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Damaging Insect Pests and Diseases and Their Threats to Agarwood Tree Plantations

(Serangga Perosak dan Penyakit Berbahaya serta Ancamannya terhadap Perladangan Pokok Gaharu)

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ABSTRACT

The cultivation of agarwood tree species such as Aquilaria *has grown dramatically during the last ten years. This development is driven by the desire to produce sustainable agarwood to meet the high market demand. In the past, the main source of agarwood had been from natural forests, which resources are now declining. Although there are various examples of pests and diseases affecting early plantations, these damages were often overlooked. Recently, the emergence of new pests and diseases in large-scale* Aquilaria *tree plantations has raised concerns among planters and researchers, as the damage level to the trees may vary from unsubstantial to tree mortality. Lack of information on the types of pests and diseases in* Aquilaria *plantations makes it difficult to properly manage these threats, leading to economic losses. This review summarizes the insect pests and diseases known to damage cultivated agarwood trees in various countries including China, India, Indonesia, and Malaysia. As we learn from the cultivation practices of other monoculture crops, these insect pests and pathogens are a major challenge to the healthy growth of agarwood trees. The implementation of an integrated pest and disease management at an early stage of plantation establishment may hold the key to help control and contain these threats from turning into major outbreaks.*

Keywords: Aquilaria*; good agriculture practice;* Gyrinops*; pest and disease management; Thymelaeaceae*

ABSTRAK

Penanaman pokok spesies gaharu seperti Aquilaria *telah berkembang secara intensif sejak sepuluh tahun yang lepas. Perkembangan ini didorong oleh keinginan menghasilkan gaharu secara mampan bagi memenuhi permintaan pasaran yang tinggi. Pada suatu ketika dahulu, sumber utama kayu gaharu adalah dari hutan semula jadi, walau bagaimanapun, sumbernya kini telah merosot. Walaupun pada awalnya terdapat pelbagai contoh perosak dan penyakit yang menjejaskan perladangan telah diperhatikan, namun kesannya sering diabaikan. Kebelakangan ini, kemunculan perosak dan penyakit baharu di dirian* Aquilaria *berskala besar telah menimbulkan kebimbangan dalam kalangan penanam dan penyelidik, memandangkan tahap kerosakan pada pokok ini mungkin berbeza; bermula dengan ketidakstabilan sehingga mampu menyebabkan kematian. Kekurangan maklumat terhadap jenis perosak dan penyakit di ladang* Aquilaria *telah menyukarkan proses pengurusan lalu mengakibatkan kerugian daripada segi ekonomi. Ulasan ini merangkumi serangga perosak dan penyakit yang terbabit dalam kerosakan pokok gaharu yang ditanam di beberapa negara termasuk China, India, Indonesia dan Malaysia. Seperti yang kita pelajari daripada amalan penanaman monokultur yang lain, perosak serangga dan patogen merupakan cabaran besar bagi tumbesaran pokok gaharu yang sihat. Pelaksanaan pengurusan perosak dan penyakit bersepadu pada peringkat awal penubuhan perladangan merupakan kunci bagi pengawalan dan sekatan kepada ancaman daripada terjadinya wabak.*

Kata kunci: Amalan pertanian baik; Aquilaria*;* Gyrinops*; pengurusan perosak dan penyakit; Thymelaeaceae*

INTRODUCTION

Plantations that grow agarwood tree species from the genera *Aquilaria* and *Gyrinops* (Thymelaeaceae) are currently forming in many parts of Asia due to the promising market prospects. Traditionally, agarwood is harvested from wild trees, a practice which is no longer viable due to the slow and laborious process of sourcing, further made worse by the depleting wild resources. Most importantly, the practice is a threat to the survival of the species (Barden et al. 2000). To achieve sustainable supply, entrepreneurs and farmers have started cultivating agarwood tree species in large plantations as monocultures or integrated cultures with other tree crops such as *Tectona grandis*, *Gmelina arborea*, *Paraserianthes falcataria*, and *Eucalyptus* sp. (Gogoi 2015; Nakashima et al. 2005; Saikia & Khan 2012).

Commercial agarwood tree planting came to light in the 1980s, when 18,000 hectares of *Aquilaria crassna* was planted in Vietnam (Tran et al. 2003). The number of plantations has since grown substantially over the years in several countries in Asia. China has had *Aquilaria* plantations for the past ten years. In 2011, more than 20 million trees were recorded (Liu et al. 2013), making China the country with the highest number of *Aquilaria* trees.

