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APPLICATIONS OF ORGANIC FUNGICIDES, ENDOPHYTIC BACTERIA, BIOFUNGICIDES, AND BIOSTIMULANTS IN CURATIVE CONTROL OF *Ganoderma*

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ABSTRACT

Basal stem rot (BSR) caused by Ganoderma boninense *is a major oil palm (OP) disease. However, the effective treatment that is practicable in the field as a recommendation remains elusive. This study aimed to assess the effectiveness of the combinations that consisted of organic fungicide (OF), biofungicide (BF), endophytic bacteria (EN), and biostimulant (BS) applied to 20-year old (TM 20) and 14-year old (TM 14) OP with a mild, moderate, and severe level of infection. Results revealed that TM 20 palm recovery response is slower for all infection levels. The effective treatments for mild infection of TM 20 were BF, EN, and BS, meanwhile, for moderate infection, the treatments included OF, BF, EN, and BS. The effective treatment for both mild and moderate infections for TM 14 was the treatment which comprises BF, EN, and BS. It seems that there is no need for BS in this mature palm for both mild and moderate* Ganoderma *sp. infection since it has rapid recovery. However, the most effective treatment for severe* Ganoderma *infection in both OP groups was a complete treatment consisting of OF, BF, EN, and BS. We found that severe BSR symptoms could be reduced by providing the complete treatment several times, both holistically and progressively.*

Keywords: basal stem rot, biofungicide, biostimulant, endophytic bacteria, organic fungicide.

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INTRODUCTION

Basal stem rot (BSR) is one of the major diseases that affect oil palm (OP) which leads to economic losses, estimated at USD256 million per year for each 1% of its infection (Alexander *et al.*, 2021). Thus far, BSR control management has been investigated in several studies (Ariffin *et al.*, 2002); however, an effective treatment that is practical in the field remains elusive (Bharudin *et al.*, 2022). The current BSR disease control includes the improvement of the cultural control methods, both mechanically and chemically. The alternative control method is the use of biological agents. However, the control methods have not been found practical in field applications. Furthermore, many experiments on BSR disease control were performed *in vitro* or limited to nurseries, with very few studies conducted in the field (Siddiqui *et al.*, 2021).

Observations in the nursery using scanning electron microscopy showed that the *Ganoderma*'s mode of infection at the early stage was indicated by the penetration of *Ganoderma* mycelium into the epidermal cells on the root surface. To penetrate the epidermal cells, the mycelium secretes lignolytic enzymes to break down the lignin in the root epidermal cells, which affects the xylem, and consequently, the transport of nutrients and water (Ho *et al.*, 2016).

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Symptoms of BSR include rotting at the base of the stem, that eventually spread to the fruiting bodies and the roots. This condition limits the uptake of water and nutrients to the leaves which finally causes leaf chlorosis (Breton *et al.* 2009; Turner and Gillbanks, 1974). Other symptoms observed are stunted crown growth, including unopened spear leaves. In more severe cases, the trunk breaks and falls (Rees *et al.*, 2012). The infection is also visible through the appearance of the *Ganoderma* fruiting body at the base of OP and the canopy becomes yellowish (Breton *et al.*, 2009).

The results of testing organic fungicide (OF) on TM 15 plants that were attacked by *Ganoderma* sp. showed that the plants were able to recover, as indicated by root growth and began to open their spear leaves and start flowering and produce fruits (Widiastuti *et al.*, 2018). OFs play a role in suppressing the activity of *Ganoderma* sp. through the toxicity of the active ingredient contained in it, namely, allicin. Biostimulants (BS) function in optimising photosynthesis. Plants that are able to suppress the attack of *Ganoderma* sp. will carry out photosynthesis again, so it is necessary to give BS to optimise their photosynthesis.

Ganoderma sp. is a soil-borne pathogen and hence the soil characteristics can affect plant responses to *Ganoderma* sp. Goh *et al*. (2020) showed an example of *Ganoderma* sp. infection in two plots named Bernam and Blenheim, at an OP estate in Perak, Malaysia. The *Ganoderma* attack was higher in Bernam compared to Blenheim. Bleinheim contains prokaryotic and eukaryotic diversity with high pH and calcium (Ca) content. In addition, Blenheim contains suppressive bacteria such as *Calditrichaeota*, *Zixibacteria*, *Omnitrophicaeota*, *Rokubacteria*, *Planctomycetes* strain AKYG587, *Defferibacteres* strain JdFR-76, and *Rubrobacter* (Actinobacteria). Meanwhile, in Bernam, there is a high proportion of *Uronema* (Ciliophora), mammals, and *Chloroflexi* and *Acidothermus* (Actinobacteria) bacteria (Goh *et al.*, 2020). The antagonistic microorganisms of *Ganoderma* were added to the soil to manipulate the diversity in the rhizosphere, which was then expected to inhibit the pathogen infection. *Trichoderma* is a biological agent that has been widely used to control *Ganoderma* sp. (Badalyan *et al.*, 2004; Munthe and Dahang, 2018). The mechanism of *Trichoderma* sp. involves microparasites, antibiotics, and nutrient competition and induces a defence response or systemic resistance response in plants. *Trichoderma*'s hypermechanism is by penetrating *Ganoderma*'s cell wall, entering the cell, and absorbing the nutrients (Ismail, 2007). *Trichoderma* sp. also produces β-1,3-glucanase and chitinase that can hydrolyse chitin from the cell wall of pathogens that cause hyphae lysis (Hazabar and Yaherwandi 2006).

