FUNGAL RESISTANCE AND PHYSICO–MECHANICAL PROPERTIES OF CINNAMON OIL- AND CLOVE OIL-TREATED RUBBERWOOD PARTICLEBOARDS

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YINGPRASERT W, MATAN N, CHAOWANA P & MATAN N. 2015. Fungal resistance and physico–mechanical properties of cinnamon oil- and clove oil-treated rubberwood particleboards. In order to protect rubberwood particleboards against moulds (*Aspergillus* sp. and *Trichothecium* sp.) and fungi (*Gloeophylum* sp. and *Trametes* sp.), application of essential oil (cinnamon or clove oil) as an antifungal agent was investigated. A solution of each essential oil in ethanol was sprayed onto rubberwood particles during a glue–particle blending process to achieve various concentrations of 0 to 3% (by mass of dried particles). Chemical compounds of essential oil deposited in the finished board after hot processing were investigated by gas chromatography–mass spectrometry analysis. Besides mould and decay resistance, physical and mechanical properties of the particleboards were examined. Cinnamaldehyde (1.8 μg g^{-1}) and eugenol (5.2 μg g^{-1}) were detected in boards treated with 3% cinnamon oil and clove oil respectively. A complete protection against growth of *Aspergillus* sp. and *Trichothecium* sp. on the boards was extended from less than 1 week till 9 weeks at 25 °C and 100% relative humidity. Percentage mass loss caused by *Trametes* sp. and *Gloeophylum* sp. was also reduced to 5%. Essential oil treatment reduced equilibrium moisture content and thickness swelling without affecting water absorption and bending properties of particleboards. Internal bond strength of particleboards remained unaffected by addition of cinnamon oil and clove oil up to 1.8%, above which a slight reduction was observed.

Keywords: Decay resistance, *Hevea brasiliensis*, cinnamaldehyde, eugenol, mould

INTRODUCTION

Rubberwood (*Hevea brasiliensis*) particleboard, a composite panel manufactured from sliver particles of rubberwood mixed with synthetic resin under optimum pressure and heat (Malony 1993), has been extensively used as raw material for indoor housing and furniture applications (Ng & Thiruchelvam 2012). Since rubberwood has low natural durability (Teoh et al. 2011), particleboards made from rubberwood are susceptible to moulds and fungi. Mould on wooden surfaces in buildings is commonly observed when products are temporarily exposed to high humidity such as water-damaged buildings (Crook & Burton 2010) or when used in warm and humid environments in tropical countries such as Thailand, Malaysia and Indonesia (Khedari et al. 2002 , Nielsen et al. 2004, Rahman & Dewsbury 2007, Isaksson et al. 2010). Moulds in buildings cause major health risks (Knutsen et al. 2012, Zhang et al. 2012). Studies have also suggested connections between exposure to indoor moulds or mould-associated products and allergic respiratory illnesses including asthma and rhinitis (Crook & Burton 2010, Knutsen et al. 2012).

Inhibition of mould growth on particleboards is possible using copper and boron-based fungicides (Zaidon et al. 2008, Tascioglu & Tsunoda 2010). However, because of toxicity and health concerns, more environmentally-friendly preservatives such as essential oils from herbs or plants should be developed. Application of essential oils such as cinnamon and clove has been reported to suppress mould growth

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(Matan & Matan 2007) and reduce the attack of decay fungi (Cheng et al. 2008) in solid wood. In addition, active components in essential oils have been successfully applied to control mould growth on gypsum boards (Singh & Chittenden 2010). Nowadays, cinnamon and clove oils are commercially available, making their uses in wood industries possible. However, there is lack of literature on the use of essential oils as fungal inhibitor in wood composite panels. There is a need to explore methods and effects of applying essential oils to particleboards either during or after manufacturing. Preferably, the techniques employed should be easily adapted to the existing equipment and particleboard manufacturing processes currently practised in particleboard industries. In addition, antifungal activities of essential oils should not be destroyed or decline in efficiency as a result of manufacturing processes. Finally, application of essential oils should not negatively affect important physical and mechanical properties of panels.

This paper intends to examine the issues identified above. Emphasis is given on demonstrating the potential of using cinnamon and clove oils as antifungal agents in rubberwood particleboard by adding a solution of essential oil during the glue–particle blending process. Gas chromatography–mass spectometry (GC–MS) analysis was employed to investigate possible antifungal constituents being left behind in the particleboards after treatment. Any side effects of applying cinnamon and clove oils on some important physical and mechanical properties of the boards were also examined.