India has half the number of trees in China, followed by Indonesia (ITTO-CITES 2015). Other countries such as Bangladesh, Bhutan, Cambodia, Laos, Malaysia, and Myanmar have about 1-2 million planted agarwood trees (ITTO-CITES 2015). Agarwood cultivation has become such an attractive industry that it was introduced out of its native geographical region into countries such as Australia in 2010 (López-Sampson et al. 2017). The more commonly planted species in these countries are *A. crassna*, *Aquilaria malaccensis*, and *Aquilaria sinensis*, while endemic species like *Aquilaria baillonii and Aquilaria rugosa*, as well as *Aquilaria filaria* and *Gyrinops verstegii* can be found planted in their native ranges in Vietnam and Indonesia, respectively.

The prospect of agarwood tree cultivation seems promising, but planters have to tend to their trees for a long time until the trees reach an age suitable for induction, a treatment to stimulate agarwood production, normally when they are five to seven years old. The major challenges for agarwood cultivation are threats from insect pests and diseases. Based on our experience with local agarwood planters, these are often overlooked due to the lack of information, as well as the assumption that forest plantations need less attention and could be left to grow with minimal management. Pest and disease outbreaks can incur huge losses to plantation owners, and with the increase in international trade, the spread of pests and diseases could become more imminent with time.

Unhealthy or stressed trees, due to improper planting conditions such as waterlogged soils and overcrowding of seedlings in the nursery, are more likely to be susceptible to attacks by pests and diseases (Lee 2011). In recent years, some pests and diseases that were not known to be a threat to wild agarwood trees are now causing substantial damages on young planted trees. The very first report of a fatal disease, the root rot disease caused by *Phytophthora parasitica*, was published 20 years ago from an observation at an agarwood plantation in Assam, India (Das & Dubey 2000). Since then, the number of new reports on pests and diseases of cultivated *Aquilaria* trees continues to rise. Various insects and microbes are known to be associated with agarwood trees but only a handful are regarded as pests, especially on seedlings and young plants (Lee & Mohd Farid 2010). In fact, in nature, agarwood formation relies very much on the interaction between the trees and the associated insects and microbes. The induction of agarwood formation in tree stems is often related to fungal infection, which triggers the tree's defense system to produce agarwood resin (Rasool & Mohamed 2016). So far, a wide variety of fungal species have been associated with agarwood formation (Mohamed et al. 2010; Premalatha & Kalra 2013), most of which are endophytic fungi that coexist naturally with the trees and do not pose any major threats (Turjaman et al. 2016).

In agricultural practices, an insect or a microbe can be regarded as a pest or agent of disease, if it disturbs the growth performance or causes abnormalities to the trees. Some may even cause mortality especially in young trees. Here, we compiled various observations on the incidence and symptoms of pests and diseases affecting agarwood trees cultivated in the nurseries, home gardens, and plantations, in major agarwood producing countries. This compilation is based on published scientific articles (online and printed), conference proceedings, books and personal observations since the 21st century (year 2000 and onwards). Collectively, we discussed on the common dilemmas and major issues faced by plantation owners, and reported on proposed agarwood plantation management strategies. This work shall serve as a reference for agarwood farmers and plantation owners to identify and manage these threats.

OVERVIEW OF THE INSECT PESTS OF AGARWOOD TREE SPECIES

To date, a total of 19 insect pest species, derived from 16 different families of five different orders, have been recorded (Table 1). The majority of the insect pests (nine out of 19) are sap-suckers from the order Hemiptera, followed by leaf defoliators and wood borers from the order Coleoptera and Lepidoptera (four out of 19, respectively); and one leaf defoliator and one sapsucker from order Orthoptera and Heteroptera, respectively. Many of these pests are reportedly found in Malaysia and Indonesia. However, some are region-specific, such as *Archernius tropicalis*, *Anomala* sp. and *Nadezhdiella* sp. in China, as well as *Heortia vitessoides*, *Neurozerra conferta* found infesting plantations in Australia and India. In terms of damage level, the leaf defoliator *H. vitessoides* inflicts major damage at the plantation level; while four other species, namely *N. conferta* (wood borer), Aleyrodidae (whiteflies), *Unaspis* sp. (scale insect) and *Pseudococcus* sp. (mealy bug), impose moderate levels of damage. Other insects are categorized as minor damaging pests. It is worth mentioning that whiteflies and scale insects are present in nurseries, which heavy infestation will cause the saplings to be less vigorous, to the extent that it can cause mortality to young plants.