Another treatment is by using endophytes and their mechanism of producing several bioactive antimicrobial and antiviral metabolites along with producing various antioxidants to suppress pathogens (Gouda *et al.*, 2016). Endophytes protect plants against pathogen attack by triggering the host to induce resistance through several molecular events. Upon pathogen attack, the interaction between plant endophytic associations leads to an alteration in the second messenger such as Ca^{2+} in the cytosol (Vadassery and Oelmüller, 2009). Jasmonic acid (JA), ethylene (ET), and salicylic acid (SA) trigger induced resistance. JA and ET pathways are known to encourage resistance toward necrotrophic pathogens; however, the SA pathway activates resistance toward biotrophic and hemibiotrophic pathogens (Ding *et al*., 2011). Moreover, biocontrol practices through endophytes may be achieved through direct inhibition of pathogens or indirectly by establishing the plant's systemic resistance (Chaudhary *et al.*, 2022; Pathak *et al*., 2022; Santoyo *et al.*, 2016).

This research aimed to assess the effectiveness of some BSR control through environment-friendly techniques. Moreover, this study addresses the question about the different responses of the two age groups of OP, firstly, for plants aged over 20 years as the maximum production period (then mentioned as TM 20) and secondly, the group of plants at peak production, aged around 14 years (in this study mentioned as TM 14).

MATERIALS AND METHODS

The research was conducted in Afdeling 1, Block 11, Cisalak Baru Plantations, the Banten Province, with the planting year of 1997 for TM 20. Furthermore, for TM 14, the research was conducted in Afdeling 1, Block 24, with the planting year of 2003. The planted area used was approximately 0.3 ha (45 palms) for both TM 20 and TM 14.

Plant Treatment

This study used four treatments based on the combination of OF, BS, biofungicide (BF), and endophytic bacteria (EN), as detailed in *Table 1*. Each treatment was tested in three categories of BSR disease's attack levels, namely mild, moderate, and severe attack, each of which was represented by three biological replicates.

The OF used was developed from the main active compound, namely, allicin, which was tested at laboratory scale as an effective inhibitor for *Ganoderma*'s growth. Furthermore, the BS utilised in this study was derived from seaweed. This compound has been currently widely developed

Figure 1. Some examples of OP affected by Ganoderma, *from left to right: TM 20 mild infection with treatment B; TM 20 moderate infection with treatment B; TM 14 severe infection with treatment A; TM 14 severe infection with treatment B.*

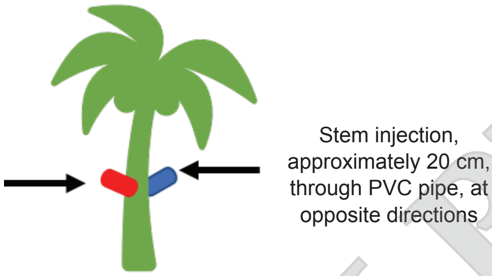

Figure 2. Illustration of OF and BS applications at opposite directions of the oil palm stem.

TABLE 1. THE TREATMENT TESTED IN THIS STUDY

Treatment	Organic fungicide (OF)	Biofungicide (BF) and Endophytic bacteria (EN)		Biostimulant (BS)
		Trichoderma (BF)	Endofit-64 and SM 58 (EN)	
Control	-	-	-	-
A	+	+	+	+
B	+	-	-	+
C	-	+	+	+
D	+	+	+	-

as commercial products. OF and BS were applied through stem injection (approximately 20 cm in depth) in opposite directions (*Figure 2*). Both treatments were applied through a 25 cm long and 2 cm in diameter polyvinyl chloride (PVC) pipe planted in OP stem at 40° to 45° slope.

BF used in this research was selected as *Trichoderma* sp., which has been effective in controlling *Ganoderma* sp. While endophytic (EN) bacteria consist of two bacterial types, *i.e.*, SM-58, which is a photosynthetic bacteria and EDF 64, which is *Serratia* sp. Both species were obtained from Indonesian Oil Palm Research Institute (IOPRI)'s collection, as reported by Eris (2017). Either BF or EN was applied at 1.0-1.5 m horizontally around the trunk.

The application of treatment for the TM 20 subjects for mild infection was at every two weeks (four times in total), while that for the moderate and severe categories was once a week (eight times in total), for two months. Application frequency for all categories in TM 14 was once a week for three months (12 times in total). This application frequency refers to the risk of falling or death of trees within 6-24 months for young palm, from their initial symptoms; meanwhile, the adult trees continue their metabolism function for 2-3 years after the first infection (Rees *et al.* 2007).

Observations were also made on five parameters, namely, the number of *Ganoderma* fruiting bodies, spear leaves that do not open (twisted), occurrence of leaves chlorosis, the number of fresh fruit bunches (FFB), and both the number and weight of the harvested FFB. Observations on TM 20 trees were carried out up to the 51st week after treatment application. Meanwhile, TM 14 trees were monitored every month until the 24th week after the treatment. Observations of harvested fruit bunches were carried out for 7 and 5 months for TM 20 and TM 14, respectively.

There were four treatments provided: Treatment A allows *Ganoderma* control by combining a wholesome ingredient, Treatment B acts as a negative control for BF and bacterial endophytes, Treatment C was given to investigate the absence of OF, and Treatment D was given to observe the plant's response upon *Ganoderma* attack without BS (*Table 1*).

Data Observation and Analysis

To facilitate the discussion, observational data obtained were then quantified by giving weighted scores based on the following provisions as shown in *Table 2*.

RESULTS AND DISCUSSION

During the observation of treatment A, the TM 20 palm tree for moderate infection, fell at the 23rd week, while another TM 20 palm with severe infection, fell at the 47th week. Further observations could not be made on these palms. *Figure 3* presents the number of fruiting bodies of *Ganoderma* sp. on TM 20 until the 51st week's observation. It was observed that *Ganoderma* fruiting bodies appeared only in the control palm, starting from the 47th until the 51st week of observation.

