (B0)	A2B0
	S2A isolate (B1)	A2B1
	H5 isolate (B2)	A2B2
	F2 isolate (B3)	A2B3
Cocopeat (A3)	No Bacteria (B0)	A3B0
	S2A isolate (B1)	A3B1
	H5 isolate (B2)	A3B2
	F2 isolate (B3)	A3B3

Inoculation of Ganoderma boninense

G. boninense used is an artificial inoculation made using the modified rubber wood block (RWB) method from the method which was carried out by Lo et al. (2023) modified. Rubber wood blocks measuring 6 × 6 × 6 cm are supplemented with a small GDP and packed in heat-resistant plastic bags, then sterilized by autoclave at 121 °C for 30 minutes. One block of agar (1 cm^3) contains isolated mycelia *of G. boninense.* Pure ones that have been grown on PDA media are inoculated into sterile RWB-containing plastic, sealed tightly, and then incubated at room temperature for two months.

Preparation of planting materials and media

Before the effectiveness test began, planting materials, including oil palm seedlings, ameliorants, and planting media, were prepared 2 weeks in advance. The oil palm seedlings used are 2 months old and in normal, healthy conditions. Hemic peat media is taken from peatland, and 5 kg is used for each pot per seedling. Biochar is crushed to reduce its size. A total of 5 kg of hemic peat was mixed with 150 g of amelioran each according to the treatment. The mixture is put in a pot. RWB is inserted until the surface depth is 5 cm from the ground level. Then, oil palm seedlings are planted at a depth of 1.5 cm. Treatment is carried out through regular watering and the removal of weeds.

Application of bacteria in planting media around the roots of oil palm seedlings

After 2 weeks of oil palm seedlings being planted, bacterial application is carried out based on the Ramli et al. (2016) Modified. Bacterial isolate cultures that have been propagated in NB media with a density of at least log10 CFU/mL are watered in the planting medium around the seedling roots. Treatment is carried out through regular watering and the removal of weeds.

Observation parameters

Observations of soil chemical properties included pH, total nitrogen (N), available phosphorus (P), and total potassium (K). pH (H_2O) was measured using a pH meter, total N was determined using the Kjeldahl method, available P was assessed using the Bray method, and total K was determined using NH_4OAC 1 N pH:7 extraction methods (Eviati and Sulaeman, 2009). Observations of seedling growth were carried out, including plant height increase (cm), number of leaves (strands), and root length (cm).

Data analysis

The data used consisted of three replicas and were analyzed using one-way analysis of variance (ANOVA). The data with a significant effect was further tested using the Tukey test at a 95% confidence level.

RESULTS AND DISCUSSION

Bacterial growth and density profile

To determine the growth profile of bacteria in the propagation media used in this study, a growth curve was made from S2A, H5, and F2 isolates (Figure 1). From the curve trend formed, it can be seen that the three are still experiencing cell increase and have not yet entered a death phase by the end of observation (96 hours after incubation).

Bacteria applied as biofertilizer must meet the minimum density criteria when applied, which is 10^8 CFU/mL. To obtain better performance, a higher density of at least 10^9 CFU/mL was used in this study, which was harvested on day 3 after incubation (Table 2).

Based on Figure 1, the growth rate of the three bacterial isolates appears to be relatively rapid, as indicated by the brevity of the lag phase (from 0 hours to 3rd and 5th hours) and the sharpness of the log phase that occurs. S2A isolates tend to grow faster with a larger number of cells than H5 and F2 isolates. The onset of the stationary phase of all three occurs at the 20th hour after incubation. Observations of bacterial growth curves in NB media were also carried out in the study of Angraini et al. (2016). From the results of his research, it can be seen that three bacterial isolates derived from limestone also exhibit a short lag phase; however, the trend of the log phase is not sharp, occurring between the 6th and 30th hour, with the beginning of the stationary phase between the 33rd and 42nd hour. The growth rates of S2A, H5, and F2 bacterial isolates in this study were significantly faster than those of other bacterial isolates. It is known that each bacterium has