OVERVIEW OF THE DISEASES OF AGARWOOD TREE SPECIES

To date, a total of six categories of plant disease, consist of 12 different diseases were recorded (Table 2). While most diseases are derived from a single causal pathogen; two are caused by more than one causal pathogen, namely the damping-off disease (six causal pathogens) and the root-knot nematode disease (three causal pathogens). These diseases were reportedly found in China, India and Malaysia. Most diseases are minor; while three imposed moderate level of damage: *Phytophthora* root rot (root colonizing that eventually causes tissue destruction when necrotrophic), white rot disease (interrupting nutrient uptake by spreading from roots to collar region with no age preference) and root-knot nematode (killing trees without age preference, including seedlings in polybags). The die-back disease was the only disease imposing major

TABLE 1. Insect pests recorded in agarwood plantations in major agarwood-producing countries, since year 2000

Type of pest	Pest species	Damages level	Signs and symptoms	Tree species	Tree stage	Countries reported	Management practice(s)	References
Wood borers	*Neurozerra conferta* (synonym *Zeuzera conferta*) (Lepidoptera: Cossidae)	Moderate (kills young plants during severe infestation, as the hollowed trunks are vulnerable to breakage during storms)	Poor and stunted crown development, swelling or depression and cankers on the bole, and appearance of dieback symptoms or decay at the top branches As the larva tunnels into the wood, frass is pushed out of the bore hole (Figure 1(a)) and accumulates on the ground (Figure 1(b)).	*Aquilaria malaccensis* *Aquilaria sinensis* *Gyrinops* spp.	In field	China India Indonesia Malaysia	Trimming and removal of infected branches Application of liquid-based pesticides into the tunnels and shut off the entrance with plasticine. Granule systemic-based pesticides	Nath and Saikia 2002; Sitepu et al. 2010; Yan et al. 2010; Mohd Farid et al. 2015
	Nadezhdiella sp. (Coleoptera: Cerambycidae. long-horned beetle)	Minor	Wilted leaves, weakened stem or branches that break easily during strong wind, and branch dieback, especially on young trees	*A. sinensis*	In field	China	Setting up insect light traps manual removal of eggs during surveys and adults at dawn Biological control using parasitic wasps *Xylophrurus coreensis* and *Sclerodermus harmandi*	Liu 2005; Yan et al. 2010
Leaf defoliators	*Heortia vitessoides* (Lepidoptera: Crambidae)	Major (feeds on young shoots and stems (Figure 2(a)), thus disturbing growth of tree. At least 30% of the trees in a plantation can be infested, and possible of spreading if untreated)	Appearance of brown, wilted leaves, coupled with a mixture of frass and silk web (Figure 2(b))	*A. malaccensis* *Aquilaria microcarpa* *Aquilaria crassna* *A. sinensis* *Gyrinops* spp.	In field	Australia China India Indonesia Malaysia	Organic pesticides using plant extracts from *Capsicum annum*, *Allium sativum* and *A. cepa*. Biological control using entomopathogenic bacteria, *Bacillus thuringiensis*. Biological control using entomopathogenic fungus, *Beauveria bassiana* and *Metarhizium anisopliae*. Organic pesticide using fruit extract from ripe or dried *Brucea javanica*. Organic pesticide using seed extract from neem and soursop. Overturning and burning of top soil during cold season. Biological control using natural predators, *Sycanus dichotomus*, *Oecophylla smaragdina* and *Polistes* spp. Biological insectides using 3000 times 0.5% emamectin benzoate and 1000 times 5% azadirachtin Commercial chemical-based insectides Mix-planting between *Azadirachta indica*	Kalita et al. 2001; Liu 2005, Yan et al. 2010; Hariri 2012; Irianto 2012; Lestari and Suryanto 2012a; Rahayu and Maharani 2012; Lestari et al. 2013; Sajap 2013; Lestari and Dariwati 2014; Lu et al. 2014; Saikia and Shrivastava 2015; Raja Rishi et al. 2016

Continue TABLE 1.