The TM 14 palms in the severe category for the B and C treatments (*Figure 3*), fell at weeks 24 and 20, respectively, hence no further observations could be made on these trees. *Figure 3* also illustrates that *Ganoderma* fruiting bodies could not be found in the mild and moderate categories. The low values observed in the mild and moderate levels of infection were not definitive indicators. Furthermore, Corley and Tinker (2003) explained that the infection can also occur without any symptoms, such as the absence of *Ganoderma* fruiting body and normal development of spear leaves, although the pathogen was already present in the plant (Widiastuti *et al.*, 2016). These results indicate that all treatments tested can be used as a preventive strategy to avoid the formation or reduction of the number of fruiting bodies of *Ganoderma* sp.

Interesting results were also found in the TM 14 palms of the severe category. Each treatment resulted in lower number of fruiting bodies, relative to the control. Treatments A, B, and C showed the presence of fruiting body formation until the 24th week, although the number was much lower relative to control. Moreover, treatment D showed the highest growth repression of *Ganoderma* fruiting bodies. It seems that a mature OP tree at a younger age (TM 14) has better recovery or immunity even without any BS treatment (treatment D), compared to older OP (TM 20).

In the TM 20 palms of the severe infection category, only treatment D showed higher production of fruiting bodies compared to other treatments. Treatments A and B which consisted of

TABLE 2. REFERENCE WEIGHTED SCORE OF PARAMETERS OBSERVED

	Parameter	Observed data	Score
1	Number of *Ganoderma* fruiting bodies	1	0.3 point per 1 fruiting body
2	Spear leaves	1-2 spear leaves	0.0
		3 spear leaves	0.3 point
		4 spear leaves	0.6 point
3	Chlorosis leaves occurrence	Absence of chlorosis leaf	1.0
		1 chlorotic leaf	2.0
		2 chlorotic leaves	3.0
		3 chlorotic leaves	4.0

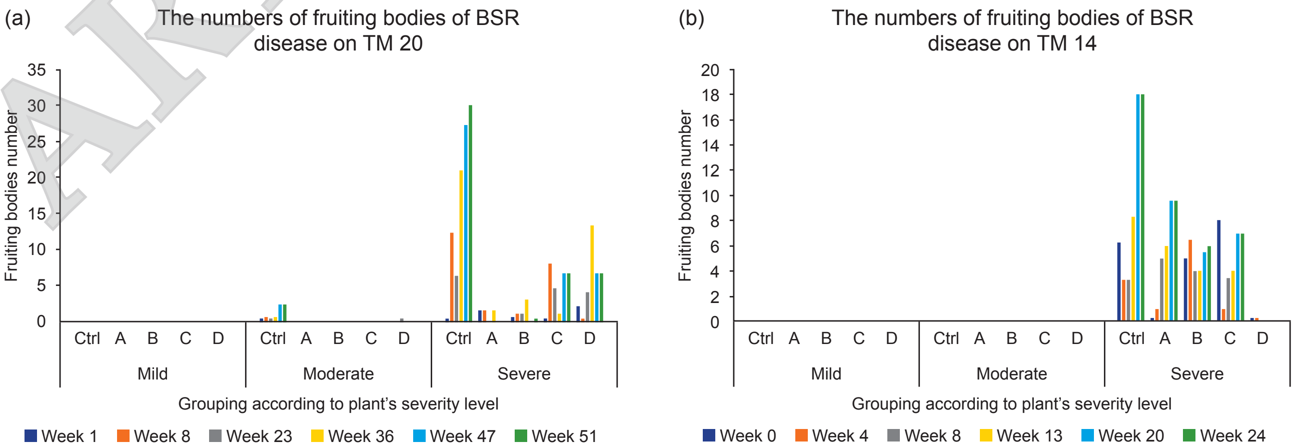

Figure 3. The number of fruiting bodies of oil palm trees in each treatment and category of BSR disease attack [(a) TM 20, and (b) TM 14].

a complete formulation of treatment and OF added with BS had caused a very low number of fruiting bodies, which were indicative of successful control. In this research, the prolific number of fruiting bodies also caused them to become dried naturally and therefore was not counted for the next observation, even if the palms were still standing then. It seems that the number of *Ganoderma* sp. fruiting bodies did not correlate with the severity of BSR disease, because sometimes there were occurrences of fallen palms with the absence of fruiting bodies in the moderate infection category, while up to 80 fruiting bodies were observed in the severely infected palms.

In the infected OP, new spear leaves did not open, due to the malfunction in the roots to absorb water. The TM 20 palms in all the control treatments of the mild infection category, did not produce any unopened spear leaves (*Figure 4a*). However, in the moderate category, the control treatments showed an increase in unopened spear leaves from the first observation up to the 36th week. A similar response pattern was found in treatment C, which showed the presence of unopened spear leaves until the 47th week of observation. No palms with unopened spear leaves were found in treatments A, B and D, from the beginning to the end of the observation. However, in the severe category, there were quite a lot of unopened spear leaves, reaching 1.6 leaves per palm in the control treatments, in the 51st week of observation. The presence of unopened spear leaves was observed in treatment B, only on the 51st week of observation, while treatments C and D showed unopened spear leaves at the beginning of the observation and were reduced by the 51st week of observation.

In contrast to the earlier findings (Sapak *et al.*, 2008) that suggest an improvement of OP seedling's vegetative growth due to endophytic bacteria treatment, our finding shows that treatment B, as the negative control of endophytic bacteria, has shown more incidence of unopened spear leaves. Further experimental investigation is needed to differentiate the responses of mature and seedlings to the endophytic bacteria treatment. The interesting result was shown in treatment A, where in the beginning, the spear leaves were unopened, but by the 36th week, there were no more unopened spear leaves up to the last observation, which was at 51 weeks. This could be due to the return of the roots' function to absorb water, enabling the spear leaves to open. The results from treatment A which contain a complete package of all ingredients which include OF, BF, EN, and BS when applied simultaneously, seem to demonstrate a beneficial role for health recovery in aged OP (TM 20).

