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Development of Biocontrol Agents to Manage Major Diseases of Tropical Plantation Forests in Indonesia: A Review [†]

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Abstract: In 2018 the area of plantation forests in Indonesia reached 8,668,670 ha. Pests and diseases have been considered as critical factors in sustainable production of plantation forests in the humid tropic areas. With the introduction of new plant species such as fast-growing plants of acacias and eucalypts, new pests and diseases have become emerging threats. Several pathogenic fungi and bacteria have been recorded in plantation forests in Indonesia since their early establishment. The fungal species associated with the most common diseases include *Ceratocystis manginecans* (Ceratocystis wilt and dieback), *Ganoderma philippii* (red root rot), *Phellinus noxius* (brown root rot and heart rot) and *Fusarium* spp. (Fusarium wilt), whereas the major bacterial pathogens are *Ralstonia* spp. (bacterial wilt) and *Xanthomonas* spp. (leaf streak). As one key component of integrated pest management, biocontrol measure plays significant roles in managing major diseases of tropical plantation forests in Indonesia. A number of forestry companies have put development of biocontrol agents as one of their priority research programs. For this scenario, antagonists have been collected and isolated from different ecosystems. This paper reviews development of biocontrol agents to manage major diseases of tropical plantation forests in Indonesia.

Keywords: *Acacia*; *Cerrena*; *Eucalyptus*; *Ganoderma*; *Gliocladium*; *Phellinus*; *Phlebiopsis*; *Ralstonia*; *Trichoderma*.

1. Introduction

The official Government publication [1] reported that in 2018 the area of plantation forests in Indonesia reached 8,668,670 ha with ca. 94% of them being scattered in the Sumatera and Kalimantan islands. In that same year, the Forestry Sector contributed USD 12,17 billion to the country's income [2]. Pests and diseases have been considered as critical factors in sustainable production of plantation forests in the humid tropic areas. With the introduction of new plant species such as fast-growing plants of acacias and eucalypts, new pests and diseases have become emerging threats. Several pathogenic fungi and bacteria have been recorded in plantation forests in Indonesia since their early establishment. The fungal species associated with the most common diseases include *Ceratocystis manginecans* (Ceratocystis wilt and dieback), *Ganoderma philippii* (red root rot), *Phellinus noxius* (*Pyrrhoderma* sp.) (brown root rot and heart rot) and *Fusarium* spp. (Fusarium wilt), whereas the major bacterial pathogens are *Ralstonia* spp. (bacterial wilt) and *Xanthomonas* spp. (leaf streak) [3,4]. As one key component of integrated pest management, biocontrol measure plays significant roles in managing major diseases of tropical plantation forests in Indonesia. Several forestry companies have put development of biocontrol agents as one of their priority research programs. For this scenario, antagonists have been collected and isolated from different ecosystems. This paper briefly reviews

development of biocontrol agents to manage major diseases of tropical plantation forests in Indonesia, focusing on root rot diseases.

Red root rot caused mainly by *G. philippii* [5–8] was once considered as the most important disease of acacias, particularly *A. mangium* [9–12]. Losses due to the disease were estimated to be as high as 40% in 9 – 14-year-old *A. mangium* plantations (Table 1). Although occurred in lower frequencies, the disease is also found on different species of eucalypts [5,13,14]. The level of damage and incidence of this disease required development of effective management to secure sustainable production of forest plantations [15,16]. Incorporation of resistant genotypes [17,18] and use of biocontrol agents of microbial consortiums [19–21] are economically and environmentally feasible control measures to minimize the losses due to the disease. The biocontrol agents developed so far to manage root rot pathogens include *Trichoderma*, *Gliocladium*, *Cerrena*, *Phlebiopsis*, and some other white rot fungal species.

Table 1. Losses due to *Ganoderma philippii* in *Acacia mangium* plantations of different ages

Location	Age (years)	Losses (%)	Reference
Indonesia	3-5 (2 nd rotation)	3-28	Irianto et al. [22]
Malaysia	14	up to 40	Lee [10]
The Philippines	6-10	10-25	Militante and Manalo [23]
India	9-14	~40	Mehrotra et al. [24]

2. *Trichoderma* and *Gliocladium*

Trichoderma and *Gliocladium* are fast growing saprophytic fungi found in varying habitats. The fungi have high degree of ecological adaptability and frequently are the most prevalent culturable fungi in soil. In addition to colonizing plant roots, the fungi attack and parasitize other fungal species. Antibiosis, competition for nutrients or space, induced resistance and inactivation of the pathogen’s enzymes are some other recognized mechanisms used by the antagonists to suppress other fungal species including the pathogenic ones. For these reasons, *Trichoderma* and *Gliocladium* have so far been some of the most common fungi used as biocontrol agents to manage several plant diseases. Table 2 lists different species and/or isolates of the fungi developed to manage root rot diseases.