MATERIALS AND METHODS

Essential oils, chemicals, rubberwood particles, adhesive and wax

Food grade cinnamon oil (containing 45% cinnamaldehyde and 25% eugenol) and clove oil (containing 85% eugenol) derived by steam distillation were purchased. Ethanol was used as a solvent of essential oil. Pure substances of cinnamaldehyde and eugenol were used for quantitative GC–MS analysis.

Rubberwood particles, obtained from a local particleboard manufacturer in Suratthani province, Thailand, were screened through meshes with 1 and 3 mm apertures for surface layer and core layer of the particleboards respectively. The particles were then dried to attain moisture content of 2% prior to processing.

Urea-formaldehyde (UF) adhesive had solid content of 65%. Wax emulsion with total solid of 59% was supplied by a local particleboard manufacturer.

Cultures and preparation of inocula

Two strains of moulds (*Aspergillus* sp. WU1003 and *Trichothecium* sp. WU1004) and two decay fungi of white rot and brown rot (*Trametes* sp. WU1005 and *Gloeophylum* sp. WU1006 respectively) were incubated at room temperature of 28 °C and relative humidity (RH) of 100% for 4 weeks. Particleboard specimens were taken at random from three different particleboard manufacturers located in the south of Thailand. Codes refer to strains held in the culture collection of the Wood Science and Engineering Research Unit, Walailak University, Nakhon Si Thammarat province, Thailand.

Homogenised cultures of test moulds were obtained from mycelia grown on malt extract agar medium at 25 °C for 14 days and were standardised to concentrations of 10^7 spores mL^{-1} by dilution with sterile water containing Tween 80 (0.1% v/v) before use. The viability of all strains was checked using quantitative colony counts at 10^7 CFU mL^{-1}.

Particleboard manufacturing

Rubberwood particles of the core layer and the surface layer were blended with UF adhesive at 8 and 10% (based on oven-dry mass of particles) respectively in a blender. Solution of either cinnamon oil or clove oil in ethanol was then slowly sprayed onto the particles to achieve essential oil loading contents of 0.6, 1.8 and 3.0% (based on oven-dry mass of particles). Three sets of controls, i.e. untreated (UT), ethanol solvent treated (ST) and 1% wax treated (WT) specimens were included.

Three-layer particleboards were manufactured with target density of 750 kg m^{-3}. The mat was formed by hand distribution in a forming box with dimensions of 350 mm × 350 mm. The ratio of the face thickness to

the total thickness of a board, known as the shelling ratio was 0.30 for all samples. The mat was pre-pressed and subsequently pressed in a single-opening hydraulic laboratory hot press at 160 °C and pressure of 4.80 MPa for 10 min. The target thickness of 10 mm was obtained using metal stoppers. Five replicate particleboards were manufactured for each treatment. The panels were machined into the required sizes before being conditioned in a conditioning room at 20 °C and 65% RH until the moisture content of the specimens attained equilibrium level.

Gas chromatography–mass spectrometry analysis

Essential oil components were extracted from 10 g of particleboard randomly collected from five replicate specimens using a method adapted from Friedman et al. (2000) and Matan et al. (2011). Specimens were sampled for the entire cross-section. After being finely ground, a subsample of 1.00 ± 0.01 g was then transferred to a glass tube filled with 10 mL of ethyl acetate. The tube was sealed using Teflon-lined cap and then mixed by shaking gently. The specimen was allowed to stand for 2 hours before the ethyl acetate extracts (10 mL) were filtrated by 0.45 µm (pore size) syringe filter. The filtrated ethyl acetate extracts were concentrated to less than 1 mL by passing a stream of nitrogen into the test tube at room temperature. Finally, the 1-µL aliquots of each solution were subjected to GC–MS analysis.