The results also indicate that for TM 14 in each infection category (*Figure 4b*), different response patterns were observed to each treatment tested. In the moderate category, treatment A showed the best result in avoiding presence of unopened spear leaves. Specifically, in the severe category, treatment C showed a decrease in the number of unopened spear leaves, contrary to treatments A and D, which have an increase in number of unopened spear leaves at the 24th week of observation. Treatment C showed good results in terms of reducing numbers of unopened spear leaves, in the moderate and severe categories. In contrast, treatment B showed an increase in the number of unopened spear leaves and was the highest compared to other treatments, although in general, unopened spear leaves were no longer found, at the 24th week.

The tree canopy is generally affected by BSR infection, which causes the roots to rot thus disturbing the water and nutrient uptake. The greenness of the leaves elucidates the ability of the plant to absorb nutrients. In the mild attack category, the TM 20 palms without any additional treatment, had increased leaf chlorosis symptoms until the end of the observation (*Figure 5*). The chlorotic palms were observed in treatments A, B and D. However, treatment C showed the most stable and lowest number of leaf chlorosis symptoms. Response in treatments C and D was evidence to support the

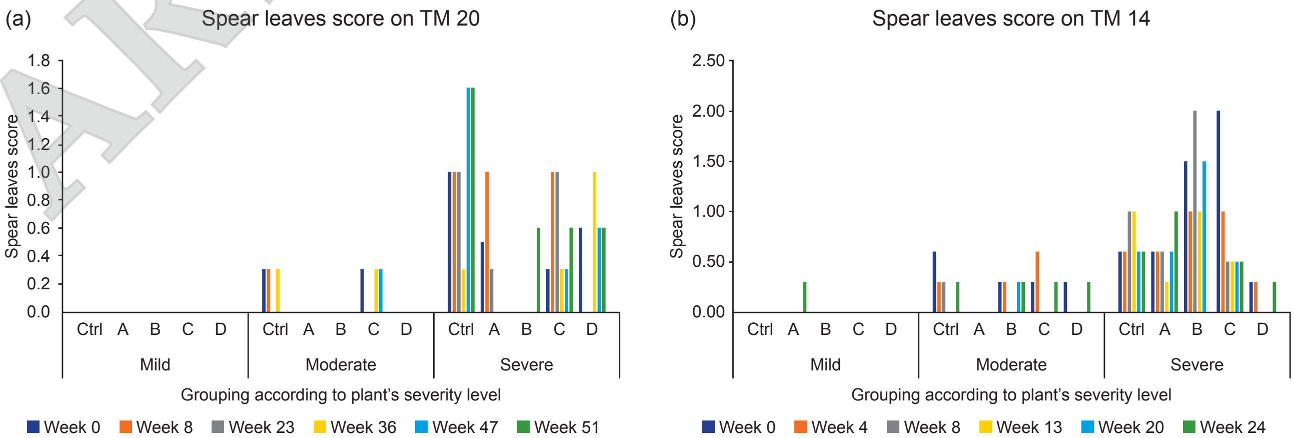

Figure 4. The unopened spear leaves values in each treatment and category of BSR disease attack [(a) TM 20, and (b) TM 14].

hypothesis that the addition of BF and EN could reduce leaf chlorosis in mild infection. Leaf chlorosis has been known as a symptom of *Ganoderma* attack due to the disturbance in nutrition and water transport mechanism in infected plants. To address this concern, some studies have underlined the role of endophytic bacteria in nitrogen uptake recovery (Da Silveira *et al.*, 2018).

The response of treatment B in the moderate category of TM 20, explained that the absence of BF and EN inflicts a higher incidence of leaf chlorosis. However, contrary to the severe category, treatment B also gave the lowest in number of leaf chlorosis. For moderate and severe categories, treatment D seems to show the tolerance of TM 20 palms (with the absence of BS in its formulation), which showed a gradual decrease of chlorotic leaves during the long-term observation (51 weeks). In the moderate category, treatment A, having a complete package of ingredients, (consisting of OF, BF, EN, and BS), can be recommended as having a beneficial role in decreasing the number of leaf chlorosis, as well as response in reducing unopened spear leaves.

In the mild infection category (*Figure 5*), there was a decline in leaf chlorosis for the TM 14 palms in treatments A, B and C, at week 20. From the beginning to the end of observation, the lowest chlorosis number occurred in treatment D. Meanwhile, in the moderate infection category, the TM 14 palms in all treatments showed a decrease in leaf chlorosis, with the fastest decline in treatment D (week 13) and maintained up to week 24. Different results were shown in the severe infection category, where the TM 14 palms only showed a decline in number of leaf chlorosis in treatment A. However, the main positive response to treatment A only appeared about 4 months after its first application.

The TM 20 palms with mild infection showed the highest number of FFB harvested in treatment C, followed by B, D and A, relative to control (*Figure 6*). In the moderate infection category, the highest number of FFB harvested was in treatment A, followed by treatments C and D. In the severe infection category, palms in the control treatment did not produce any FFB, within 51 weeks of observation. Overall, palms given treatment A produced the highest FFB harvest compared to other treatments.