Type of pest	Pest species	Damages level	Signs and symptoms	Tree species	Tree stage	Countries reported	Management practice(s)	References
	Pitama hermesalis (Lepidoptera: Crambidae)	Minor (less aggressive, with a single report that caused 25% damage to leaf area, and covered 52% of the total plantation area in Indonesia; while also recorded boring and feeding inside the fruit of *A. malaccensis*)	The larva has a habit of attaching two pieces of leaves with silk web and scraping off the green area on the leaves, making the consumed section translucent	*A. malaccensis*	In field	Malaysia Indonesia	n/a	Lestari and Suryanto 2012b; Mohd Farid et al. 2015; Ong & Lau 2016
	Archernius tropicalis (Lepidotera: Pyralidae, gardenia leaf borer)	Minor (long pupal stage allows continuous attack throughout the year)	Rolled-over fresh leaves that can be visible on branches	*A. sinensis*	In field	China	Black light trap Pesticides	Liu 2005; Xiao et al. 2006; Yan et al. 2010
Minor leaf defoliators	*Anomala* sp. (Coleoptera: Scarabaeidae, scarab beetle)	Minor (feed voraciously on young shoots, stems, and flowers as part of their diet, which could affect the growth and development of the trees)	n/a	*A. sinensis*	In field	China	Light trap Chemical sprays	Liu 2005; Yan et al. 2010; Sulistio et al. 2014
	Phaedonia inclusa (Coleoptera: Chrysomelidae, soybean leaf beetle)	Minor (causing damage to 4% of plants in the plantation)	irregular chewing marks	*Aquilaria* sp.	In field	Indonesia	n/a	Sulistio et al. 2014
	Hypomeces squamosus (Coleoptera: Curculionidae, gold dust weevil)	Minor	irregular chewing marks	*Aquilaria* sp.	In field	Indonesia	n/a	Sulistio et al. 2014
	Valanga nigricornis (Orthoptera: Acrididae, short-horned grasshopper)	Minor	irregular chewing marks	*Aquilaria* sp.	In field	Indonesia	n/a	Sulistio et al. 2014
Sap suckers	*Aleyrodidae* (Hemiptera, whiteflies)	Moderate (heavy infestation could make the plant less vigorous, and even cause mortality to young plants)	White fluffy spots beneath the leaf surface and presence of sooty mold fungus	*Aquilaria* sp.	In field In nursery	Malaysia	Yellow sticky trap Oil emulsion spray consists of 1:1 of 500 mL soap water and oil, further dilution of one tablespoon with 1000 mL water Manual leaf removal on infected region Water spray to remove insect Planting of other flowering trees to attract natural enemies Liquid or granule systemic-based pesticides	Mohd Farid et al. 2015

Continue TABLE 1.

Type of pest	Pest species	Damages level	Signs and symptoms	Tree species	Tree stage	Countries reported	Management practice(s)	References
	Unaspis sp. (Hemiptera: Diaspididae, scale insect)	Moderate (heavy infestation could make the plant less vigorous, and even cause mortality to young plants)	wilting of leaves, followed by the gradual death of the plant	*Aquilaria* sp.	In nursery	Malaysia	Chemical spray using diluted malathion Yellow sticky trap Oil emulsion spray consists of 1:1 of 500 mL soap water and oil, further dilution of one tablespoon with 1000 mL water High pressure water spray Planting of other flowering trees to attract natural enemies Liquid or granule systemic-based pesticides	Mohd Farid et al. 2015; Lee S.Y., personal observation
	Pseudococcus sp. (Hemiptera: Pseudococcidae, mealy bug)	Moderate (Reported destroying the root tip and tree base, and attacks 1-year-old trees in field)	wilting of leaves, followed by the gradual death of the plant	*Aquilaria* sp.	In field	Malaysia Indonesia	n/a	Mohd Farid et al. 2015; Handika et al. 2016
	Anasa tristis (Hemiptera: Coreidae, squash bug)	Minor (Causing about 1-2% damage)		*Aquilaria* sp.	In field	Indonesia	n/a	Sulistio et al. 2014
	Leptocorisa oratorius (Hemiptera: Alydidae, rice bug)	Minor (Causing about 1-2% damage)	curled, deformed, and discolored leaves, which affect plant growth	*Aquilaria* sp.	In field	Indonesia	n/a	Sulistio et al. 2014
	Leptocorisa sp.(Hemiptera: Alydidae, berrysoap bug)	Minor	curled, deformed, and discolored leaves, which affect plant growth	*Aquilaria* sp.	In field	Malaysia	Use of chemical pesticides on young leaves and shoots	Mohd Farid et al. 2015; Lee S.Y., personal observation
	Helopeltis sp (Hemiptera: Miridae, mosquito bug)	Minor	curled, deformed, and discolored leaves, which affect plant growth	*Aquilaria* sp.	In field	Malaysia	n/a	Lee and Mohd Farid 2010; Sajap 2010; Ong et al. 2014
	Dysdercus sp. (Heteroptera: Phyrrhocoridae, cotton stainer bug)	Minor	curled, deformed, and discolored leaves, which affect plant growth	*Aquilaria* sp.	In field	Malaysia	n/a	Lee and Mohd Farid 2010; Sajap 2010; Ong et al. 2014
	Membracidae (Hemiptera, thornbug)	Minor		*Aquilaria* sp.	In field	Malaysia	n/a	Lee and Mohd Farid 2010; Sajap 2010; Ong et al. 2014
	Flatidae (Hemiptera: planthopper)	Minor		*Aquilaria* sp.	In field	Malaysia	n/a	Lee and Mohd Farid 2010; Sajap 2010; Ong et al. 2014