The GC–MS analysis was carried out on a Hewlett-Packard model equipped to a DB-5 column with dimensions of 30 m × 0.25 mm internal diameter and 0.25 µm film thickness. The average helium carrier gas flow rate was 1 mL min^{-1}; the split ratio of the column was 50:1 and the injector and detector temperatures were set to 250 and 260 °C respectively. The column oven temperature was held at 60°C for 30 s, then programmed to 150 °C at 40 °C min^{-1} and then to 260 °C at 5 °C min^{-1}. Samples (1.0 µL) were injected manually. The ionisation energy was at 70 eV with scan time of 1 s and mass range of 50–550 amu. The components of essential oil were identified by comparison of their mass spectra with those of a computer library (NIST 0.8L). Only chemical components having probability ≥ 95% were recorded. Data obtained were confirmed by comparison of their retention indices, either with those of authentic compounds or with data from the literature. The relative percentages of all components identified were obtained by peak-area normalisation without correction factors. The percentage values for components were the mean of three injections of each treatment. Standard curves, used for quantitative analysis, were separately prepared for each component of cinnamaldehyde and eugenol. The amount of component was expressed as mass component per gram of particleboard.

Mould test on rubberwood particleboard

Antifungal efficiency of rubberwood particleboards incorporated with cinnamon and clove oils against *Aspergillus* sp. and *Trichothecium* sp. was performed in accordance with the ASTM D4445-03 (ASTM 2003) with some modifications. The specimen (50 mm × 50 mm) was dipped in each mould-spore inoculum (10^7 spores mL^{-1}). A total of five replicates per treatment were employed. Specimens were then placed on a glass rod on top of moistened filter paper in sterile glass bottle to maintain high humidity (100% RH). The glass bottles were incubated at 25 °C and 80% RH in an environmental chamber for up to 12 weeks. The time periods needed for initiation of mould growth (T_i) and 50% mould coverage ($T_{50\%}$) on the particleboard were recorded.

Fungal decay test on rubberwood particleboard

Fungal decay resistance of rubberwood particleboards incorporated with cinnamon and clove oils against the white-rot fungus *Trametes* sp. and the brown-rot fungus *Gloeophylum* sp. was examined in accordance with ASTM D1413-07 (ASTM 2007) with some modifications. Soil block culture bottles were prepared using sieved oven-dried soil of 90 g filled in culture bottles. Sterile water was added to maintain 130% of water holding capacity of soil in the bottles. Rubberwood feeder strips (3 mm × 28 mm × 35 mm) were placed on the surface of the soil. The bottles were autoclaved at 121 °C for 30 min.

After cooling down, the feeder strips placed in sterilised bottles were inoculated with fungal inoculum sections from freshly-grown culture. The bottles were incubated at 25 °C and 80% RH in an environmental chamber for 2 weeks until mycelium of the decay fungus completely colonised the feeder strips.

The particleboard specimens (25 mm × 25 mm), steam-sterilised at 100 °C for 20 min, were placed on feeder strips in contact with fungal mycelium. The bottles containing specimens were incubated at 25 °C and 80% RH for 12 weeks in an environmental chamber. After incubation, the surface mycelium was removed. The specimens were reconditioned at 20 °C and 65% RH in a conditioning room until constant mass. Average percentage mass loss was determined from the conditioned mass before and after exposure to decay fungus. Five specimens were tested for each treatment group.

Physical and mechanical property tests

Physical and mechanical properties of the essential oil-treated rubberwood particleboards, including density, equilibrium moisture content (EMC) at 20 °C and 65% RH, thickness swelling (TS), water absorption (WA), modulus of elasticity (MOE), modulus of rupture (MOR) and internal bond (IB) were determined according to the ASTM D1037-99 (ASTM 2001) with slight modification of the TS and WA specimen size of 50 mm × 50 mm. Mechanical properties tests were performed on a 10 kN Universal testing machine.

Statistical analyses

All results were expressed as means ± standard deviations. Effects of essential oil on properties of rubberwood particleboards were evaluated by analysis of variance at the 0.01 level of significance. Duncan's multiple range tests were conducted to determine significant differences between means.

RESULTS AND DISCUSSION

Essential oil components in particleboard

Qualitative GC–MS analysis (Table 1) revealed that major constituents of cinnamon oil (cinnamaldehyde and eugenol) and clove oil (eugenol), responsible for antifungal activities of the essential oils, were retained in treated particleboards after hot pressing at 160 °C for 10 min. These constituents were also detected in cinnamon and clove oils heated at various temperatures up to 180 °C for 3 hours (Tomaino et al. 2005). The process of hot pressing appeared to increase the proportion of cinnamaldehyde (from 65 to 81% of total extracted constituents) but decreased the proportion of eugenol (from 25 to 14% of total extracted constituents) in cinnamon oil-treated particleboards. Within clove oil-treated particleboard, only eugenol was detected after hot pressing. Various minor components of both essential oils such as linalool, carryophyllene, alpha-caryophyllene, caryophyllene oxide and o-cymene were completely eliminated from particleboards after hot pressing. Linalool in anise oil was reported to be partially destroyed by heat at 100 °C (Matan et al. 2012).

