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Evaluation of Endophytic *Trichoderma* and Other Microbes for Potential Biocontrol of *Ganoderma* Basal Stem Rot Disease on Oil Palm Seedlings

DEDEK HARYADI, HADI HENDRA, MANJIT SIDHU, TUMPAL PANJAITAN, YOHANNES SAMOSIR AND MUKESH SHARMA

Asian Agri Group R&D Centre, Bahilang Estate, Tebing Tinggi, North Sumatra, Indonesia

To minimise infection risk and impact of basal stem rot (BSR) disease on its new second generation oil palm replants, Asian Agri has adopted a four stage integrated disease management (IDM) strategy of which, protection of newly planted oil palm seedlings with an effective biocontrol agent is an important component. At its R & D Centre, evaluation of soil microbes is being carried out in three phases. Potential microbes from in vitro *laboratory screenings (phase 1) are further tested in the nursery (phase 2) with final validation of successful candidates in field trials (phase 3).*

This paper reports on the results of eight nursery trials which evaluated a total of 42 in-house Endophytic Trichoderma (ET) isolates and 13 commercial bioagent products for their effectiveness in controlling the BSR pathogen, Ganoderma boninense.

All 42 ET isolates conferred some degree of protection to the oil palm seedlings against Ganoderma *infection, when compared to the unprotected control seedlings. Nevertheless, there were significant differences in the efficacy of the 42 ET isolates. Ten ET isolates averaged below 25 per cent disease incidence (DI) of which, ET 501 was the most effective and most consistent in performance. ET 501 recorded a low average DI of only 14 per cent as compared to 81 per cent in the control seedlings. Its consistency in performance was reflected in all eight trials with a narrow DI range of 6 - 20 per cent as compared to a DI of 73 - 88 per cent in the control seedlings. The high DI range in the control seedlings in all eight trials also confirmed the aggressive pathogenicity of the* Ganoderma *isolate used for screening. The latter is critical, as low values could lead to wrong interpretation and analysis of the performance of the products being tested.*

Of the 13 commercial products evaluated, all conferred some degree of protection to the inoculated seedlings, although only five products recorded average DI levels below 50 per cent (range: 21 - 43 per cent). However, none of the 13 commercial products were as effective as Asian Agri's ET 501 isolate, which consistently recorded the lowest DI values in these comparative screening trials.

Laboratory and nursery screening is invaluable, as they help to identify and shortlist potential candidates for final evaluation in the field. Direct screening in the field would be costly and time consuming, in view of the large number of isolates and products to be tested. However, field validation is vital as soil chemistry, climate and microbial populations in the rhizosphere may differ between nursery and field, hence affecting the efficacy of the applied bioagents. In view of this, the most promising ET isolates are being further tested in field trials on both mineral and peat soils, to confirm their effectiveness prior to commercial use.

Keywords: *Basal stem rot, Endophytic* Trichoderma, Ganoderma boninense*, oil palm seedlings.*

Basal stem rot (BSR) caused by *Ganoderma boninense* is regarded as the most destructive disease of oil palm in Malaysia and Indonesia (Idris, 2009; Susanto, 2009). Although formerly considered to be a disease of older palms (Turner, 1981), it is now emerging to become a

problem even in younger palms (Haryadi *et al*., 2016; Khairudin, 1990; Ariffin *et al*., 1989). Infection levels of up to 40 per cent have been recorded in 12-year-old oil palm replanted from oil palm and coconut (Rao *et al*., 2003; Hoong, 2007). In third generation oil palm in North Sumatra, Indonesia, much higher infection incidence of 75 per cent have been reported (Susanto & Sudharto, 2003). Likewise, from being a disease of palms cultivated on coastal clays, it has expanded to become a problem even on more free draining inland, volcanic and peat soils (Ariffin *et al*., 2000; Sidhu *et al*., 2016).

