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CHAMPIONING SUSTAINABLE TREATMENT OF OIL PALM BASAL STEM ROT DISEASE VIA BIOLOGICAL CONTROL AGENTS

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ABSTRACT

Oil palm is the most important commodity crop for Malaysia and Indonesia. However, it is being threatened by a disease identified as basal stem rot (BSR) caused by Ganoderma *spp. Common approaches such as chemical and cultural control have failed to demonstrate total effectiveness in controlling BSR disease. Nevertheless, these practices cause detrimental effects on the environment. Therefore, the attention on adopting biological control agents (BCA) as one of the sustainable methods to eradicate and control BSR disease is on the rise. The current review highlights on the attempts and outcome of applying various BCA such as fungi, bacteria and actinomycetes as single or mixed application to control BSR disease in oil palm.*

Keywords: basal stem rot, biological control agent, bacteria, fungi, actinomycetes.

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INTRODUCTION

Oil palm is the most important commodity crop being planted across Malaysia including Peninsular, Sarawak and Sabah. Planted area of oil palm has reached 5.85 million hectares in 2018 and utilised 60% of the agricultural lands in Malaysia (Kamarudin *et al.*, 2019). Malaysia's palm oil export was recorded with a rise of 6% in January-June 2020 with an approximate export value of USD5.50 billion compared to the first half of 2019 (MPOC, 2020). Malaysia is the second major palm oil producer after Indonesia with the forecast of total planted areas of mature palms at 11.75 million hectares in 2019/2020 (Mcdonald and Rahmanulloh, 2019). Oil palm is a golden commodity crop producing versatile raw materials for food industry and non-food industries such as biodiesel and oleochemical.

Regardless of whether large or small scale oil palm planters, Malaysian planters are challenged by the most destructive oil palm disease called basal stem rot (BSR) disease. This devastating disease is caused by *Ganoderma* spp., white rot fungi that could be seen visibly at the bole of an infected palm tree if the infection is at the advanced stages. There are three species reported to be associated with BSR disease, they are *Ganoderma boninense*, *Ganoderma zonatum* and *Ganoderma miniatocinctum* (Idris *et al.*, 2000; Moncalvo, 2000). However, *G. boninense* has been identified as the most aggressive major causal pathogen of BSR disease in Peninsular Malaysia (Idris *et al.*, 2000; Wong *et al.*, 2012). Conversely, the most dominant virulent species in Sarawak state particularly in Betong and Miri areas has been identified as *G. zonatum* causing BSR disease and upper stem rot (USR) (Rakib *et al.*, 2017).

The pathogen causes rotting of the roots, bole and subsequently the stem leading to the failure in delivering water and nutritions from the root to the aerial parts of the palm (Chong *et al.*, 2017). Symptoms observed on mature palms include multiple unopened leaflets, flattening of the crown, pale coloured leaf canopy, presence of basidiocarps at the bottom of the stem (Turner, 1981) and collapse of the palm at the final stages of infection. Early detection of this disease is tough as the palms display noticeable symptoms at advanced stages when the disease severity reaches approximately 60%-70% (Chong *et al.*, 2017).

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In addition, all these symptoms could occur as single or in combination depending on the environmental conditions and care given to the palms. No absolute pattern of disease progression has been reported till to date (Chong *et al.*, 2017).

The BSR disease is able to cause direct loss (death of the palm) or indirect loss causing reduction in the number of fresh fruit brunches (FFB) leading to yield losses. For the year 2020, BSR disease infection of planted areas is forecasted to touch 443 430 ha or affecting 65.6 million palm trees (Roslan and Idris, 2012). Hence, it is crucial to eradicate this devastating disease to prevent any further direct or indirect loss of productive palms.

There are many approaches that could be adopted to mitigate BSR. The most common is via chemical control by application of fungicide. Hexaconazole has been the typical fungicide used to control BSR. It is applied to symptomatic palms via trunk injection, soil drenching, or a combination of these two methods (Idris *et al.*, 2002; Halimah *et al.*, 2012). Even though hexaconazole fungicide application was proven to increase the productive life-span of an infected palm, the residue and non-targeted beneficial microorganism is of concern. In addition, by the end of 2019, all Malaysian oil palm planters and millers are required to obtain sustainability certification, such as the Malaysian Sustainable Palm Oil (MSPO) or the Roundtable on Sustainable Palm Oil (RSPO) by complying with the sustainability standard requirements in order to export certified palm oil to international markets (Kamarudin *et al.*, 2019). Requirement on the sustainability certification, urges the planters to adopt good agricultural practices (GAP). This could be achieved by minimising the usage of synthetic chemical fertilisers, pesticides, fungicides and weedicides.