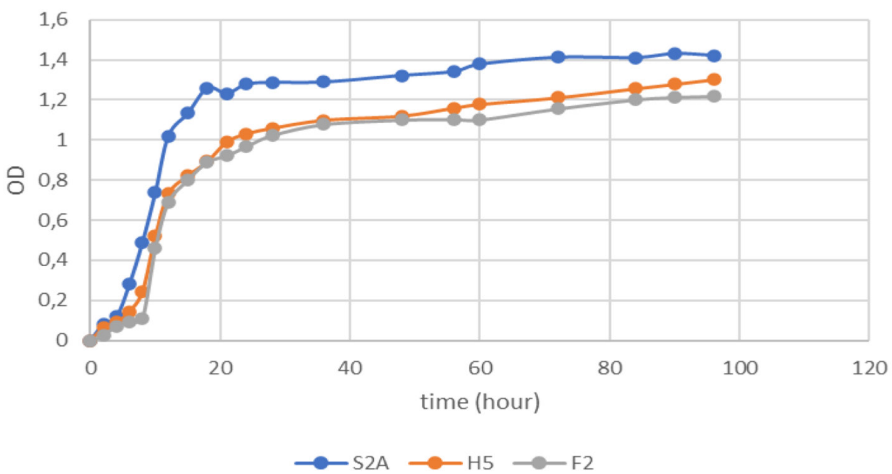

Figure 1. Growth curves of S2A, H5 and F2 Bacteria in NB media

Table 2. Density of the number of bacteria at 3 days after incubation

Isolate bacteria	Bacterial density (log10 CFU/ mL)
S2A	25.2
H5	6.90
F2	3.20

Note: primary data (2024).

different adaptability that affects the speed of its growth in the new medium.

On day 3 after incubation, all three had reached a log10 CFU/mL density (Table 2). S2A isolates showed a higher density than the other two isolates, even reaching 4–8 times the density of H5 and F2 isolates at the same observation time. This can be caused because S2A isolates are isolates derived from sapric peat and are found at the top of the soil surface, making them more directly exposed to environmental changes than deeper soils. Therefore, this bacterium has a better life adaptability than isolates derived from hemic and fibric. However, overall, all three have a rapid growth rate. The growth rate and the long stationary phase of the three can be indicators that all three have good adaptability and viability when applied in the soil.

Effect of bacterial and ameliorant applications on soil fertility improvement

The physicochemical properties of the initial hemic peat soil, prior to the application of potential bacterial and ameliorant treatments, were observed as an initial condition (Table 3). This condition describes the characteristics of hemic peat used as a medium. It can be seen that the initial planting medium used has a very acidic pH, with high organic carbon and total nitrogen, moderate phosphorus availability, and very low potassium exchange.

Soil pH

Based on the results of the soil chemistry analysis, the pH parameter showed a significant effect of a single ameliorant (Figure 2). At the same time, the application of bacteria did not affect the soil pH.

Peat is known to have a very high acidity, which significantly affects the availability of nutrients for plants. In this study, hemic peat with an initial pH of 3.80 was used as a planting medium without the addition of dolomite (a pH-increasing material). The application of ameliorants in the form of biochar (A1), ash (A2), and cocopeat (A3) can increase the soil pH. The application of ash is the most effective treatment, increasing the soil pH to 5.04, which is noticeably higher than that of the other two ameliorants but significantly different from the controls. An increase in pH can directly affect the availability of nutrients in peat, especially phosphorus (P) and potassium (K), which were initially unavailable but are now made available and absorbed by plants.

The ash used in this study is sourced from empty oil palm bunches. This ash is high in potassium and contains several other alkaline ions, making it very alkaline (Arfiana et al., 2021), whereas biochar and cocopeat have a lower pH. This causes the application of ash to increase the pH more rapidly and to a higher level than biochar

Table 3. Results of the initial analysis of soil characteristics before treatment

Parameter	Value
pH	3.80
Organic C (%)	54.82
Total N (%)	1.62
P available (ppm)	51.14
K converted (cmol(+)kg^{-1})	0.26

Note: primary data (2024).