In Asian Agri Group estates, BSR is a major problem in first generation oil palm cultivated on alluvial, volcanic and peat soils in North Sumatra province, Indonesia. High infection levels, significant loss in palm stand and rapid deterioration in yield has necessitated early replanting with superior second generation D x P progenies in a number of affected estates (Sidhu *et al.*, 2016). To minimise the infection risk and impact of the pathogen on second generation replants, a four stage integrated disease management (IDM) strategy has been introduced. This comprises of intensive land preparation with a certification scheme (stage 1), planting varieties with a higher disease tolerance (stage 2), inoculation and protection of oil palm seedlings with an effective bioagent (stage 3) and early detection and removal of newly infected palms (stage 4) to contain spread of the disease (Sidhu *et al*., 2016).

Asian Agri's R & D Centre (AA R & D Centre) has given much attention and prioritised research on stages 2 and 3 of its IDM strategy. In the former case, 18 moderately tolerant and high yielding D x P crosses (Topaz GT) have been developed and released for planting in *Ganoderma* high risk estates (Harkingto *et al*., 2019). Likewise, considerable research has also been undertaken to isolate, identify, culture and evaluate microbes for potential use against BSR, either as protectants or as curative agents. Evaluation of microbes is carried out in three stages. Potential microbes from *in vitro* laboratory screenings are further tested in the nursery with final validation by field trials. Haryadi *et al.* (2019) has previously reported on the results of *in vitro* laboratory screenings. This paper documents the results of eight nursery trials evaluating the efficacy of 42 in-house *Trichoderma* species isolates and 13 commercial bioagent products for *Ganoderma* suppression and control.

MATERIALS AND METHODS

Preparation of bioagents

Bioagents evaluated in the nursery trials comprised of 42 in-house endophytic *Trichoderma* (ET) isolates collected from Asian Agri oil palm estates in North Sumatra province, Indonesia and 13 commercial products containing various microbes such as *Trichoderma* spp., *Bacillus* spp., *Hendersonia* spp., *Mycorrhiza* spp., and *Streptomyces* spp. as active ingredients.

Culturing and production of the 42 ET isolates from Asian Agri estates was as described by Haryadi *et al*. (2019). The 13 bioagents from external sources were commercially formulated products.

Preparation of rubber wood blocks (RWB) and method of inoculation

RWBs of 6 cm x 3 cm x 3 cm size were sterilised for two hours at 120º C 15 psi and the process was repeated again the next day for a further two hours. The RWBs were then inoculated with active *G. boninense* mycelium and incubated for two months at room

temperature and 70 per cent relative humidity.

Artificial inoculation of oil palm seedlings with *G. boninense* was carried out using a modification of the RWB sitting technique developed by Breton *et al.* (2006). Germinated seeds from a single *Ganoderma* susceptible D x P cross was initially planted in small polybags (5 cm x 10 cm) and 5 g of the respective ET isolate was added into the planting hole before seed planting. One month after seed planting, the seedlings were transplanted into larger polybags (20 cm x 30 cm) and placed on top of the *Ganoderma* RWB. Prior to transplanting, a further 10 g of the ET isolate was incorporated into the planting hole for inoculation of the seedlings. Inoculation with commercial products followed a similar protocol but at dosages and application frequency recommended by the manufacturers.

Trial design and disease incidence evaluation

A total of eight nursery trials were conducted in overlapping stages over a four-year period to assess the effectiveness of the 42 in-house ET isolates and 13 commercial bioagent products. Trial design was randomised complete block design (RCBD) with five replications, with each treatment consisting of 20 seedlings per replicate. The seedlings were raised under artificial shade of 70 per cent, 30ºC ± 2º C temperature and relative humidity of 70 - 80 per cent.

Each trial also comprised of an unprotected control (exposed to *Ganoderma* RWB without bioagent inoculation) as a benchmark to assess efficacy of bioagent treatments and pathogenicity of the *Ganoderma* inoculum. In all trials, the most aggressive *Ganoderma* isolate was used (Haryadi *et al.*, 2019).

Disease incidence (DI) evaluation was carried out at monthly intervals for a period of 12 months. This was based on visual changes in the foliage of the seedlings (chlorosis, necrosis), appearance of fungal mycelium, fruiting bodies and rotting of the bole and root mass. All dead seedlings without fungal mycelium or fruiting bodies underwent destructive sampling and had their tissue plated on *Ganoderma* selective medium (GSM) to confirm infection. Likewise, as some infected seedlings may not show external symptoms (Haryadi *et al.*, 2019), destructive sampling was also carried out on all "symptomless" seedlings and their tissue plated on GSM for confirmation of infection.