Biocontrol could be the best alternative to adopt in controlling the disease without causing any environmental harmfulness (O'Brien, 2017; Aboutorabi, 2018). In addition, it is also lower in cost compared to the cultural and chemical control methods (Aboutorabi *et al.*, 2018).

AN OVERVIEW: BIOCONTROL OF BASAL STEM ROT (BSR) DISEASE

The term 'biocontrol' is defined as the incorporation of one or multiple microorganisms such as fungi, bacteria, virus and actinomycetes to suppress the population of disease-causing pathogens; either applied onto the soil or to the plants. These incorporated microorganisms are recognised as biological control agents (BCA) which exhibit antagonistic reaction towards the pathogen. Thus, BCA exhibit the potential to prevent the establishment of the disease or its severity. The BCA is also highly specific towards the targeted pathogen without affecting the normal flora.

Over the past years, there have been extensive studies on the identification of effective BCA for controlling BSR disease (Musa *et al.*, 2018; Naidu *et al.*, 2018; Muniroh *et al.*, 2019). Their potentials have been investigated initially via various *in vitro* studies for screening and better understanding purpose prior to greenhouse and field trials. The basic method used to evaluate the efficacy of BCA are through dual culture (Naher *et al.*, 2015; Shariffah-Muzaimah *et al.*, 2015), poison agar (Marzuki *et al.*, 2015; Shariffah-Muzaimah *et al.*, 2015) and culture filtrate assay (Shariffah-Muzaimah *et al.*, 2015; Ramli *et al.*, 2016). The higher percentage of inhibition of radial growth (PIRG) value displays higher suppression efficacy the BCA towards the pathogen. The inhibition effect could be due to the ability of the BCA to suppress the growth performance of the pathogen through various mechanisms such as competition for nutrient and space, antibiosis, production of cell wall degrading enzymes (CWDE), and production of secondary or defence metabolites (Heydari and Pessarakli, 2010; Chong *et al.*, 2017; O'Brien, 2017). The BCA may utilise a single or an array of mechanisms in inhibiting a pathogen. In many BCA studies, plant growth promotion (PGP) was one of the benefits demonstrated apart from disease suppression (Nur Azura *et al.*, 2016; Muniroh *et al.*, 2019). In some cases, the degree of suppression by BCA towards plant pathogens tends to be lower when tested in field compared with the result achieved on agar plate for the same BCA. This could reflect the diversity of environment (O'Brien, 2017) and complexity of interaction between microbes in the soil. Hence, it is crucial to evaluate the suppression of BCA towards the pathogen not only *in vitro* but also *in vivo* (Nusaibah *et al.*, 2017). Various genera of BCA will be discussed in this article. Recent studies utilising BCA to control BSR disease of oil palm is summarised in *Table 1*.

Biocontrol Agent- Fungi

The most common fungi applied as BCA for pathogen eradication across variety of crops are *Trichoderma* spp. In Malaysia, the most common *Trichoderma* spp. proven to be antagonist towards *G. boninense* are *Trichoderma asperellum*, *Trichoderma harzianum* and *Trichoderma virens* (Naher *et al.*, 2012; Sundram, 2013; Nusaibah *et al.*, 2017; Angel *et al.*, 2018; Ho *et al.*, 2018; Musa *et al.*, 2018). A study conducted by Naher *et al.* (2015) determined the antagonistic and growth performance of *T. harzianum* T32 strain against *G. boninense* on different types of media namely potato dextrose agar (PDA), potato sucrose agar (PSA) and malt extract agar (MEA). Cultural morphology of

TABLE 1. SUMMARY OF RESEARCH FINDINGS IN THE PAST FIVE YEARS (2015-2019)