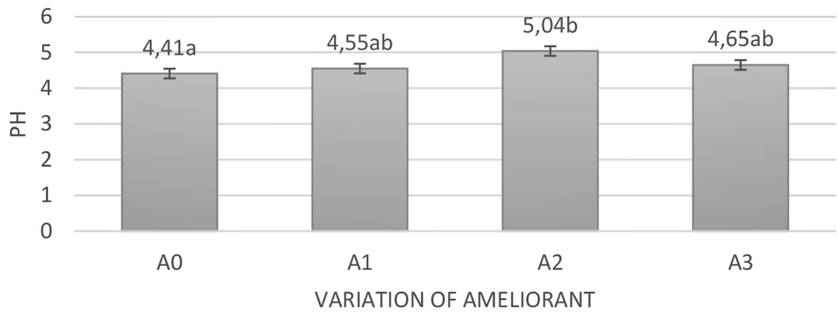

Figure 2. Effect of ameliorant types on soil pH

and coir pith (cocopeat). Biochar is a porous carbon that, when applied to soil, increases the cation exchange capacity and retains more alkaline cations, but does not directly increase pH like ash. The role of biochar lies in its porous physical characteristics, which enable it to increase water resistance and soil aeration. In contrast, cocopeat generally has a lower pH than ash and biochar. Cocopeat plays a significant role in enhancing groundwater resistance and improving specific soil nutrients. Based on the pH value of the planting medium after adding the three ameliorants, the value remains classified as acidic. The addition of amelioran at a dose of 150 g/pot is insufficient to increase the pH of the peat, making it not acid. Therefore, it is necessary to increase the dose or apply it repeatedly to achieve a higher pH in the medium.

Total N

In the total nitrogen (N) parameter, there is an interaction between the ameliorant and bacteria, and both alone have a significant effect on the increase in total N in peat media, as seen in Figure 3. Almost all treatments had a real effect, except for A0B3 and A2B0 treatments. The highest results were observed in the addition of amelioran cocopeat (A3) on all types of bacteria, reaching a total N value of 2.32–2.70% (classified as a very high category). Only the biochar + S2A (A1B1) isolate treatment showed a significant difference in total N compared to the other biochar treatments, while the latter did not differ noticeably from the controls. Singly applying ash (A2B0) did not increase the total N of the soil, but its interaction with all the isolates individually had a significant effect. The significant increase in total N in the application of cocopeat is suspected to be due to the good interaction of cocopeat with bacteria, because these three bacteria can fix N. Cocopeat can support the improvement of the physical, chemical, and biological properties of the soil (Singh et al., 2025), so that it can contribute to the diversity and activity of soil microbes in binding N and converting it into NH_3. Additionally, cocopeat is classified as an ameliorant rich in organic matter, which means its decomposition in the soil can increase nutrient availability (Prakash et al., 2021). Unlike cocopeat, ash is an ameliorant that contains only alkaline minerals, not organic matter. In addition to increasing pH, the presence of ash contributes micro-ions such as Mg and Ca that are urgently needed by soil microbes in their metabolic processes (Sun et al., 2025).

Available P

In Figure 4, it can be seen that the interaction of the ameliorant and bacteria gives a noticeably different result to the P content of the available soil. The best results were observed in the A2B1 treatment of ash with the S2A isolate. S2A isolates can dissolve P and produce siderophores (Achmad et al., 2025, unpublished). This causes the total P content in the planting medium to be initially bound in the available form.

The dissolution mechanism can be in the form of organic or enzymatic acid secretion, as well as the presence of siderophores produced by bacteria (Lozano-González et al., 2023; Xie et al., 2025). In this research result, the presence of ash significantly contributes to increasing the pH of the planting medium, helping to break the bonds between P with Fe and Al, which are abundant in peat. This is in line with Irfansyah (2013), who stated that the presence of Al and Fe is related to

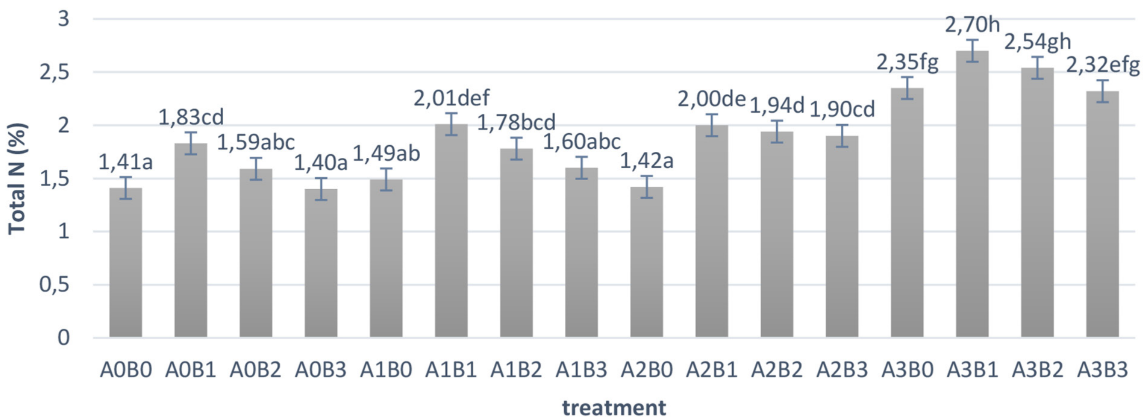

Figure 3. Effect of ameliorant and bacterial interactions on the average value of total N