Table 2. Some *Trichoderma* and *Gliocladium* species developed to manage root rot pathogens

Root Rot Pathogen	Biocontrol Agent	Reference
<i>Ganoderma lucidum</i>	<i>Trichoderma harzianum</i>	Bhaskaran [25]
<i>Ganoderma boninense</i>	<i>Trichoderma harzianum</i> <i>Trichoderma</i> spp. <i>Gliocladium viride</i>	Dharmaputra et al. [26] Soepena et al. [27] Susanto et al. [28]
<i>Ganoderma</i> spp.	<i>Trichoderma</i> spp.	Widyastuti [29]
<i>Phellinus weirii</i>	<i>Trichoderma viride</i>	Nelson et al. [30]
<i>Armillaria</i> sp.	<i>Trichoderma polysporum</i> , <i>harzianum</i> <i>Trichoderma</i> sp. <i>Trichoderma harzianum</i> , <i>T. viride</i> , <i>T. hamatum</i>	Berglund and Ronnberg [31] Hagle and Shaw [32] Raziq and Fox [33]

A number of free-living isolates collected from different origins and localities have been screened in vitro for their efficacy against root rot pathogens such as *Ganoderma* or *Phellinus*. Some of

the collections are able to overgrow the pathogens (Figure 1). One problem with the free-living isolates, however, is their consistency in the field. Isolates with excellent inhibitory effects in laboratory tests may not be a good performer in the field. In addition, one particular isolate which is effective in certain environmental conditions is not necessarily equally good in other conditions. To illustrate, two trials were established in two different locations in the Province of Riau, Sumatera, i.e., sites A and B. Results of the trials showed that *Trichoderma* isolated from site A performed best by reducing *Ganoderma* incidence by 7.0% in site A. Similarly, *Gliocladium* isolated from site B was the most effective in site B, decreasing *Ganoderma* incidence by 10.0% [19,20].



Figure 1. *Ganoderma* (G) in pure culture (left) and *Trichoderma* (T) is overgrowing *Ganoderma* in dual culture (right) [19,20].

Endophytic *Trichoderma*, on the other hand, is considered more stable and have a wider plasticity. Endophytes share intimate symbiotic association with the plant hosts. They enter the host systems without triggering vulnerability to pathogen. Compared to free-living (rhizospheric) counterparts, endophytic antagonists are also better protected against abiotic stress and competing microbes. In addition, they are able to enhance both plant health and plant vigor and persist in the root through the rotation [34], providing hope for more effective disease management. Research focus then shifted more to endophytic *Trichoderma*. In this scenario we also isolated a great number of putative endophytic isolates (Figure 2) from different ecosystems and localities in Riau [21]. Out of more than 200 putative endophytic *Trichoderma* isolated and subsequently screened, some were able to reduce significantly incidence of red root rot disease on *Acacia mangium* seedlings in the nursery screening (Figure 3).

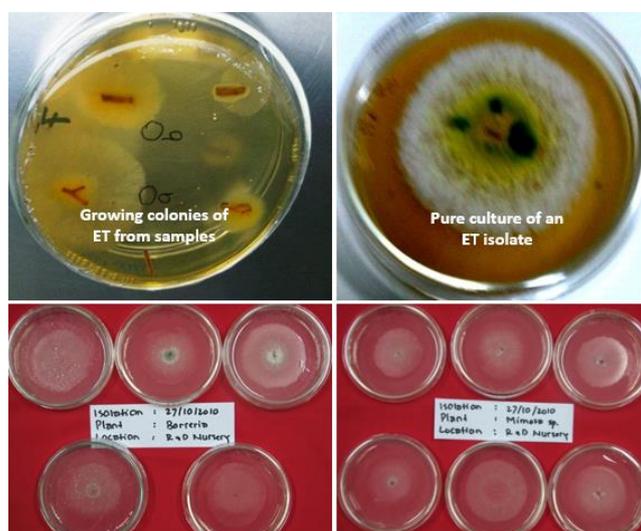


Figure 2. Isolation of putative endophytic *Trichoderma* [21].