Year	Location	Biocontrol agent	Type of study	Source
2015	Peninsular Malaysia	*Actinomycetes*	*In vitro*	Shariffah-Muzaimah *et al.* (2015)
		Trichoderma harzianum T32	*In vitro*	Naher *et al.* (2015)
		Arbuscular mycorrhizal fungi with *Pseudomonas aeruginosa* UPMP3	*In vitro* and *in vivo* (nursery and bait seedling)	Sundram *et al.* (2015)
		Cladobotryum semicirculare	*In vitro* (dual culture, mycoparasitism test, poison agar)	Marzuki *et al.* (2015)
	Sabah	Multiple strains of *Bacillus* spp. and *Trichoderma* spp.	*In vitro* (agar well diffusion assay, SEM, PIRG)	Alexander *et al.* (2015)
2016	Peninsular Malaysia	*Scytalidium parasiticum*	*In vitro* and *in vivo* (nursery)	Goh *et al.* (2016)
		Pseudomonas aeruginosa GanoEB1, *Burkholderia cepacia* GanoEB2, *Pseudomonas syringae* GanoEB3	*In vitro* and *in vivo* (nursery)	Ramli *et al.* (2016)
		Streptomyces sanglieri	*In vitro*	Nur Azura *et al.* (2016)
2017	Peninsular Malaysia	*Trichoderma harzianum* and *Bacillus cereus*	*In vitro* and *in vivo* (nursery)	Nusaibah *et al.* (2017)
	Sabah	Multiple strains of *Bacillus* spp. and *Trichoderma* spp.	*In vitro* and *in vivo* (field)	Alexander *et al.* (2017)
	Indonesia	*Trichoderma harzianum*, *Trichoderma longibrachiatum*, *Lasiodiplodia venezuelensis*, *Dothidiomycetes* sp.	*In vitro* (chitinase analysis)	Esyanti *et al.* (2017)
2018	Indonesia	*Bacillus methylotrophicus*	*In vitro* (antifungal cyclic lipopeptides)	Pramudito *et al.* (2018)
	Peninsular Malaysia	*Trichoderma virens* 159C	*In vitro*	Angel *et al.* (2018)
	Sabah	*Streptomyces* spp.	*In vitro*	Lim *et al.* (2018)
	Peninsular Malaysia	*Trichoderma harzianum*	*In vitro*	Ho *et al.* (2018)
		Trichoderma asperellum, *Trichoderma harzianum*, *Trichiderma virens*	*In vivo* (nursery)	Musa *et al.* (2018)
		Hymenomycetes	*In vitro* and *in vivo* (nursery)	Naidu *et al.* (2018)
		Streptomyces spp.	*In vitro* and *in vivo* (nursery)	Shariffah-Muzaimah *et al.* (2018)
2019	Peninsular Malaysia	*Pseudomonas aeruginosa* UPMP3 and *Trichoderma asperellum* UPM16	*In vitro*	Muniroh *et al.* (2019)
	Indonesia	*Trichoderma* sp., *Aspergillus* sp. and *Mucor* sp.	*In vitro* (screening)	Puspita *et al.* (2019)

Note: SEM – scanning electron microscopy; PIRG – percentage of inhabitation of radial growth.

T. harzianum T32 exhibited concentric ring in all media with greenish colony observed on PDA and PSA while yellowish green colony on MEA. The study concluded that, biocontrol activity of *T. harzianum* T32 against *G. boninense* varied on different types of media in which the highest PIRG rate (70%) was recorded on PDA (Naher *et al.*, 2015).

To further understand the mechanism adopted by *T. harzianum*, Ho *et al.* (2018) identified the transcripts involved during induced systemic resistance (ISR) of oil palm by analysing the root transcriptomes of oil palm seedlings inoculated simultaneously with both *G. boninense* and *T. harzianum* compared with either pathogen only or BCA only inoculated seedlings. The *in vivo* study showed that *T. harzianum* was able to delay or inhibit the development of BSR disease symptoms in BCA treated infected seedlings by modulating genes in the host that are involved in the biosynthesis of phytohormones methyljasmonate (MeJA), methylsalicylate (MeSA) and ethylene antioxidant (L-ascorbate and myo-inositol) and few unique secondary metabolites (Ho *et al*., 2018).

Naher *et al.* (2015) also concluded that the inoculation of fungal cell wall suspension of endophytes (*T. harzianum*, *T. longibrachiatum*, *Dothidiomycetes* sp., *Lasiodiplodia venezuelensis*) into oil palm plantlets in Murashige and Skoog (MS) medium and broth was able to induce plant defence mechanism against *G. boninense* by synthesising one of the pathogenesis related protein namely chitinase (Naher *et al*., 2015).