The TM 14 palms with mild and moderate infection, had produced the highest number of FFB when given treatment D (*Figure 6*), followed by treatments C and A. Palms given treatment D also showed a better development of FFB. The

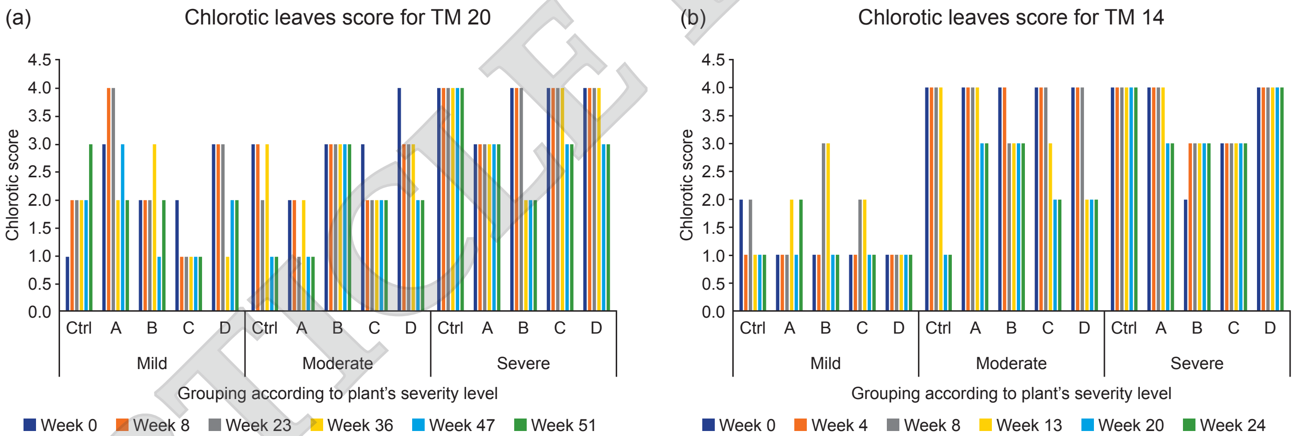

Figure 5. The value of oil palm trees with chlorotic leaves in each treatment and category of BSR disease attack [(a) TM 20, and (b) TM 14].

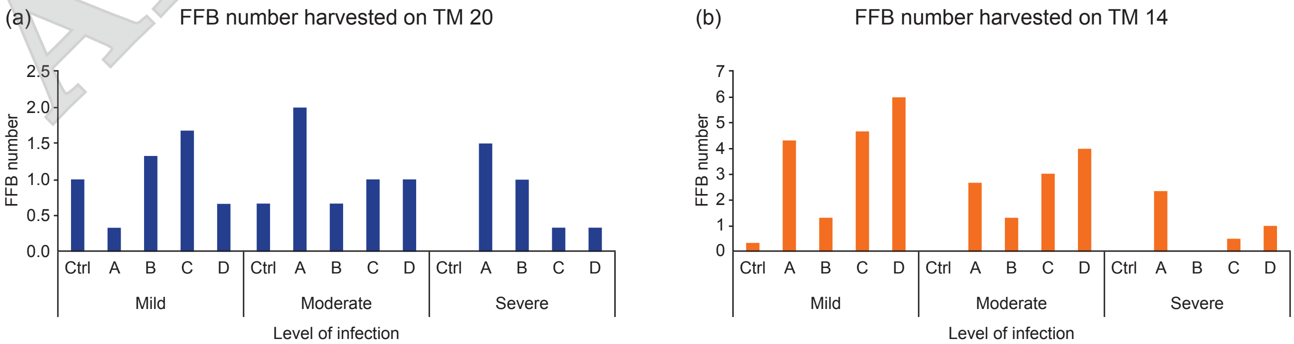

Figure 6. Total number of FFB harvested in each treatment and category of BSR disease attack [(a) TM 20, and (b) TM 14].

formation of FFB started at 24 months; and was observed over 51 weeks or 12 months. In the severe infection category, palms given treatment A produced the highest number of FFB. These results indicated that during a severe infection, the palms need to be supported by the complete formulation of treatments, to enable the palm to restore nutrients to produce the optimal number of FFB. It can be seen in the number of FFB that can still be slowly produced, with sizes not as large as the FFB produced by palms with mild and moderate levels of *Ganoderma* infection.

Fruit formation normally starts between 30 to 160 days after pollination (Tranbarger *et al.*, 2011). Due to the *Ganoderma* infection, the length of time required for the formation of FFB and harvesting was delayed in the TM 20 palms. Furthermore, it was reported that severe infection can linearly affect FFB performance (Evizal and Prasmatiwi, 2022).

The weighing results of FFB produced by the TM 20 palms (*Figure 7*) in the mild and moderate infection categories, showed the same trend with the FFB numbers. Palms with mild infection of *Ganoderma*, when given treatments C and B, had produced the highest FFB weights, while the lowest FFB weights were observed in treatment A. Palms with a moderate infection when given treatment A, had produced the highest FFB weight. However, palms in the severe infection category when given treatment B, had produced much higher FFB weight, compared to treatment A. The smaller weight of FFB in treatment A was apparently due to the disruption of nutrients in palms with *Ganoderma* infection.

In the mild infection category, the TM 14 palms had produced the highest weight of FFB in treatments D, followed by A and C, which was far above the control treatment. At the moderate and mild infection, the palms produced the highest FFB weight in treatment D. However, palms in the severe infection category can still produce high FFB weights, provided they are treated with the complete treatment package of OF, BF and BS.

Comparison of the Response of TM 20 and TM 14 Plants to Treatment

Under normal conditions, the TM 20 palms have passed the peak production phase, and moving towards the old palm age of 25 to 30 years. Meanwhile, the TM 14 palms are still in the peak production stage. Therefore, responses to the four treatments were varied due to the production phase differences. In general, the fresh fruiting bodies of *Ganoderma* were formed in much greater numbers in the control than in treatments A, B, C and D. However, the number of fruiting bodies observed did not always correlate with the level of *Ganoderma* infection since the dead, fallen trees have a varied number of *Ganoderma* fruiting bodies. For example, the fallen TM 20 palms, had no fruiting bodies in the moderate infection category, while there can be up to 80 fruiting bodies in the palms of the severe infection category. On two fallen TM 14 palms with severe infection, the number of fruiting bodies varied between 4 and 87. It is therefore suspected that the colonisation of *Ganoderma* sp. in the stem could better determine the severity of infection compared to the number of fruiting bodies observed.