Percentage DI was calculated based on the formula devised by Campbell and Madden (1990), as shown below:

$$DI = \frac{\text{Number of seedlings confirmed to be infected}}{\text{Total number of seedlings per treatment}} \times 100\%$$

RESULTS AND DISCUSSION

Development of external BSR infection symptoms

The development of BSR disease in all eight trials was monitored monthly. Infection was first observed 2 - 3 months after inoculation and continued to rise steadily until the tenth month, thereafter, infection levels rose only slowly and started to plateau out. Visually, the earliest symptoms of infection commenced with the chlorosis of the lower leaves, followed by rapid desiccation from the oldest to the youngest leaves, as the disease progressed (*Figure 1a*). Mycelial development was not seen at this early stage. Rakib *et al.* (2015) also noted similar disease progression in their investigation and observed that dead infected seedlings may or may not have visible above

Figure 1a Chlorosis and dessication of lower leaves, two to three months after inoculation with Ganoderma *RWB*

Figure 1b Appearance of Ganoderma *fruiting body, three to four months after inoculation with* Ganoderma *RWB*

ground fungal mass. In the current study, *Ganoderma* fruiting bodies first appeared 3-4 months after inoculation, occurring as a mycelial mass at the base of the seedlings, followed by the emergence of a button-like fruiting body (*Figure 1b*).

Infected seedlings often also displayed rotten bole and roots. Random sampling and GSM plating of tissues taken from seedlings displaying foliar symptoms, mycelial mass and rotting boles and roots, confirmed that these symptoms were positively associated with BSR disease infection. In contrast, none of the tissues taken from "symptomless" seedlings gave rise to *Ganoderma* fungal growth on GSM. Results of this study confirmed that visual symptoms associated with *Ganoderma* infection could be reliably used to assess DI in nursery trials.

Efficacy of ET isolates and commercial bioagent products

Results of the eight nursery screening trials are summarised in *Tables 1* and *2*. The results indicate that all 42 ET isolates conferred some degree of protection to the oil palm seedlings against *Ganoderma* infection, when compared to the unprotected control seedlings. Average DI values for treated seedlings ranged from 14-80 per cent whilst those of unprotected control seedlings averaged at 81 per cent. In addition, there were significant differences in the efficacy of the 42 ET isolates. Ten ET isolates averaged below 25 per cent DI of which ET 501 was the most effective and most consistent in performance. ET 501 recorded a low average DI of only 14 per cent and its consistency in performance was reflected in