Recently, new biocontrol candidates' namely ascomycetous mycoparasitic and mycophilic fungi such as *Cladobotryum semicirculare* (Marzuki *et al*., 2015) and *Scytalidium parasiticum* (Goh *et al*., 2016) were reported with potential suppression of BSR disease. *Cladobotryum semicirculare* is a type of fungicolous fungus from *Hypocreales* under ascomycetes genus which consists of the biggest group of sporocarp or fruiting body-inhabiting fungi. *Cladobotryum* sp. was reported to cause disease outbreaks on mushroom production (McKay *et al*., 1999) and severe losses in *Ganoderma tsugae* production in a mushroom farm in Taiwan (Kirschner *et al*., 2007). This had driven Marzuki *et al.* (2015) to study their antagonistic or parasitic interaction on *G. boninense*. In this study, *Cladobotryum*-liked isolates were isolated from fruiting bodies of *G. boninense* and identified as *C. semicirculare*. Dual culture test demonstrated that *C. semicirculare* was able to suppress radial mycelial growth of various *Ganoderma* spp. (Marzuki *et al*., 2015). *Ganoderma lucidum* (G32) and *G. boninense* G37 were the most suppressed with PIRG rate of 74.8% and 74.7%, respectively (Marzuki *et al*., 2015). Poison agar test showed that *C. semicirculare* was able to inhibit the growth of *G. lucidum* (G32) with 25%-49% inhibition rate and *G. boninense* (G14) with 35%-55% with 50% or 100% filtrate concentration, respectively (Marzuki *et al*., 2015). In mycoparasitism test (*in vitro*), melanised structures were observed on *Ganoderma* mycelia which served as protective organs to protect *Ganoderma* against antagonist effects of *C. semicirculare* (Marzuki *et al*., 2015). Marzuki *et al.* (2015) was the first report to conclude *G. boninense* as the potential host of *C. semicirculare*. *Cladobotryum semicirculare* has the ability in reducing the regeneration or recovery of *Ganoderma* mycelia in mycoparasitism test. Field evaluation on its potential for disease suppression is obligatory. Another ascomycetes fungus, *Scytalidium parasiticum* AAX0113 isolated from the basidiocarp of *G. boninense* was studied on its disease suppression efficacy on oil palm seedlings (Goh *et al*., 2016). *Scytalidium parasiticum* was recognised as necrotrophic mycoparasite of *G. boninense* when hyphae coiling, short lateral hyphal branch enlarged contact structures and appressorium-like organs were observed in mycoparasitism test. Comparable to *C. semicirculare*, *S. parasiticum* could also suppress *G. boninense* fruiting bodies regeneration. In the nursery study, *S. parasiticum* was proven as non-pathogenic to oil palm seedlings. *Scytalidium parasiticum* could suppress BSR disease by reducing disease severity to 76.6% on treatment of *Ganoderma* G10 with *S. parasiticum*. Nonetheless, *S. parasiticum* has been proven to contribute in improving the seedlings growth performance with greater leaf area observed in treatments compared to control (Goh *et al*., 2016).

In a study published by Naidu *et al.* (2015), a total of seven white rot hymenomycetes were isolated from fruiting bodies of healthy palms and all the isolates were tested for their antagonistic efficacy against *G. boninense* as well as biodegradation properties. Out of seven isolates, *Pycnoporus sanguineus*, *Trametes lactinea* and *Grammothele fuligo* showed high PIRG values ranging from 81%-84% in dual culture study with *G. boninense*. In biodegradation assessment, *G. fuligo*, *P. sanguineus*, *Rigidoporus* sp., *T. lactinea* and *Lentinus tigrinus* showed great mass losses in between 19.33%-32.50% due to the ability in producing one or more lignocellulolytic enzymes. *Grammothele fuligo* and *P. sanguineus* isolates demonstrated the best biodegradation activity and were further evaluated on their biodegradation performance on both colonised and uncolonised woods with *G. boninense* mycelium (Naidu *et al*., 2017). This advanced study has demonstrated that both *G. fuligo* and *P. sanguineus* could efficiently degrade diseased oil palm wood waste in an ecologically friendly manner (Naidu *et al*., 2017). Moreover, pathogenicity and growth promoting properties of these seven hymenomycetes isolates were also determined by Naidu *et al.* (2018). Naidu *et al.* (2018) found that all these isolates were non-pathogenic to oil palm and enhanced vegetative growth of seedlings under greenhouse condition. However, up to date, there is no further report on these hymenomycetes against *G. boninense*. It would be advantageous if a more thorough assessment is conducted based on the response of plant defence enzymes, gene expression and metabolites induced via treatment with these hymenomycetes.