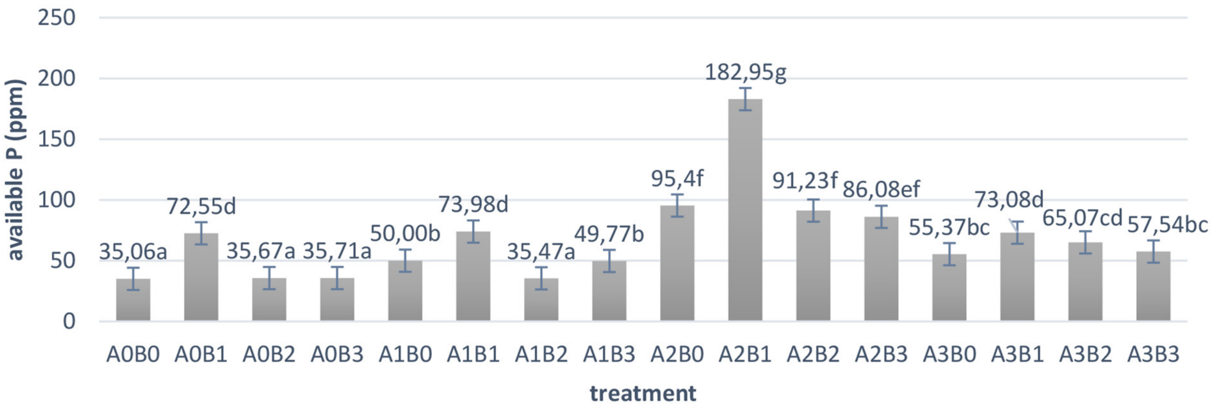

Figure 4. Effect of ameliorant and bacterial interactions on soil available P

the availability of P. The application of an ameliorant that can increase soil pH can significantly increase the solubility of P and suppress the solubility of Al and Fe in the soil.

Total K

At the total K of soil, there is a noticeable influence of ameliorant and bacterial interactions. The highest yield of total peat K content was shown in the addition of S2A isolate alone, and in combination with biochar and ash (Figure 5).

The S2A isolate is an isolate that can dissolve K, which can increase its availability, especially when combined with ash and biochar. However, the highest results are observed in the combination of ash and the S2A isolate. This can be caused by the contribution of K from the ash content. Additionally, with an increase in pH, the exchange capacity of soil cations also increases, thereby enhancing the storage capacity of cations in the soil, including K, and reducing their loss due to leaching (Harefa & Zebua, 2024; Yang et al., 2024).

Effect of bacterial and ameliorant applications on oil palm seedling growth

This study used artificial infection inoculants of *Ganoderma boninense* on the planting medium. This certainly has an impact on plant growth, as the presence of *G. boninense* causes stem base rot, which initially attacks the roots and subsequently impairs the transport of nutrients to other tissues (Safni and Lisnawita, 2025). Early symptoms can be observed on the leaves, where necrosis is visible in infected seedlings (Figure 6).

The results of observation for 10 weeks showed that, in general, there was no appearance of *G. boninense* bodies on the surface of the planting medium or on the stems of oil palm seedlings in all treatments. However, some had experienced symptoms of mild to moderate damage (necrosis) to the leaves, especially in treatment without the application of bacterial isolate (B0). This can be caused by the influence of bacteria that act as biocontrol biofertilizers, so that they can increase the availability of nutrients for plants