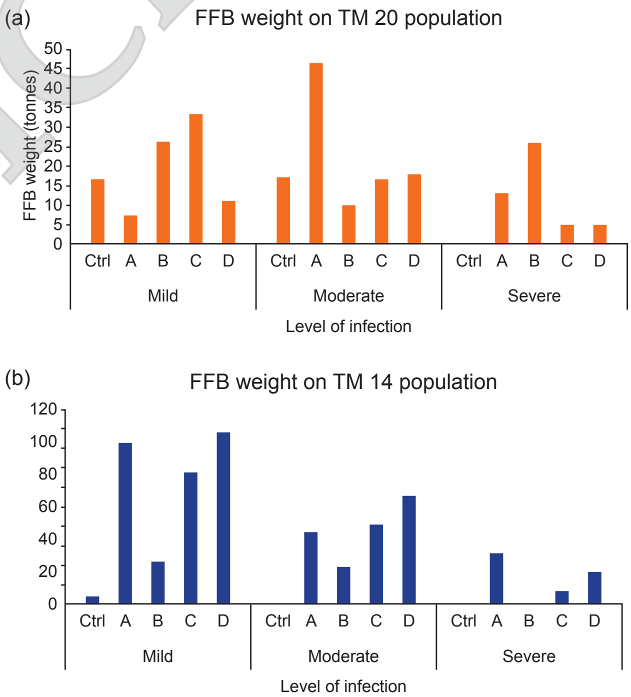

Figure 7. Total weight of FFB harvested in each treatment and category of BSR disease attack [(a) TM 20, and (b) TM 14].

There was also a tendency of high correlation between a number of fruiting bodies and unopened spear leaves (*Table 3*). In TM 20 palms, the correlation was high in week 8, even though no more treatment was added for the moderate and severe infection categories. The phenotypic response through number of unopened spear leaves and *Ganoderma* fruiting bodies was high. For TM 14 palms, the critical period of infection was visible between week 0 and 13, indicated by the high incidence of *Ganoderma* fruiting bodies that was positively correlated to the high number of unopened spear leaves.

Several potential treatments are summarised in *Table 4*, based on several main phenotypic parameters indicative of *Ganoderma* infection on TM 14 and TM 20. These treatments succeeded in influencing the dynamics of the presence of *Ganoderma* fruiting bodies, leaf chlorosis, unopened spear leaves, and FFB on the palms. In this study, the emphasis on the best treatment was based on the decrease in the number of fruiting bodies of *Ganoderma* sp., unopened spear leaves, and leaf chlorosis, along with an increase or a high number and weight of FFB after treatment. It is assumed that with the treatment, the number of *Ganoderma*

TABLE 3. CORRELATION ANALYSIS BETWEEN PARAMETERS

TM 20

Week 1	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.55**	1.00		
Chlorosis	0.40	0.48	1.00	
FFB	-0.38	-0.46	-0.42	1.00

Week 8	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.81**	1.00		
Chlorosis	0.48	0.40	1.00	
FFB	-0.55	-0.28	-0.81	1.00

Week 23	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.82**	1.00		
Chlorosis	**0.60**	0.46	1.00	
FFB	-0.63	-0.51	-0.43	1.00

Week 36	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	0.61	1.00		
Chlorosis	0.58	0.58	1.00	
FFB	-0.71	-0.60	-0.57	1.00

Week 47	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	0.97	1.00		
Chlorosis	0.60	0.63	1.00	
FFB	-0.68	-0.71	-0.45	1.00

Week 51	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	0.92	1.00		
Chlorosis	0.61	0.62	1.00	
FFB	-0.76	-0.75	-0.36	1.00

TM 14

Week 0	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.85**	1.00		
Chlorosis	0.09	0.21	1.00	
FFB	-0.72	-0.77	-0.50	1.00

Week 47	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.69**	1.00		
Chlorosis	0.17	0.46	1.00	
FFB	-0.50	-0.62	-0.35	1.00

Week 8	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.79**	1.00		
Chlorosis	0.26	0.19	1.00	
FFB	-0.78	-0.57	-0.32	1.00

Week 13	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.84**	1.00		
Chlorosis	0.43	0.38	1.00	
FFB	-0.73	-0.70	-0.16	1.00

Week 20	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	**0.57**	1.00		
Chlorosis	0.42	0.38	1.00	
FFB	-0.59	-0.19	-0.14	1.00

Week 24	Fruiting bodies	Spear leaves	Chlorosis	FFB
Fruiting bodies	1.00			
Spear leaves	0.41	1.00		
Chlorosis	**0.59**	**0.66**	1.00	
FFB	-0.67	-0.40	-0.62	1.00

fruiting bodies will decrease, and the spear leaves will open, which decreases the unopened spear leaves number, followed by a decrease in leaf chlorosis; thus, the metabolism of the palm tree recovers and gradually becomes healthy. In very mature TM 20 palms, their responses to the treatments take longer, up to 51 weeks, while for TM 14, it takes only about 20 weeks.