Biocontrol Agent-Bacteria

Numerous endophytic bacteria have been reported on their antagonistic activity against *G. boninense* including *Burkholderia cepacia* (Buana *et al*., 2014; Ramli *et al*., 2016) and *Pseudomonas* *aeruginosa* (Zaiton *et al.*, 2006; Ramli *et al.*, 2016; Muniroh *et al.*, 2019). In the recent research conducted by Lim *et al.* (2019), *P. aeruginosa* was successfully isolated from soil of a virgin and undisturbed forest area of Crocker Range. *P. aeruginosa* in this study caused distortion on hyphae of *G. boninense* and lowered its density of mycelium (Lim *et al.*, 2019). In ethyl acetate crude extract of this endobacteria, the best inhibitory effect against *G. boninense* with minimum inhibitory concentration (MIC) recorded as low as 0.04 mg ml^{-1}. The compound which may have contributed to the antagonistic effect was identified as 3-demethylubiquinone-9 using Liquid Chromatography-Mass Spectrometry (LC-MS) (Lim *et al.*, 2019).

Ramli *et al.* (2016) successfully isolated endophytic bacteria from symptomless oil palm root tissues. The isolates were identified as *P. aeruginosa* GanoEB1, *Pseudomonas syringae* GanoEB3 and *B. cepacia* GanoEB2. These endophytic bacteria were tested in nursery trial using pre and post treatment against BSR disease infected seedlings. In the study, it was concluded that *P. aeruginosa* GanoEB1 was the best potential BCA among other endobacteria to control BSR disease (Ramli *et al.*, 2016). It was also noted that pre-treated oil palm seedlings have better disease endurance than non-treated seedlings when challenged with *G. boninense* (Ramli *et al.*, 2016). Further evaluation in the field was emphasised by the authors to verify its effectiveness in suppressing BSR disease (Ramli *et al.*, 2016).

Although *P. aeruginosa* demonstrated great potential in suppressing BSR disease in many studies, *P. aeruginosa* has the disadvantage of being incapable to produce spores. This switches researchers to pay attention to spore bearing bacteria namely *Bacillus* spp. (Aboutorabi, 2018). *Bacillus* spp. have been proven to have disease suppression on *G. boninense* over the years (Susanto *et al.*, 2005; Suryanto *et al.*, 2012; Nusaibah *et al.*, 2017). A novel fengycin (antifungal cyclic lipopeptides) produced by *Bacillus methylotrophicus* HC51 was detected and exhibited strong inhibition on growth of *G. boninense* (Pramudito *et al.*, 2018). This new fengycin was characterised with substitution of L-ornithine into lysine (Pramudito *et al.*, 2018). Potential of *Bacillus* sp. was further evaluated on the possibility of formulating into biofungicide (Puspita *et al.*, 2019). In this study, *Bacillus subtilis* was formulated into different biofungicide tablets to control *G. boninense* in oil palm nurseries (Puspita *et al.*, 2019). The best formulation established in this research contained spores of endophytic *Bacillus* sp., solid waste, talc and tapioca flour in which it successfully delayed the disease incubation period and reduced the disease intensity to 0% within 140 days. Substantial growth improvement was observed on seedlings compared to the control treatment (Puspita *et al.*, 2019).

Multiple Biocontrol Agents

Considerable number of research has been done to evaluate the antagonist efficacy of BCA against *G. boninense*. However, one of the problems associated with biocontrol is the lack of consistency in suppressing disease by application of a single BCA (O'Brien, 2017). Effectiveness of disease suppression of BCA is largely affected by environmental factors (Guetsky *et al.*, 2001). To enhance efficacy and consistency of BCA in suppressing *G. boninense*, several researches have been identifying efficacy of using multiple BCA in controlling BSR disease. This would allow various BCA to provide synergistic effects for disease suppression by adopting different modes of biocontrol mechanism and survive in broader range of environmental conditions (Chong *et al.*, 2017). However, selection of compatible BCA would be challenging. Combination of BCA must have synergistic relationship in complementing each other to enhance their feasibility on disease suppression as well as promoting plant growth.