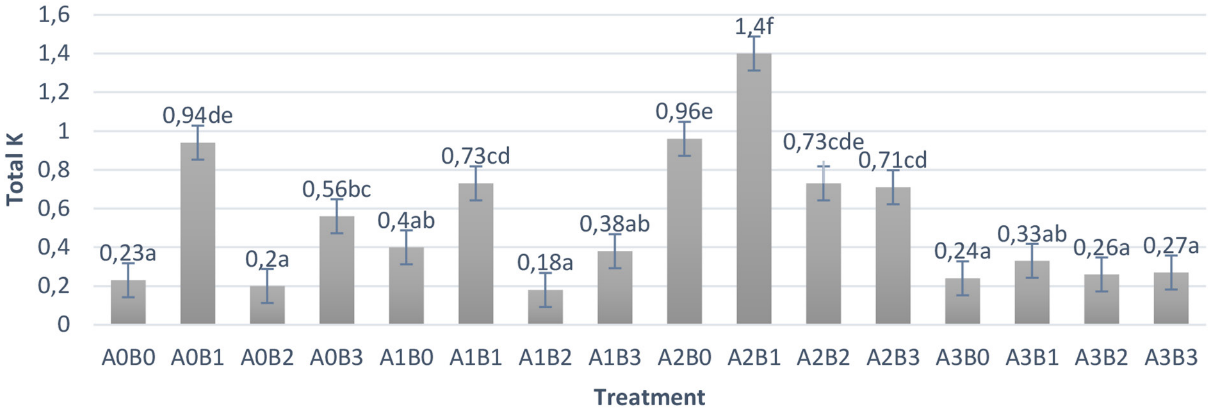

Figure 5. Effect of ameliorant and bacterial interactions on total K

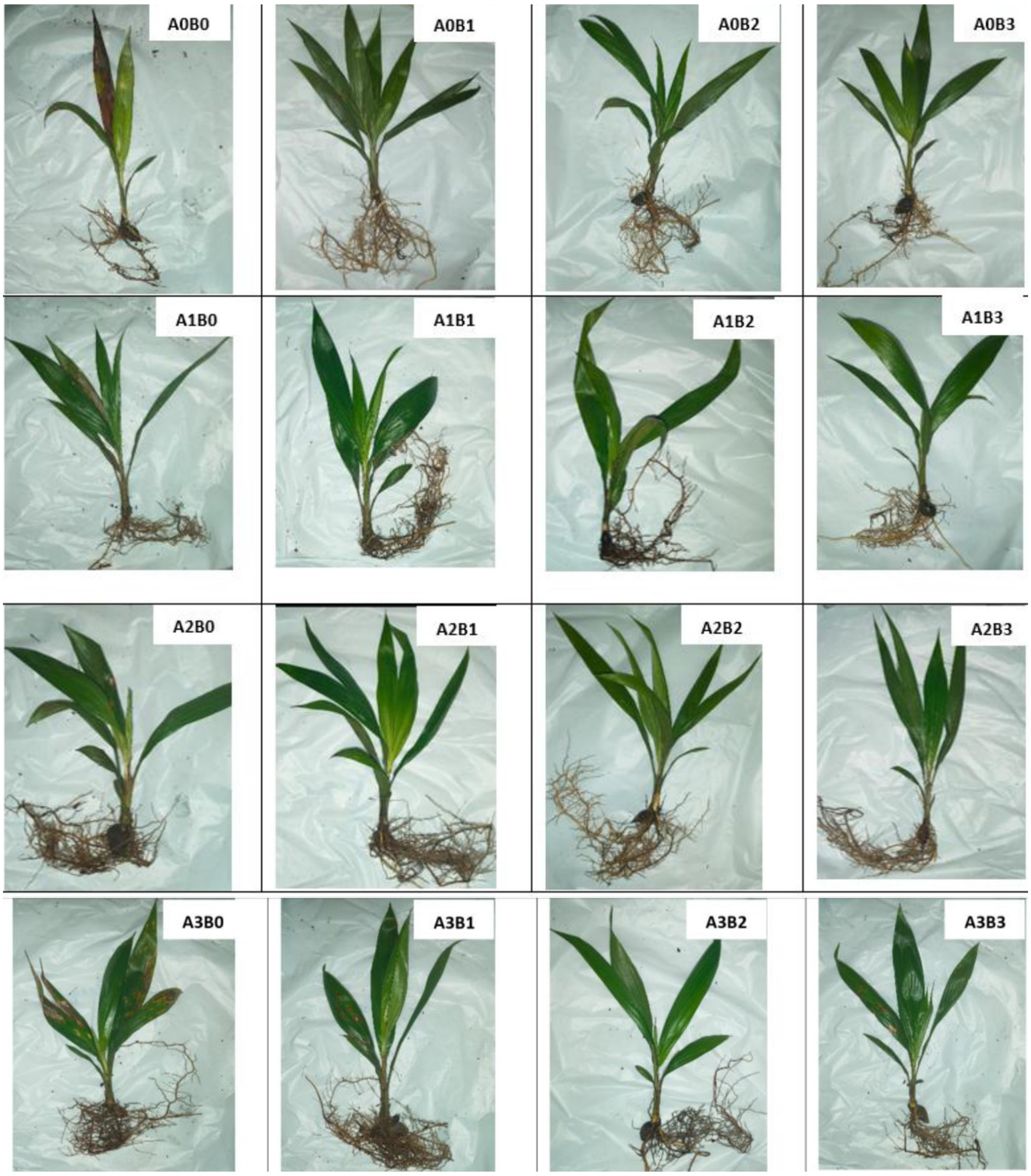

Figure 6. Condition of oil palm seedlings after 10 weeks of application of amelioran and potential bacteria with *G. boninense* infection in the planting medium

that support growth to increase plant resistance to diseases naturally, and are supported by the role of S2A, H5, and F2 bacteria as biocontrol agents so that they can suppress the growth and spread of *G. boninense* around plant roots.

Number of leaves

The results of the treatment on the number of oil palm seedlings showed no effect of the addition of bacteria. However, a significant effect of the addition of amelioran (Figure 7). Ash addition (A2) yielded the best results in terms of leaf count increase after 10 weeks of application. It was significantly different from both the biochar treatment and its control. Leaves are a crucial part of the plant that play a significant role in the growth and rate of plant photosynthesis. The number of leaves affects the process of photosynthesis. Photosynthesis, as an energy production process, will run well if the condition of plant leaves is also good, both quantitatively and qualitatively. Generally, the nutrient N plays a significant role in leaf formation and photosynthesis processes. However, in this study, the treatment with the highest total soil N yield, namely cocopeat, is not the best ameliorant in terms of the number of leaves; instead, ash treatment is. This can be caused because, in addition to containing K, the

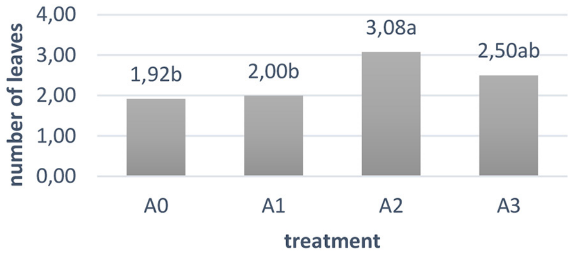

Figure 7. Effect of amelioran on the number of oil palm seedlings