TABLE 2. Plant diseases and their causal agents in agarwood plantations in major agarwood-producing countries, since year 2000

Type of disease	Disease name	Causal pathogen (Phylum: Order)	Damage level	Tree species	Signs and Symptoms	Tree stage	Countries reported	Management practice	References
Leaf spot disease	*Phyllosticta* leaf spot	*Phyllosticta capialensis* (Ascomycota: Botryospaeriales)	Minor	*A. sinensis*		In field	China	n/a	Chen 2007
	Brown spot	unknown	Minor	*A. sinensis*		In field	China	n/a	Chen 2007
	Colletotrichum leaf spot	*Colletotrichum gloeosporiodes* (Ascomycota: Glomerellales)	Minor	*A. malaccensis* *A. sinensis*	irregular light brown spots comprising dead tissues can be found along the veins of the infected leaves, giving a sun-scorched impression Sunken cankers can be also seen on the infected branches and twigs	In field	China Malaysia	n/a	Chen 2007; Ong et al. 2014
	Corynespora leaf spot	*Corynespora cassicola* (Ascomycota: Pleosporales)	Minor	*A. malaccensis*	Spindle-shaped spots with yellow halo and pin-head reddish brown dots at the center can be seen on the infected leaf, and enlarges over time.	In field	India	n/a	Borah et al. 2012
	Algal leaf spot	*Cephaleuros* sp. (Chlorophyta: Trentepohliales)	Minor	*A. malaccensis*	greyish, green, brown or orange cushion-like blotches, which may appear crusty or flaky Leaf tissue beneath the spots is usually dead	In field	Malaysia	n/a	Ong et al. 2014
	Sooty mold	unknown	Minor (affects the photosynthetic ability of the infected leaves if left untreated)	*Aquilaria* sp.	Black spots that do not penetrate into the leaf and can be easily rubbed off	In field In nursery	Malaysia	n/a	Ong et al. 2014
Root rot disease	*Phytophthora* root rot	*Phytophthora parasitica* (Oomycota: Peronosporales)	Moderate (hemibiotrophic; it initially starts off as a biotroph colonizing the root region, and then switches to become necrotrophic to cause tissue destruction and eventually root decay)	*A. malaccensis*	leaf wilting and premature drop-off	In field	India	n/a	Das and Dubey 2000

Continue TABLE 2.