Since large proportions of cinnamaldehyde and eugenol were detected in particleboards treated with cinnamon and clove oil respectively, they were further examined using quantitative GC–MS analysis (Figure 1). The amounts of cinnamaldehyde (0.6 to 4.6 μg g^{-1}) and eugenol (2.9 to 15.9 μg g^{-1}) extracted from particleboards before hot pressing were roughly proportional to the content of cinnamon oil (0.6 to 1.8%) and clove oil (0.6 to 1.8%) mixed into the particleboards. After hot pressing, the amounts of cinnamaldehyde and eugenol in particleboards were reduced by approximately 58 and 71% respectively. Cinnamaldehyde appeared to be slightly more stable to heat than eugenol. Cinnamaldehyde (0.3 to 1.8 μg g^{-1}) and eugenol (0.7 to 5.2 μg g^{-1}) retained within the particleboards after hot pressing could act as antifungal agents.

Mould test on rubberwood particleboard

The values of T_i and $T_{50\%}$ appeared to increase with increasing amounts of cinnamon and clove oils mixed into the boards (Figure 2). Efficacy of cinnamon and clove oils against test moulds was comparable and both moulds appeared to be equally strong. The maximum content of cinnamon and clove oils used in this study, i.e. 3% gave complete protection (with zero mould

Table 1 Qualitative GC–MS analysis of chemical components in 3.0% cinnamon oil- and 3.0% clove oil-treated particleboards before and after hot pressing

Compound	3.0% Cinnamon oil		3.0% Clove oil	
	Before hot pressing	After hot pressing	Before hot pressing	After hot pressing
o-Cymene	0.06 ± 0.01	–	–	–
Linalool	2.49 ± 0.06	–	–	–
Benzaldehyde, 2-methoxy	0.19 ± 0.01	–	–	–
Cinnamaldehyde, (E)-	64.56 ± 1.59	81.14 ± 1.70	0.22 ± 0.01	–
Eugenol	24.49 ± 0.60	14.45 ± 0.30	98.81 ± 3.55	100.00 ± 0.00
Carryophyllene	1.27 ± 0.03	–	0.44 ± 0.02	–
Cinnamyl acetate	1.09 ± 0.03	0.95 ± 0.02	–	–
2H-1-Benzene-2-one	0.71 ± 0.02	–	–	–
Alpha-carryophyllene	0.26 ± 0.01	–	0.33±0.01	–
Cinnamaldehyde, o-methoxy-	2.28 ± 0.06	1.41 ± 0.03	–	–
Carophyllene oxide	0.79 ± 0.02	–	–	–
Total identified	98.19 ± 0.34	97.95 ± 2.01	99.81 ± 3.27	100.00 ± 0.00