A cocktail of *Trichoderma* spp. including *T. virens*, *T. asperellum* and *T. harzianum* were used by Musa *et al.* (2018) in evaluating the efficacy of antagonistic activity against *G. boninense* on oil palm seedlings. In the *in vivo* study, cocktail treatment exhibited disease reduction in infected seedlings at 83.03% on foliar symptoms and 89.16% on bole symptoms compared to other single treatments (Musa *et al.*, 2018).

Muniroh *et al.* (2019) studied proficiency of *P. aeruginosa* and *T. asperellum* as a mixture of BCA to suppress BSR disease in oil palm. Both microbes demonstrated synergistic relationship that led to a successful biocontrol attempt against *G. boninense* (Muniroh *et al.*, 2019). Nevertheless, both BCA have demonstrated positive phosphate solubilising activity and indole acetic (IAA) production. However, siderophore was only observed in *T. asperellum* in which all these traits could improve plant growth of the palms. Ability to excrete various cell wall degrading enzymes including chitinase, cellulase and β-1,3-glucanase were also detected; which could be responsible for the growth inhibition of *G. boninense* in both dual culture and culture filtrate studies.

Furthermore, the consortium of *Trichoderma* spp. and *Bacillus* spp. tested by Alexander *et al.* (2015) had induced the stripping of *G. boninense* hyphal structure by destroying the cellular structure and highly disrupted, disaggregated, shrivelled and lysis of *G. boninense* hyphal were observed under scanning electron microscopy (SEM). Production of cell wall degrading enzymes (CWDE) could be the factor associated on their antagonist activity in suppressing mycelia growth of *G. boninense* up to 70% (Alexander *et al.*, 2015).

According to Nusaibah *et al.* (2017), a nursery trial was performed to determine disease suppression efficacy on the mixture of *T. harzianum* and *Bacillus cereus*. The seedlings were inoculated with *G. boninense* with a novel disease inoculation technique namely dip, place and drench (DPD) (Nusaibah *et al.*, 2017) which differed from the existing method using Rubber Wood Blocks (RWB) (Idris *et al.*, 2006). The result had concluded that single application of *B. cereus* was found to be the most effective treatment in suppressing BSR disease. It had achieved the highest, 94.75% of disease reduction followed by single applications of *T. harzianum* (78.98%) and a mixture of both *T. harzianum* and *B. cereus* (68.49%). This validates the importance of *in vivo* trial to verify the efficacy on disease suppression achieved in *in vitro* test. Results achieved in *in vitro* test may be in contrary with the *in vivo* trial result (Nusaibah *et al.*, 2017). This is because microbes may behave differently in the natural environment compared to the controlled laboratory environment (Nusaibah *et al.*, 2017). Based on the reviewed studies above, it could be concluded that *Bacillus* spp. may perform better as a stand-alone application than as a consortium of BCA with other genera.

The Potential of Actinomycetes as Biocontrol Agent to Suppress Oil Palm Basal Stem Rot

Compared to endophytic fungi and bacteria, endophytic actinomycetes obtain much lesser attention on the biocontrol efficacy. Actinomycetes are a group of Gram-positive bacteria with fungal liked morphology due to their branched, filamentous or hyphae-type elongated cells (Singh *et al.*, 2018). It is widely known for the ability to produce a wide range of antibiotics including actinomycetin, micromonosporin, mycetin, actinomyces lysozyme, actinomycin, streptothricin, proactinomycin and streptomycin (Waksman *et al.*, 2010). Most of the actinomycetes are isolated from the genus *Streptomyces* (Kumari *et al.*, 2013). Actinomycetes are proven to have the ability to promote plant growth contributed by the secretion of siderophores and IAA (Gopalakrishnan *et al.*, 2014). Therefore, *Streptomyces* could be a potential biocontrol candidate towards various soil borne pathogens. A study has proven the biocontrol ability of a marine isolated *Streptomyces vinaceusdrappus* in controlling a root rot disease in tomatoes, caused by *Rhizoctonia solani* (Yandigeri *et al.*, 2015). Besides displaying superior disease reduction in tomatoes plants, treatment plants with respective *Streptomyces* also have shown significant growth performance advantage (Yandigeri *et al.*, 2015). Besides that, actinomycetes from *Streptomyces* spp. also demonstrated biocontrol efficacy against various soil borne disease caused by *Phytophthora cinnamomic* on avocado (You *et al.*, 1996). *Pythium aphanidermatum* on cucumber (El-Tarabily *et al.*, 2009) and *Fusarium oxysporum* f. sp. *ciceris* on chickpea (Amini *et al.*, 2016). However, not many reports on actinomycetes against BSR disease were documented.