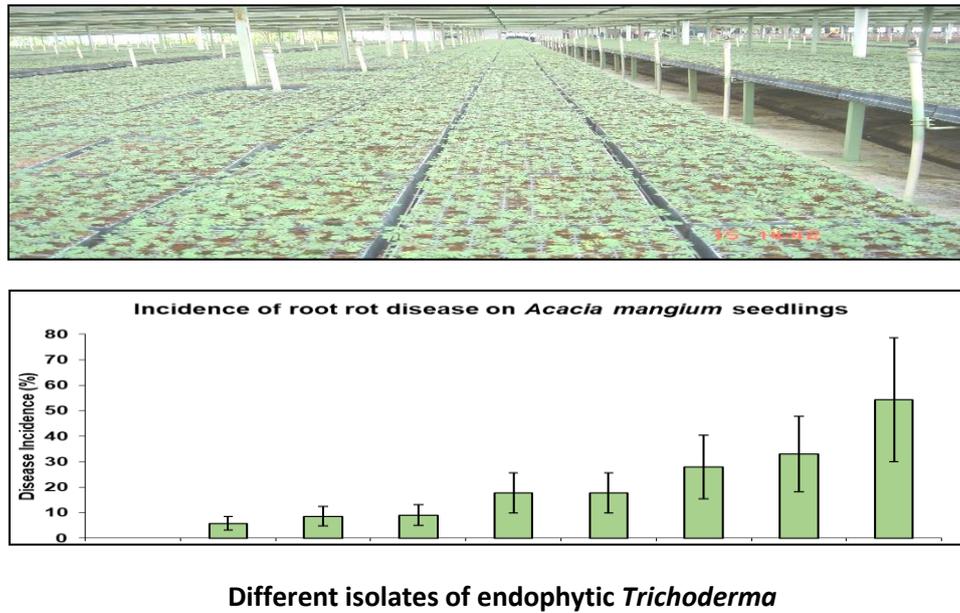


Figure 3. Nursery screening of endophytic isolates of *Trichoderma* (top). Some isolates of endophytic *Trichoderma* were able to reduce incidence of red root rot disease on *Acacia mangium* seedlings (bottom) [21].

3. White Rot Fungi

Other biological control agents commonly used to control root rot diseases are non- or weak pathogenic white fungi. These fungi could break down wood debris faster than the pathogen, occupy the same resource as the pathogen, compete for nutrients, produce inhibitory secondary metabolites, and are able to mycoparasitize the pathogen [35,36]. The commercially available *Phlebiopsis gigantea* is widely used in northern hemisphere to control root rot pathogen *Heterobasidion annosum*. Despite this, white rot fungi had not been adequately explored in Indonesia until recently as biological control agents that can compete with *G. philippii* or *P. noxius* for wood resources. *Phlebiopsis* and *Cerrena*, another biocontrol agent, inhibit mycelial growth of the root-rot pathogens *G. philippii* and *P. noxius*. Both species compete the root rot pathogens for space and nutrients. Previous in vitro tests have demonstrated their antagonism against the pathogens. We also explored methods of applying the antagonists to effectively control red root disease in plantations [37,38]. They were inoculated onto stumps to prevent infections and colonization by pathogens (Figure 4).



Figure 4. Stump inoculation of *Phlebiopsis* spp. and *Cerrena* spp. to prevent infection and colonization by *Ganoderma philippii* or *Phellinus noxius* [37,38].

In addition to *Phlebiopsis* and *Cerrena* [37,38], we collected 107 samples of other white-rot fungi from forestry plantations in Riau Province to investigate their potentials as biological control agents of root rot diseases. As reported earlier, the fungi were isolated from rotten woods including trunks and twigs, and fruiting bodies [39]. Out of the 107 samples collected, 28 from rotten woods and 51 from fruiting bodies were successfully isolated. Screenings of the isolated fungi were carried out on wood block, wood disc, and malt extract agar containing wood-powder. Results of the three-step screenings (Figure 5) indicate that two isolates, WFA033 and WFA068, have potentials as biological control agents against the red root rot pathogen, *G. philippii*.



Figure 5. Dual culture of WFA033 (left) and WFA068 (right) isolates and *Ganoderma philippii* on wood disc (top) and on MEA-WP (bottom) media. The white rot fungi overgrow and inhibit the growth of *G. philippii* [39].

4. Endophytic Bacteria

Bacterial wilt disease (BWD) has recently emerged as an economically important disease of tropical plantation forests in Indonesia, especially on *Eucalyptus* stands [40–42]. The causal agents, *R. solanacearum* and *R. pseudosolanacearum*, have a broad range of host plants including 450 species of over 50 families. The pathogens usually invade the host through root injuries, crosses the root cortex and overruns the xylem vessels leading to sudden wilting and plant death. Controls had so far been limited to crop rotation, intercropping (agriculture), use of resistant materials. Use of antagonists, fungal or bacterial with endophytic or rhizospheric nature isolated from the same crop or unrelated crops should also be considered as a crucial component of BWD integrated management. For this, a consortium of endophytic bacteria was developed to manage BWD on *Eucalypts* seedlings in Riau Province. The microbes demonstrated ability to suppress *R. solanacearum* in artificial media. The product remains effective after several years; it reduces disease risk and prolongs incubation period.

5. Conclusions

Pests and diseases are likely to continuously challenge plantation forests in Indonesia. However, there are also opportunities to manage them. As one key component of integrated disease management, biocontrol agents provide a significant contribution to the effort. Future research on antagonistic microbes should focus more on isolation of locally more adapted and stable isolates of microbial consortiums to increase their efficacy. Introduction of endophytic microbes into the scenario should be encouraged.

Conflicts of Interest: The author declares no conflict of interest.

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