– = Not detected

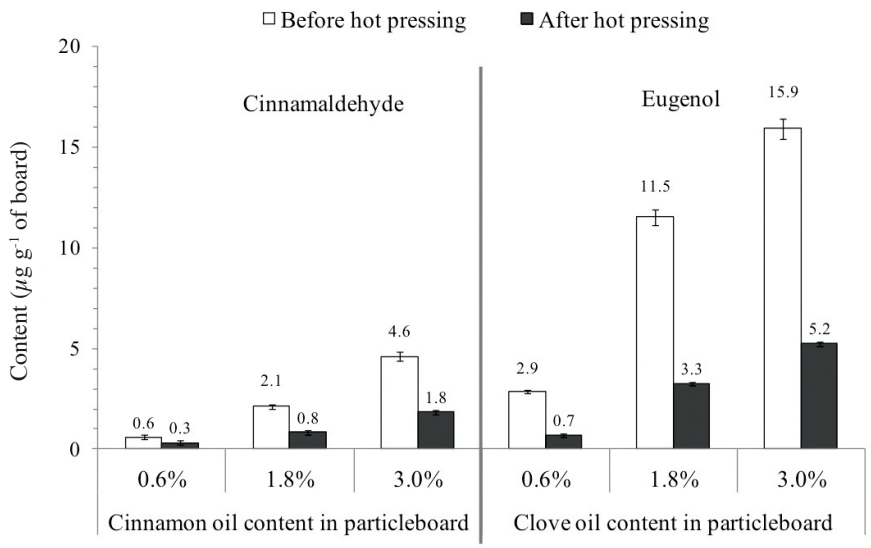

Figure 1 GC–MS analysis of contents of cinnamaldehyde and eugenol extracted from rubberwood particleboard treated with cinnamon and clove oils respectively at various concentrations before and after hot pressing

growth) against *Aspergillus* sp. and *Trichothecium* sp. on rubberwood particleboard for 9 weeks at 25 °C and 100% RH.

Good antifungal effects of cinnamon and clove oils have been reported to be due to their main components which are cinnamaldehyde and eugenol respectively (Matan & Matan 2007, Matan et al. 2011, Singh & Chittenden 2010). Cinnamaldehyde and eugenol were reported to delay the lag phase and inhibit growth of *Aspergillus* species (Rodriguez et al. 2008, Narayanan et al. 2013). As a result, cinnamaldehyde and eugenol retained within particleboards after hot pressing must act as antifungal agents that retarded mould growth. Both constituents have been shown to inhibit