TABLE 1
DISEASE INCIDENCE (DI) IN OIL PALM SEEDLINGS INOCULATED WITH DIFFERENT ET ISOLATES

Treatment number	*ET isolate treatment*	*Seedling mortality (%)*								*Average*
		Trial 1	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Trial 6*	*Trial 7*	*Trial 8*	
1	ET 501	20	19	19	19	9	6	13	7	14^{a*}
2	ET 534	-	-	-	-	-	-	-	18	18^{ab}
3	ET 5122	-	-	-	16	-	20	-	-	18^{abc}
4	ET 5118	-	-	-	21	-	-	-	-	21^{ab}
5	ET 545	-	-	-	-	-	-	-	22	22^{ab}
6	ET 532	-	-	-	-	-	-	-	23	23^{ab}
7	ET 5100	-	-	-	23	-	-	-	-	23^{ab}
8	ET 554	-	-	-	-	25	-	-	-	25^{abc}
9	ET 555	-	-	-	25	-	-	-	-	25^{abc}
10	ET 537	-	-	-	13	-	-	48	15	25^{abc}
11	ET 5120	-	-	-	23	-	30	-	-	27^{abc}
12	ET 526	-	-	-	-	-	-	-	27	27^{abc}
13	ET 598	-	-	-	-	-	-	28	-	28^{abc}
14	ET 522	32	25	-	29	-	-	-	-	29^{abc}
15	ET 529	-	-	-	29	-	-	-	-	29^{abc}
16	ET 552	-	-	-	-	29	-	-	-	29^{abc}
17	ET 527	-	-	-	-	-	-	33	27	30^{abc}
18	ET 5105	-	-	-	30	-	-	-	-	30^{abc}
19	ET 5109	-	-	-	30	-	-	-	-	30^{abc}
20	ET 543	-	-	-	-	-	-	-	32	32^{abc}
21	ET 553	-	-	-	-	-	-	32	-	32^{abc}
22	ET 528	-	-	-	-	-	-	-	33	33^{abc}
23	ET 5117	-	-	-	34	-	-	-	-	34^{abc}
24	ET 565	39	52	38	29	-	-	-	-	40^{bcd}
25	ET 551	-	-	-	-	-	-	40	-	40^{bcd}
26	ET 549	-	-	41	-	-	-	-	-	41^{bcd}
27	ET 523	-	-	-	30	33	-	70	50	46^{cde}
28	ET 577	-	-	-	-	-	-	53	40	47^{cdef}
29	ET 525	-	-	-	26	-	-	-	70	48^{cdef}
30	ET 5103	-	-	-	-	-	-	48	-	48^{cdef}
31	ET 576	-	-	-	-	-	-	48	51	50^{cdef}
32	ET 548	-	-	-	-	-	-	35	81	58^{efgh}
33	ET 5103	-	-	-	-	-	-	-	63	63^{efg}
34	ET 576	-	-	-	-	-	-	70	62	66^{efg}
35	ET 540	-	-	-	-	-	-	-	66	66^{efg}
36	ET 541	-	-	-	-	-	-	67	-	67^{efg}
37	ET 5124	-	-	-	-	-	-	-	71	71^{fg}
38	ET 563	-	-	-	-	-	-	62	82	72^{fg}
39	ET 530	-	-	-	-	-	-	78	67	73^{fg}
40	ET 557	-	-	-	-	-	-	-	73	73^{fg}
41	ET 599	-	-	-	-	-	-	-	75	75^{fg}
42	ET 5114	-	-	-	-	-	-	80	-	80^{g}
43	Control	84	82	88	81	83	73	83	76	81^{g}

* Values with similar alphabets are not statistically different

TABLE 2
DISEASE INCIDENCE (DI) IN OIL PALM SEEDLINGS INOCULATED WITH DIFFERENT COMMERCIAL BIOAGENT PRODUCTS

Treatment number	*ET isolate treatment*	*Seedling mortality (%)*								*Average*
		Trial 1	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Trial 6*	*Trial 7*	*Trial 8*	
1	Asian Agri ET 501	20	19	19	19	9	6	13	7	14[a*]
2	Lonsum-SBJ8	-	-	-	-	-	-	21	-	21[a]
3	Decopalma	-	-	-	23	-	-	-	43	33[b]
4	Mycoplex	-	-	-	40	-	-	-	-	40[b]
5	Endopalma	-	-	-	21	-	-	-	60	41[b]
6	Excalibur	-	-	-	33	53	-	-	-	43[b]
7	Rhizagold	61	61	61	-	-	-	-	-	61[c]
8	Stimax	58	60	71	-	-	-	-	-	63[cd]
9	Pro-Fil	62	64	69	-	-	-	-	-	65[cd]
10	Agronta	55	66	75	-	-	-	-	-	65[cd]
11	Farm booster	-	-	-	-	-	-	69	-	69[cd]
12	High yield treatment (HYT)	-	-	73	-	-	-	-	-	73[cd]
13	Gano-EF	-	-	63	-	-	78	85	-	75[cd]
14	Living soil microbes (LSM)	-	-	-	-	60	-	89	-	75[cd]
15	Control	84	82	88	81	83	73	83	76	81[d]

* Values with similar alphabets are not statistically different

all eight trials with a narrow DI range of 6-20 per cent, as compared to a DI of 73-88 per cent in the control seedlings. ET 534, ET 5122, ET 5118, ET 545, ET 532, ET 5100, ET 554 and ET 555 also showed good potential with DI less than 25 per cent. However, apart from ET 5122, none of the promising ET isolates have been tested more than once and will require further screening to validate their consistency in performance. The latter is an important prerequisite for bioagent testing and development. The high DI (range 73-88 per cent) in the unprotected control seedlings also confirmed the aggressive pathogenicity of the *Ganoderma* isolate. The consistency in pathogenicity of the *Ganoderma* isolate being used for screening is critical, as low values could lead to inaccurate analysis of the performance of the tested bioagents.