Damping-off disease	Damping-off disease	*Botrytis* spp. (Ascomycota: Helotials), *Cylindrocladium* spp. (Ascomycota: Hypocreales), *Fusarium* spp. (Ascomycota: Hypocreales), *Pythium* spp. (Oomycota: Peronosporales), *Phytophtora* spp. (Oomycota: Peronosporales), *Rhizoctonia solani* (Basidiomycota: Cantharellales)	Minor (Premature death of young seedlings)	*A. malaccensis* *A. sinensis*	Poor seedling emergence with post-emergence, water-soaked stems, felled-over young plants leading to irregular, spreading patches of dead and dying plants Young shoots and leaves show irregular stain-like patches followed by leaf decay Rotting and dying root tips, visible spots along the stem, with sunken cankers Browning or rotting of non-germinated seeds, which the stem of the seedling shrinks, rots near the stem collar, resulting to plant collapse	In nursery	China India Malaysia	Biocontrol using arbuscular mycorrhizal fungus *Glomus fasciculatum* to control *Pythium*'s attack. Prevention through use of pathogen-free seeds, media and water. Raising pots one meter above ground Use of fungicide containing thiabendazole, captan, benomyl, and thiram	Li and Chen 2008; Tabin et al. 2009; Lee 2011
Pink disease	Pink disease	*Erythricium salmonicolor* (Basidiomycota: Corticiales)	Minor (affects less than 10 % of the 80 ha two-and-a-half-year-old plantation with no mortality)	*Aquilaria* sp.	White mycelia grow rapidly on the stem surface, followed by canker formation under infected bark. Formation of pink pustules. Epicormic shorts growing below the cankers. Wilting foliage on the infected stem, stem dieback, and breakage of the branches due to high wind	In field	Malaysia	Remove infected stems and braches Use of fungicide such as Bordeaux mixture or tridemorph	Lee 2011
Die-back disease	Die-back disease	*Lasiodiplodia theobromae* (Ascomycota: Botryosphaeriales)	Major (fatal, killing more than 30% of the trees in a plantation)	*A. sinensis*	Wilting trees with leaves attached on twigs and branches. Visible brownish to grey stain-like round spots occurring at lower part of the trunk, expands over time, then causes sunken stem surfaces, shrinkage, and cracks. Formation of galls and cankers on the stem	In field	China	n/a	Fan et al. 2013; Zhang et al. 2013
Root-knot nematode disease	Root-knot nematode	*Meloidogyne incognita*, *M. javanica*, *M. arenaria* (Nematoda: Tylenchida)	Moderate (attacks trees of all ages, including seedlings in polybags)	*A. sinensis*	Stunted growth, yellowish leaves and premature leaf falls Visible, overlapping galls around root area	In field In nursery	China	Biocontrol using *Paecilomyces lilacinus*	Wu and Lu 1994; Xu et al. 2011; Xu et al. 2012

level of damage, with the ability to cause 30% mortality in plantations in China.

COMMON DILEMMA AND MAJOR ISSUES IN AGARWOOD PLANTING

The problems of pest and disease progressively challenge agarwood tree plantations over the years. Foresters, researchers, and plantation owners will need to identify innovative new methods to overcome them. At present, research on agarwood tree pests and diseases is limited. As a newly established industry, information on the agarwood tree-planting management was scarce to begin with. Instead, much attention has been given to the production of quality agarwood. Based on our experience through field visits and interviews, planters from Malaysia often take the 'plant, leave, harvest' approach when dealing with forest tree species, assuming that the tree could withstand the natural elements in the field and continue to thrive and grow, just because it is a forest tree species. Agarwood tree growth performance in plantations is often not assessed, and remedial steps to aid in growth are not taken due to incompetent management, causing unnecessary losses.

The main harvests from the planting of forest tree species are often timber or natural byproducts such as latex or fruits. In agarwood tree planting, attention is paid on the induction and subsequent production of agarwood of high quality and yield. This means that agarwood trees are often left to grow on themselves in wait for a suitable time for the induction and harvest of the fragrant agarwood resin, the main produce of the industry. The selection of tree species is often driven by consumer preference, as the agarwood aroma is species- and locality-dependent (Lee & Mohamed 2016). To date, reports on *Aquilaria* performance in field trials are limited, and no breeding programs are known. Breeding for pest- and disease-resistant *Aquilaria* has little weight as the tree is a relatively new crop and the threats are as yet, not devastatingly widespread. In addition, to develop a plantation breed with high resistance towards pests and diseases would be time-consuming due to the longer life cycle in forest trees compared to other agricultural crops. Although hybridization between species might yield a stronger breed (Mirzaie-Nodoushan et al. 2015), the emergence of new problems is also possible. Based on our previous communication with agarwood tree planters from Peninsular Malaysia, planters prefer cheaper and more feasible alternative approaches, such as by increasing the stand number or by mix-planting.