ash of empty oil palm bunches also contains other alkaline minerals, such as Magnesium (Mg). In the process of photosynthesis in leaf tissue, Mg ions are needed as the main component of chlorophyll and become cofactors of photosynthetic enzymes (Ishfaq et al., 2022). The presence of ash can increase Mg, thereby enhancing the process of photosynthesis and the formation of new tissues in oil palm seedlings, which in turn increases the number of leaves.

Plant height increase

The combination of ameliorant and bacteria interaction showed a significant effect on the increase in height of oil palm seedlings after 10 weeks of application. However, it was observed that the single ash treatment (A2B0) yielded the highest increase in seedling height, at 11.07 cm, and the difference was not noticeable in the application of ash + S2A isolate (A2B1) treatment, which increased by 10.77 cm (Figure 8).

Overall, the addition of S2A and H5 isolates resulted in the most significant increase in plant height among all ameliorant types compared to the control and addition of F2 isolates. This can be attributed to the ability of S2A and H5 isolates to form biofilms, whereas F2 isolates do not (Achmad et al., 2025). The formation of biofilms by bacteria can increase their viability in the soil and protect plant roots from disease attacks and abiotic stress. This creates a healthier root environment, even in conditions of infected media, such as *G. boninense*. When the soil, root, and microbial conditions are optimal, the availability and absorption of nutrients, as well as growth, can be increased.

Root length

The interaction of ameliorant and bacteria showed a noticeably different effect on the root length of oil palm seedlings after 10 weeks of