The first report in screening potential of actinomycetes against *G. boninense* was documented by Tan *et al.* (2002). In their research, few *Streptomyces* spp. were found relatively more effective than *Micromonospora* spp. in controlling *G. boninense*. Another *in vitro* screening of actinomycetes from rhizosphere of oil palm was done by Shariffah-Muzaimah *et al.* (2015) where four isolates (AGA 043, AGA 048, AGA 347, AGA 506) were highlighted for their ability to inhibit *G. boninense*. A continuation study on these four isolates was performed and their efficacy of biocontrol against *G. boninense* in powder form after fermentation was tested in BSR disease infected oil palm seedlings (Shariffah-Muzaimah *et al.*, 2018). Isolate AGA347 was reported as the best formulation with 73.1% of disease reduction compared to other isolates (30.1%-54.8%). Isolate AGA347 was then identified as *Streptomyces hygroscopicus* subspecies *hygroscopicus* (Shariffah-Muzaimah *et al.*, 2018).

In vitro antagonistic efficacy of *Streptomyces sanglieri* was reported by Nur Azura *et al.* (2016) in suppressing *G. boninense*. The antifungal compounds identified from *S. sanglieri* were cycloheximide and actiphenol (Nur Azura *et al.*, 2016). To further study colonisation and potential as a BCA in the oil palm roots, *S. sanglieri* strain was inoculated into pre-germinated oil palm seeds and observed for six months period. Results showed that *S. sanglieri* could enhance the plant growth performance including root development, plant height, root length, number of secondary roots and wet weight (Nur Azura *et al.*, 2016). Colonisation of this strain in root area of oil palm seedlings was studied by re-isolating from the root segments one- and six-month after inoculation and observed under SEM. *Streptomyces sanglieri* was found to grow on the root epidermal surface after one-month inoculation and later penetrating the epidermal cell junctions after six-month of inoculation. Both *in vitro* and *in vivo* results had recommended *S. sanglieri* as a potential BCA towards BSR disease control (Nur Azura *et al.*, 2016).

In Sabah, a total of 20 soil samples collected from Crocker Range forest was used to isolate potential actinomycetes which have biocontrol ability towards to *G. boninense* (Lim *et al.*, 2019). Out of 72 types of actinomycetes isolates, A19 was reported to have the highest PIRG value with 80% and causing hyphae damage on *G. boninense* under SEM. Besides that, ethyl acetate extract of *Steptomyces* spp. A19 recorded a minimum inhibitory concentration (MIC) at 0.18 mg ml^{-1}. Several anti-fungal compounds were also detected via LC-MS including ribostamycin, benzylmatic acid, landomycin B and salinomycin which may contribute to suppress BSR disease in oil palm (Lim *et al*., 2019).

CONCLUSION

Efficacy of fungi, bacteria and actinomycetes as potential BCA in suppressing oil palm BSR disease were proven and documented in many studies. Most of these studies only performed the *in vitro* assessment and a few reported on the *in vivo* studies in the greenhouse. However, field trial was lacking, it is crucial to assess efficiency of these BCA in the field environment as BCA may behave differently in the field environment compared to agar plate or controlled environment (greenhouse trial). The interaction of BCA with the complexity of abiotic and biotic factors in the field may affect their efficacy as potent BCA in the controlled environment. In addition, assessment on carrier material for BCA is vital to be studied as there is potential of commercialisation of BCA into bio-fertiliser or bio-fungicide. Exploration of other potential microorganisms is also desirable in expanding the insight of potential BCA in controlling BSR disease. Little concern was placed on the *Streptomycetes* and more study should be attempted in evaluating their efficacy either as single application or as a consortium with different genera for greater disease suppression through adoption of altered mechanisms. A strict and reliable control measure is necessary to eradicate and prevent further spreading of the disease. The urge to explore natural controlling mechanism will not only be beneficial as it is also sustainable and could be a reliable substitute to synthetic chemical fungicides.

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