Similar to the 42 ET isolates, all 13 commercial products also conferred some degree of protection to the oil palm seedlings against BSR *Ganoderma* infection. Average DI values for the 13 products ranged from 21 - 75 per cent as compared to 81 per cent in the unprotected control. As seen with the ET isolates, there was also significant differences in the efficacy of the commercial products. Lonsum–SBJ8 containing *Trichoderma virens* was the most effective with DI values of 21 per cent. Decopalma, Mycoplex, Endopalma and Excalibur, which contained a mix of several microbes recorded DI values of 33-41 per cent and were the four other commercial products

with some potential for suppressing *Ganoderma* infection. Nevertheless, none of the 13 commercial products were as effective as Asian Agri's ET 501, which consistently recorded the lowest DI values in these comparative screening trials. The consistency of Lonsum – SBJ8 and Mycoplex remains unknown as only a single evaluation was carried out and further testing will be required. Decopalma, Excalibur and Endopalma were screened twice, peforming well in Trial 4 (DI range : 21-23 per cent) but poorly in Trials 5 and 8 (DI range : 43-60 per cent) indicating inconsistency in performance. None of the other nine bioagent products showed any commercial potential due to their low efficacy (*Table 2*).

The promising results obtained with some of the in-house ET isolates were consistent with the findings of other researchers evaluating the efficacy of the genera *Trichoderma*, as protectants against *G. boninense* infection. Soepana *et al.* (2000), Yurnaliza *et al.* (2014), Musa *et al.* (2017), Sundram *et al.* (2008) and Haryadi *et al*. (2019) all reported good biocontrol of *G. boninense* by a number of *Trichoderma* strains such as *T. asperellum, T. reesei, T. brevicompatum, T. harzianum* and *T. virens* in laboratory and nursery trials. Mukherjee *et al.* (2012) attributed the ability of *Trichoderma* species to parasitise, suppress or even kill other plant pathogenic fungi as an important mechanism for its success as a biocontrol agent. Shiomi *et al.* (2006) reported that ET are able to penetrate and become systematically disseminated in the host plant, actively colonising the apoplast, conducting vessels and occasionally the intracellular spaces (Hallman *et al*., 1997). These modes of endophytic action could induce resistance in oil palm seedlings and suppress the number of *G. boninense* infections. The ET strains must not only have the potential mechanisms for biocontrol such as antibiosis and myco-parasitism, but also a strong competitive ability to displace the causative pathogen, so as to reduce the root colonisation opportunity for the pathogen. It must be able to favourably compete and adapt well within the environment in which it will operate and be able to rapidly colonise and proliferate on existing and newly formed roots immediately after its application (Sariah *et al*., 2005; Nusaibah & Musa, 2019). However, Abdullah *et al.* (2003) noted that ET could only protect the palms from infection or when infection by *G. boninense* was at a very early stage. The lack of ability of ET strains to cure severely infected oil palm in field trials has also been documented by Haryadi (2019).

CONCLUSION

The eight nursery trials confirmed the potential of *Trichoderma* spp as an effective biocontrol agent of *G. boninense*. Ten in-house ET isolates performed well, of which three isolates ET 501, ET 534, and ET 5122 suppressed *Ganoderma* DI levels below 20 per cent. Of the latter, ET 501 was the most effective and consistent, performing well in all eight nursery trials. Majority of the remaining effective ET isolates have only been screened once or twice and will require further testing to confirm their consistency. ET 501 was also more effective than all 13 commercial products evaluated. However, it would be premature to assume that a biocontrol agent effective in laboratory and nursery screenings, would perform equally well when applied in the field. Laboratory and nurseries are "controlled environments" whereas, field conditions are more open and harsher and the applied ET isolate will face the impact of frequent weather changes, differences in soil chemistry and not to mention,

the competition from native soil microbe populations in the rhizosphere. Differences in the pathogenicity of the various *Ganoderma* strains occurring naturally in the field, is another factor that needs to be considered.