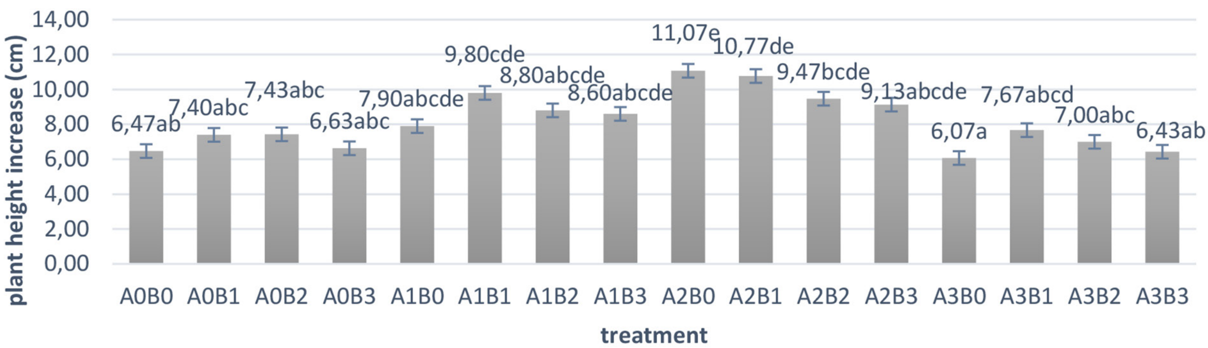

Figure 8. The effect of ameliorant and bacterial interaction on the increase in height of oil palm seedlings

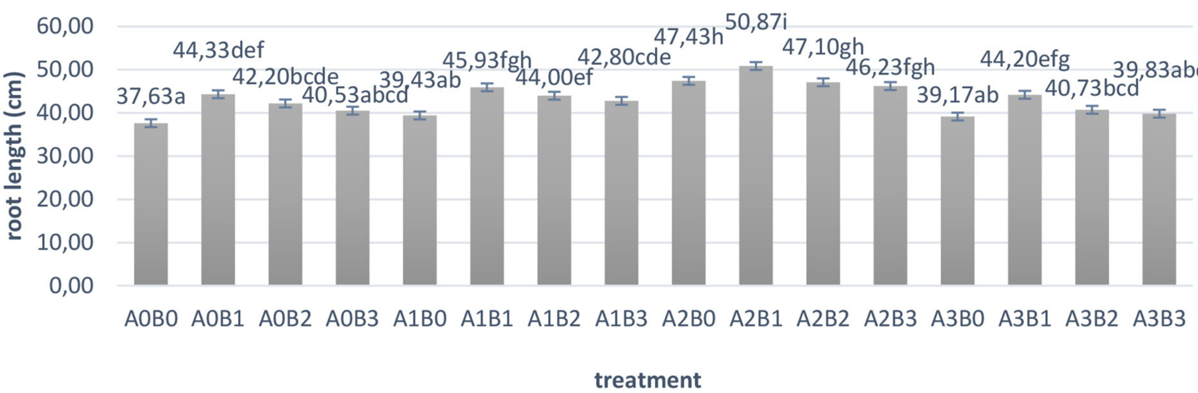

Figure 9. Effect of ameliorant and bacterial interaction on the root length of oil palm seedlings

application. In general, the application of bacterial isolates to the planting medium can increase the length of the roots longer than the treatment without bacteria in all types of ameliorants. It can also be seen that the S2A isolate has a real influence on root length compared to the H5 and F2 isolates. In the ash + S2A isolate treatment, the best results were given with a root length of 50.87 cm (Figure 9). The role of soil bacteria as bioferilizers and biocontrols plays a significant role in this parameter, since the roots of plants are the first tissues that come into direct contact with *G. boninense*. This causes roots to be at high risk of rotting and damage at an early stage; however, the presence of bacteria in the planting medium can increase root length, as it also plays a role in suppressing the growth of *G. boninense*. The ability of the S2A isolate to produce biofilm and siderophores has a more pronounced effect on the defense of oil palm seedlings against disease infections and acidic conditions in the planting medium.

CONCLUSION

The application of ameliorants and bacteria that act as biocontrol and biofertilizers in infected peat media has a significant influence on soil parameters and oil palm seed growth. S2A isolates show the best adaptation in growth in propagation media, while H5 and F2 isolates show similar growth trends. Ash treatment has a singular and significant influence on soil pH parameters and leaf count. The best interaction between ameliorant and bacteria is observed in the combination of ash (A2) and S2A (B1) isolate, which affects the parameters of total N, available P, and total K in the soil, as well as plant height and root length of oil palm seedlings. The use of ameliorants and bacteria as biofertilizers and biocontrol agents can be a way to address soil fertility issues and soil-borne diseases, particularly in oil palm plantations on peatlands. By optimizing formulations and improving application, this could become a solution for sustainable agriculture, replacing the use of chemical fertilizers and pesticides in oil palm plantations.

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