TABLE 4. POTENTIAL TREATMENTS FOR CURATIVE TREATMENTS OF BSR

BSR disease attack rate	Potential treatment	
	TM 20	TM 14
Mild	C	D
Moderate	A	D
Severe	A	A

For TM 20 palms in the mild infection category, the best treatment was C (BF, EN and BS), while for TM 14 palms, it was D (OF, BF and EN). On trees with moderate attacks, the best treatments for TM 20 palms were A (OF, BF, EN and BS) and D (OF, BF and EN), while for TM 14 palms, the best treatments were D (OF, BF and EN) and C (BF, EN and BS). In severely affected palms, recovery was apparent in treatment A (OF, BF, EN, BS) for both TM 20 and TM 14 palms. A seaweed-based BS has been assayed for its antifungal function against *G. boninense* (Aziz *et al.,* 2018), and the efficacy relies on different phytol components, due to seaweed species extracted. The application of the product in each treatment of this study was only conducted in a single period. The use of the chemical fungicide hexaconazole to control BSR, as recommended by the Malaysian Palm Oil Board, is applied three times within six months. The dosage of that fungicide was 4.5 g, dissolved in 3 L of water (The Star, 2021). It is recommended that the treatments need to be carried out at least every six months.

CONCLUSION

Ganoderma BSR disease in OP is identified through signs (part of the pathogen) and symptoms that appear on the palm. Both are the main determinants of the criteria for the development of pathogen colonisation in destroying plant tissue and indicating the existence of malignancy in plants. The treatments given to TM 20 and TM 14 palms exhibited a dynamic effect in reducing the number of fruiting bodies of *Ganoderma* sp., unopened spear leaves and leaf chlorosis occurrences, and an increase in the number and weight of FFB after treatments. The response to cell repair was slower and required more time to recover in the older TM 20 palms compared to TM 14. It is concluded that applications of OF, BF, END and BS have the potency to cure the basal stem rot disease caused by *Ganoderma* sp. However, the continuous application of these products is necessary, since *Ganoderma* propagules are supposed to be present in the root area and possibly even in plant tissues.

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REFERENCES

Alexander, A; Lo, R K S and Chong, K P (2021). The effectiveness of selected biological agents in controlling *Ganoderma boninense. J. Sustain. Sci. Manag., 16(6)*: 128-137. DOI: 10.46754/jssm.2021.08.011.

Aries, S; Febrianto, E B; Sakiah; Ridho, M and Karnando, D (2021). *Ganoderma boninense* control in palm oil plantations using *Trichoderma harzianum* in various media. *IOP Conf. Ser. Earth Environ. Sci.*, 819 012001.

Ariffin, D and Idris, S A (2002). Progress and research on *Ganoderma* basal stem rot of oil palm. Seminar on Elevating National Oil Palm Productivity and Recent Progress in the Management of Peat and *Ganoderma.* 5-6 May 2002. MPOB, Bangi.

Aziz, S D A; Jafarah, N F and Yusof, N B (2018). Phytol-containing seaweed extracts as control for *Ganoderma boninense*. *J. Oil Palm Res., 21(2):* 238-247. DOI: 10.21894/jopr.2019.

Badalyan, S M; Innocenti, G and Garibyan, N G (2004). Interactions between xylotrophic mushrooms and mycoparasitic fungi in dual-culture experiments. *Phytopathol Mediterr., 43*: 44-48. DOI: 10.14601/Phytopathol_Mediterr-1733.

Bharudin, I; Ab Wahab, A F F; Abd Samad, M A; Yie, N X; Zairun, M A; Bakar, F D A and Murad, A M A (2022). Review update on the life cycle, plant-microbe interaction, genomics, detection and control strategies of the oil palm pathogen *Ganoderma boninense. Biology, 11(2).* DOI: 10.3390/biology11020251.

Breton, F; Miranti, R; Lubis, Z; Hayun, Z; Setiawati, U; Flori, A; Nelson, S; Durand, G T; Jacquemard, J C and Hubert, D F (2009). Implementation of an early artificial inoculation test to screen oil palm progenies for their level of resistance and hypothesis on natural infection. The 5th Quadrennial International Oil Palm Conference, Bali Nusa Dua Convention Center, Indonesia. 17-19 June 2014.

Chaudhary, P; Agri, U; Chaudhary, A; Kumar, A and Kumar, G (2022). Endophytes and their potential in biotic stress management and crop production. *Front. Microbiol., 17*. DOI: 10.3389/ fmicb.2022.933017.

Corley, R H and Tinker, P B (2003). *The Oil Palm*. 4th edition. Blackwell Publishing, London.

Da Silveira, A P D D; Iório, R D P F; Marcos, F C C; Fernandes, A O; Souza, S A C D D; Kuramae, E E and Cipriano, M A P C (2018). Exploitation of new endophytic bacteria and their ability to promote sugarcane growth and nitrogen nutrition. *Antonie van Leeuwenhoek, 112*: 283-295 (2019). DOI: 10.1007/s10482-018-1157-y.

Ding, L; Xu, H; Yi, H; Yang, L and Kong, Z *et al*. (2011) Resistance to hemi-biotrophic *F. graminearum* infection is associated with coordinated and ordered expression of diverse defense signaling pathways. *PLoS ONE, 6(4)*: e19008. DOI: 10.1371/ journal.pone.0019008.

Eris, D D (2017). *Bakteri Endofit Asal Tanaman Arecaceae sebagai Pemacu Pertumbuhan dan Agens Biokontrol Penyakit Bercak Daun pada Kelapa Kopyor* (Cocos nucifera *L var. Kopyor*). IPB, Bogor Agricultural University.

Evizal and Prasmatiwi (2022). Penyakit Busuk Pangkal Batang dan Performa Produktivitas Kelapa Sawit. *Jurnal Agrotropika (21)*: 47-54.

Flood, J; Hasan, Y; Turner, P D and O'Grady, E B (2000). The spread of *Ganoderma* from infective sources in the field and its implications for management of the disease in oil palm. Ganoderma *Diseases of Perennial Crops* (Chapter 8). CABI Publishing. p. 101-112.