RESEARCH ON INTEGRATED PEST MANAGEMENT

An integrated pest management (IPM) program is crucial in controlling and reducing insect pests in forest tree plantations. A combination of several pest control approaches such as biological control using entomopathogenic fungi and bacteria, as well as the periodic use of pesticides, is a good IPM approach that can substantially decrease threats from insect and pathogen. Among all the threats reported, *H. vitessoides* is considered a serious pest in *Aquilaria* plantations (Raja Rishi et al. 2016), targeting three major planted *Aquilaria* species, *A. crassna*, *A. malaccensis*, and *A. sinensis*, as well as *G. verstegii*, planted mainly in Indonesia. Outbreaks of *H. vitessoides* in agarwood tree plantations have been reported in India, China, Malaysia, Indonesia, and Australia (Saikia & Shrivastava 2015), but not in Myanmar, Cambodia, Laos, Vietnam, and Thailand, though this does not necessarily imply its absence in those regions. The infestation is so widespread that it raised the attention of many researchers to look into suitable pest control measurements to reduce the loss inflicted to the plantations. When comparing all reported strategies against pests and diseases of agarwood tree plantations, research on the pest management of *H. vitessoides* is the most abundant (Table 1). Various IPM strategies have been introduced, such as biological controls using parasitic wasps, entomopathogenic fungi and bacteria, organic pesticides from plant extracts, fruit extracts and seed extracts, biological insecticides from natural compounds, introduction of natural predators, land and soil management, mix-planting, and commercial chemical-based insecticides. The threats seemed to have been well-identified and were given serious attention. The research on the antennal and behavioral responses of female *H. vitessoides* to *A. sinensis* was carried out to investigate the responsible volatiles that attracted the moth (Qiao et al. 2012). It was later discovered that female moths are more attracted to young leaves, rather than old leaves, and four identified compounds, hexanal, (Z)-3-hexenyl acetate, nonanal and decanal, are essential components for optimal attraction. At present, while studies on *H. vitessoides* infestations concentrate on planted agarwood-producing species, *Aquilaria* and *Gyrinops*, there is one report of similar attacks on a related tree species, *Phaleria macrocarpa* from Indonesia (Emilia 2013). Plant volatiles are major molecules in insect-host recognition (Qiao et al. 2012) and may explain why trees under the same family Thymelaeaceae tend to attract similar pests. Additional studies, however, are necessary to support this hypothesis. On the other hand, the boreholes and galleries produced by *N. conferta* infestation are believed to facilitate fungal infection in the wood, thus accelerates the formation of agarwood on the infested trees (Kalita et al. 2015). Based on a survey conducted on seven different *A. malaccensis* plantations in northern Indian, it is likely to conclude that there is a tree age preference among these wood borers when attacking their plant hosts. *Aquilaria* trees within the age group of 8-16 years invited most attacks; followed by trees in age group of above 16 years. *Aquilara* trees that are eight-year-old and below, were likely not targets to the wood borers. While there are numerous reports on searching and selecting suitable plant pathogens for use as agents in resinous agarwood induction, the role of an insect-mediated fungal colonization of the wood tissue of *Aquilaria* trees has not been properly studied. Such work could provide new information on the biotic interactions between the tree, fungi and insects, which can further strengthen research on agarwood production, identifying

beneficial insects in promoting agarwood formation on the infested trees.

GOOD AGRICULTURAL PRACTICE

A Good Agricultural Practice (GAP) for agarwood tree plantations was first drafted in 2005 in China (Liu 2005). This effort was taken as China regards cultivated agarwood tree as a renewable resource for traditional medicine ingredients (Lu 2000). As one of the agarwood-producing countries, Malaysia has recently published its own GAP guidelines (FDPM 2012). Other countries like India refers to planted agarwood trees as a renewable resource for aromatic and medicinal plants, and encourages agarwood tree cultivation in home gardens (Saikia & Khan 2012). In agarwood tree cultivation, sound GAP guidelines could steer the industry towards a more systematic and controlled production of quality agarwood (Liu 2005). Therefore, in efforts to sustainably produce quality agarwood, GAP models such as those applied by established agarwood tree plantations, or guidelines from other forest species plantations, could be reviewed, revised, and implemented by individual agarwood-producing country.

CONCLUSION

Agarwood tree species are tropical forest trees growing in natural environment, interacting freely with an abundance of insects and microbes. These trees were never a management concern before, but now that the trees have been introduced into plantations, and pests and diseases are becoming a problem to plantation management. The monoculture practice of agarwood tree plantations, compounded by no prior selection for resistant planting materials, may push further the problem. At present, the pests and diseases discussed herein are not posing major threats to agarwood tree plantations, but it may change in the near future, as we have seen with the effects of *H. vitessoides* infestation. Although large-scale cultivation of agarwood tree species is relatively new, good management practices can be adopted from experiences in managing pests and diseases of other planted forest tree species such as rubber, eucalyptus, and *Acacia*.

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