Despite their shortcomings, laboratory and nursery screenings are invaluable and are necessary, as they identify and shortlist potential candidates for final evaluation in the field. Direct evaluation in the field would be extremely costly and time consuming, in view of the large number of isolates to be screened. For stage 3 screening or validation in the field, AA R & D Centre has also established two field trials on mineral and peat soils, to confirm the effectiveness of ET 501 as a protectant against *Ganoderma* infection. The trials are still in progress.

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REFERENCES

ABDULLAH, F., ILIAS, G.M.N., NELSON, M., IZZATI, N. and YUSUF, U. 2003. Disease assessment and the efficacy of *Trichoderma* as a biocontrol agent of basal stem rot of oil palms. *Sci Putra* **12**:31-33.

ARIFFIN, D., IDRIS, A.S. and SINGH, G. 2000. *Status of* Ganoderma *in oil palm*. In*:* Ganoderma *Diseases of Perennial Crops* (J. Flood, P.D. Bridge and M. Holderness, eds.). Wallingford: CABI Publishing. 49-68.

ARIFFIN, D., SINGH, G. and LIM, T.K. 1989. *Ganoderma* in Malaysia - current status and research strategy. In: *Proceedings of PORIM International Palm Oil Development Conference*. Bangi: Palm Oil Research Institute of Malaysia. 249-297.

BRETON, F., HASAN, Y., HARIADI, LUBIS, Z. and DE FRANQUEVILLE, H. 2006. Characterisation of parameters for the development of an early screening test for basal stem rot tolerance in oil palm progenies. *Journal of Oil Palm Research* 24-36.

CAMPBELL, C.L. and MADDEN, L.V. 1990. *Introduction to Plant Disease Epidemiology*. USA: John Willey and Sons. ISBN-13: 978-0471832362, 523pp.

HALLMANN, J., QUADT-HALLMANN, A., MAHAFFEE, W.F. and KLOEPPER, J.W. 1997. Bacterial endophytes in agricultural crops. *Can. J. Microbiol* **43**:895-914.

HARKINGTO, HARYADI, D., ANG, B.B., SIDHU, M., SAMOSIR, Y. HENDRA, H., PURWANTI, S., AKBAR, R., PANJAITAN, T. and SHARMA, M. 2019. Integrated management of *Ganoderma boninense* disease through use of moderately tolerant oil palm varieties. Paper presented at the International Seminar on Breeding for *Ganoderma* Tolerance in Oil Palm, 2019. The International Society for Oil Palm Breeders, Malaysian Palm Oil Board, Kuala Lumpur, Malaysia. 1-12 pp.

HARYADI, D. 2019. Evaluation on the Effectiveness of Potential Endopyhtic *Trichoderma* in Preventing and Suppressing *Ganoderma boninense* Infection in Oil Palm Seedlings. Ph.D Thesis, Universiti Malaysia Sabah, Malaysia. 89-111.

HARYADI, D., ERIKSON, D., PANJAITAN, T. and SIDHU, M. 2016. Pengendalian terpadu penyakit busuk pangkal batang (*Ganoderma boninense*) pada tanaman kelapa sawit generasi kedua di kebun Asian Agri. Paper presented at the *Ganoderma* Workshop, Bah Lias Research Station, North Sumatra, Indonesia. Preprint, 17pp.

HARYADI, D., SIDHU, M.S., PANJAITAN, T., HENDRA, H. and CHONG, K.P. 2019. The potential of endophytic *Trichoderma* from oil palm (*Elaeis guineensis* jacq.) roots of North Sumatra, Indonesia against *Ganoderma boninense. Journal of Oil Palm Research* **31**(4): 592-603.

HOONG, H.W. 2007. *Ganoderma* disease of oil palm in Sabah. *The Planter* **83** (974):299-313.

IDRIS, A.S. 2009. Basal stem rot in Malaysia - biology, epidemiology, economic importance, detection and control. Paper presented at the International Workshop on Awareness, Detection and Control of Oil Palm Devastating Diseases. Kuala Lumpur, Malaysia. Translated version. 3-44.

KHAIRUDIN, H. 1990. Basal Stem Rot of Oil Palm: Incidence, Etiology and Control. Thesis. Selangor, Malaysia : Universiti Pertanian Malaysia. 1-134.