Goh, Y K; Zoqratt, M Z H; Ayub, Q and Ting, A S Y (2020). Determining soil microbial communities and their influence on *Ganoderma* disease incidences in oil palm (*Elaeis guineensis*) via high-throughput sequencing. *Biology, 9*: 424. DOI: 10.3390/biology9120424.

Gouda, S; Das, G; Sen, S K; Shin, H-S and Patra, J K (2016). Endophytes: A treasure house of bioactive compounds of medicinal importance. *Front. Microbiol., 7*: 1538. DOI: 10.3389/fmicb.2016. 01538.

Gupta, R *et al.* (2017). Microbial modulation of bacoside: A biosynthetic pathway and systemic defense mechanism in *Bacopa monnieri* under *Meloidogyne incognita* stress. *Sci. Rep., 7*: 41867. DOI: 10.1038/ srep41867.

Hazabar, T and Yaherwandi (2006). *Biological control of plant pests and diseases*. Universitas Andalas Press: Padang.

Ho, C T; Tan, Y C; Yeoh, K A; Ghazali, A K; Yee, W Y and Hoh, C C (2016). *De novo* transcriptome analyses of host-fungal interactions in oil palm (*Elaeis guineensis* Jacq.). *BMC Genomics, 17*: 66. DOI: 10.1186/s12864-016-2368-0.

Ismail (2007). Potential of *Trichoderma* spp. as biological control agents. Agricultural Technology Research Center: Sulawesi Selatan.

Jyothilakshmi, V and Oelmüller, R (2009). Calcium signaling in pathogenic and beneficial plant microbe interactions. *Plant Signal. Behav., 4(11)*: 1024-1027. DOI: 10.4161/psb.4.11.9800.

Minarsih, H; Widiastuti, H and Santoso, D (2018). Deteksi *Ganoderma* secara molekuler pada kebun kelapa sawit yang diberi perlakuan biofungisida Ganor. *Menara Perkebunan, 86(1)*: 21-28. DOI: 10.22302/iribb.jur.mp.v1i1.289.

Munthe, K P S and Dahang, D (2018). Hosting of Hendersonia against *Ganoderma* (*Ganoderma boninense)* disease in oil palm (*Elaeis guineensis* Jacq.). *Int. J. Multidiscip. Res. Dev., 5*: 46-50.

Pathak, P V; Rai, K; Can, H; Singh, S K; Kumar, D; Bhardwaj, N; Roychowdhury, R; Basilio de Azevedo, L C; Kaushalendra; Verma, H and Kumar, A (2022*). Plant-endophyte interaction during biotic stress management. Plants, (11) 2203*. DOI: 10.3390/ plants11172203.

Paterson, R R M (2020). Depletion of Indonesian oil palm plantations implied from modelling oil palm mortality and *Ganoderma boninense* rot under future climate. *AIMS Environ. Sci., 7(5)*: 366-379. DOI: 10.3934/environsci.2020024.

Rees, R W; Flood, J; Hasan, Y; Wills, M A and Cooper, R M (2012). *Ganoderma boninense* basidiospores in oil palm plantations: Evaluation of their possible role in stem rots of *Elaeis guineensis*. *Plant Pathol., 61(3)*: 567-578. DOI: 10.1111/j. 1365-3059.2011.02533.x.

Rees, R W; Flood, J; Hasan, Y and Cooper, R M (2007). Effects of inoculum potential, shading and soil temperature on root infection of oil palm seedlings by the basal stem rot pathogen *Ganoderma boninense*. *Plant Pathol., 56*: 862-870. DOI: 10.1111/j.1365-3059.2007.01621.x.

Santoyo, G; Moreno-Hagelsieb, G; Orozco-Mosqueda, M D C and Glick, B R (2016). Plant growth - Promoting bacterial endophytes. *Microbiol. Res., 183*: 92-99. DOI: 10.1016/j.micres.2015.11.008.

Sapak, Z; Meon, S and Ahmad, Z A M (2008). Effect of endophytic bacteria on growth and suppression of *Ganoderma* infection in oil palm. *Int. J. Agri. Biol., (10)*: 127-132.

Siddiqui, Y; Surendran, A; Paterson, R R M; Ali, A and Ahmad, K (2021). Current strategies and perspectives in detection and control of basal stem rot of oil palm. *Saudi J. Biological Sci., 28(5)*: 2840-2849. DOI: 10.1016/j.sjbs.2021.02.016.

The Star (2021). MPOB develops technology to control upper stem rot in oil palm trees. https://www.thestar.com.my/business/business-news/2021/10/01/mpob-develops-technology-to-control-upper-stem-rote-in-oil-palm-tree.

Tranbarger, T J; Dussert, S; Joët, T; Argout, X; Summo, M; Champion, A; Cros, D; Omore, A; Nouy, B and Morcillo, F (2011). Regulatory mechanisms underlying oil palm fruit mesocarp maturation, ripening and functional specialization in lipid and carotenoid metabolism. *Plant Physiol., 156(2)*: 564-584. DOI: 10.1104/pp.111.175141.

Turner, P D and Gillbanks, R A (1974). Oil palm cultivation and management. Kuala Lumpur, Malaysia. Incorporated Society of Planters.

Walls, A F A; Wearne, R H and Wright, P J (1996). Analytical characteristics of plantation eucalypt woods relating to kraft pulp yields. *Appita J., 49*: 427-432.

Widiastuti, H; Dewantara, D and Santoso, D (2016). Potensi fungisida organik Ganor untuk perbaikan pertumbuhan dan produksi tanaman kelapa sawit terserang *Ganoderma* sp. *Menara Perkebunan, 84(2)*: 98-106.