MUKHERJEE, P.K., BUENSANTEAI, N., MORÁN-DIEZ M. E., DRUZHININA I. and KENERLEY C. M. 2012. Functional analysis of non-ribosomal

peptide synthetases (NRPSs) in *Trichoderma virens* reveals a polyketide synthase (PKS)/NRPS hybrid enzyme involved in the induced systemic resistance response in maize. *Microbiology* **158**:155-165.

MUSA, H., HASAN, M.A., ISYAKU, M.S., HALIDU, J. and SULEIMAN, A. S. 2017. Antagonistic potential of *Trichoderma* species against *Ganoderma* disease of oil palm. *Nigerian Journal of Agriculture, Food and Environment* **13** (2):60-67.

NUSAIBAH, S.A. and MUSA, H. 2019. A review report on the mechanism of *Trichoderma* spp. as biological control agent of the basal stem rot (BSR) disease of *Elaeis guineensis*. In: *Trichoderma* - The Most Widely Used Fungicide - Mohammad Manjur Shah, Umar Sharif and Tijjani Rufai Buhari, IntechOpen, doi: 10.5772/intechopen.84469.

RAKIB, M.R.M., BONG C.F.J., KHAIRULMAZMI, A. and IDRIS, A.S. 2015. Aggressiveness of *Ganoderma boninense* and *G. zonatum* isolated upper and basal stem rot of oil palm (*Elaeis guineensis*) in Malaysia. *Journal of Oil Palm Research* **27** (3):229-240.

RAO, V., LIM, C.C., CHIA, C.C. and TEO, K.W. 2003. Study on *Ganoderma* spread and control. *The Planter* **79** (927):367-383.

SARIAH, M., CHOO, C.W., ZAKARIA, H. and NORIHAN, M.S. 2005. Quantification and characterisation of *Trichoderma* spp. from different ecosystems. *Mycopathologia* **159**:113-117.

SIDHU, M., SHARMA, M., AZIZ, A., LIMBONG, A., SIHOTANG, S. and SANJAYA, B. 2016. Towards attaining high yields and long term sustainibility of second generation oil plam replants in North Sumatra, Indonesia –The Asian Agri experience. Paper presented at 15th International Peat Congress 2016 – *Peatlands in harmony.* Kuching, Sarawak, Malaysia. Preprint 20pp.

SOEPENA, H.R., PURBA, Y. and PAWIRO-SUKARTO, S. 2000. A control strategy for basal stem rot (*Ganoderma*) on oil palm. In: Ganoderma *Diseases of Perennial Crops* (Flood, J., Bridge, P.D. and Holderness, M.). United Kingdom: CAB International. 83-88.

SUSANTO, A. 2009. Basal stem rot in Indonesia - biology, epidemiology, economic importance, detection and control. In: *Proc. of the International Workshop on Awareness, Detection and Control of Oil Palm Devastating Diseases*. Bangi: Malaysian Palm Oil Board. 63-94.

SHIOMI, H.F., SILVA, H.S.A., DE MELO, I.S., NUNES F.V. and BETTIOL, W. 2006. Bioprospecting endophytic bacteria for biological control of coffee leaf rust. *Sci. Agric.* **63** (1).

SUNDRAM, S., ABDULLAH, F., AHMAD, Z., and YUSUF, U. K. 2008. Efficacy of single and mixed treatments of *Trichoderma harzianum* as biocontrol agents of *Ganoderma* basal stem rots in oil palm. *Journal of Oil Palm Research* **20**:47-83.

SUSANTO, A. and SUDHARTO. 2003. Status of *Ganoderma* Disease on Oil Palm in Indonesia. Paper presented at the Third International Workshop on *Ganoderma* Diseases of Perennial Crops. Medan, Indonesia. 1-12 pp.

TURNER, P.D. 1981. *Oil Palm Diseases and Disorders.* Kuala Lumpur: Oxford University Press. 88-110.

YURNALIZA, I., ARYANTHA, N.P., ESYANTI, R.R. and SUSANTO, A. 2014. Antagonistic activity assessment of fungal endophytes from oil palm tissues against *Ganoderma boninense* Pat. *Plant Pathology Journal* **13**:257-267.