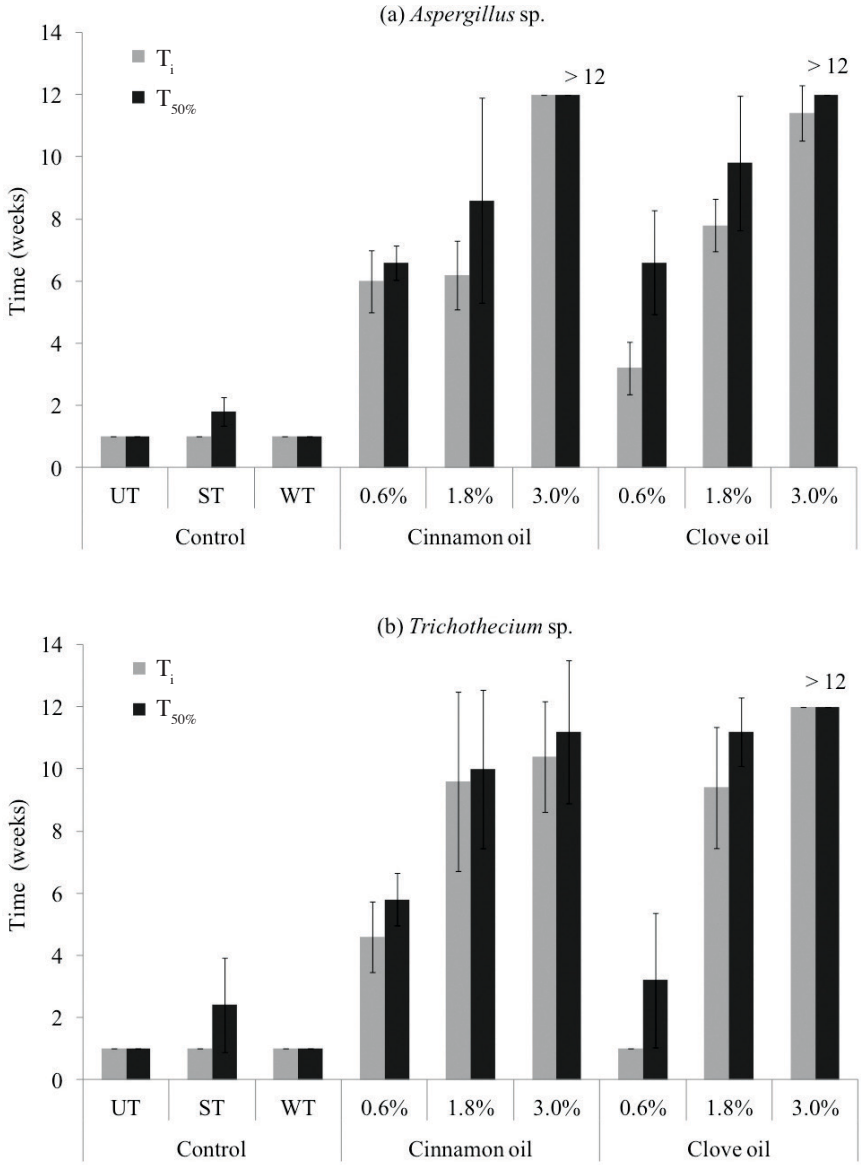

Figure 2 Periods required for mould initiation (Ti) and for 50% mould coverage ($T_{50\%}$) of (a) *Aspergillus* sp. and (b) *Trichothecium* sp. on cinnamon oil- and clove oil-treated rubberwood particleboards; UT = untreated, ST = ethanol solvent treated, WT = wax treated

growth of various moulds on gypsum boards (Singh & Chittenden 2010) and areca palm leaf sheaths (Matan et al. 2011). Ethanol was also reported to exhibit certain antifungal activities on various moulds (Dantigny et al. 2005, Dao & Dantigny 2011). However, ethanol was expected to largely vaporise during hot pressing. As a result, no fungal inhibition improvement on the value of T_i was observed in the ethanol solvent-treated particleboards. Slight improvement in the value of $T_{50\%}$ from 1 week to 2 weeks was observed which might be a result of the residual ethanol left behind in the particleboards after hot pressing. Addition of wax emulsion, which was also reported by Lesar and Humar (2011), did not improve the mould resistance of boards.

Since moulds grow mainly on the particleboard surface, only essential oil components in the vicinity of the particleboard

surface are essential in protection against mould growth. It is possible that essential oil treatment of rubberwood particles in the glue–particle blending process be performed only for the surface layer. This would reduce the amount of essential oil used which reduces material cost and the amount of volatile organic compounds which may be produced from volatile components of essential oil.

Fungal decay test on rubberwood particleboard

The ethanol solvent-treated particleboards showed similar mass loss to untreated particleboards at 27% caused by *Trametes* sp. and at 15% caused by *Gloeophylum* sp. (Figure 3). Wax treatment reduced mass loss caused by *Trametes* sp. (from 27% to 17%) but had no effect against *Gloeophylum* sp. Addition of wax emulsion was reported to slow down the attack of wood decay fungi, but it could not stop the attack (Lesar & Humar 2010). Particleboards treated with cinnamon and clove oils showed mass loss to about 5% with increasing amount of essential oil mixed into the particleboards up to 3.0%.

In controls without essential oil, *Trametes* sp. caused more mass loss (27%) than *Gloeophylum* sp. (15%). Pandey and Nagveni (2007) point out that the white rot fungus degrades all components of wood, while the brown rot fungus removes the cellulosic fraction leaving the lignin undegraded but structurally modified. It is clear that good antifungal activities of particleboards treated with cinnamon and clove oils must arise from cinnamaldehyde and eugenol retained within particleboards after hot pressing. Both constituents in cinnamon and clove oils were also reported to exhibit strong antifungal activities against *T. versicolor* in comparison with other constituents in the oils (Voda et al. 2003, Cheng et al. 2006). Cinnamaldehyde and eugenol were suggested to alter cell wall structure and reduce cell wall synthesis of wood decay fungi resulting in the leakage of fungal cytoplasm causing the fungal death (Yen & Chang 2008).

Physical and mechanical properties of rubberwood particleboard

Density of particleboards was not significantly different with average value of 709 ± 27 kg m^{-3}. Both essential oils with increasing loading content up to 3.0% gradually reduced the EMC values of particleboards measured at 20 °C and 65% RH from 8.6 to 7.8%. Components in the essential oils should reduce moisture absorption of wood particles within the boards. This reduction in EMC, however, appeared to contribute very little to the mould resistance on the surface of the essential oil-treated boards as boards treated with wax emulsion having EMC of 8.1% similar to boards treated with 1.8% essential oils were covered with mould within 1 week.

Water immersion test of particleboards with increasing content of both essential oils up to 3.0% showed reduction in thickness swelling from 19 to 13% and from 26 to 16% after 2 hours and 24 hours respectively. The amount of water absorbed by treated boards, on the other hand, was not influenced by the amount of essential oils added. The values of WA of the essential oil-treated particleboards were not significantly different from that of the untreated particleboard at 65.6 and 80.9% after 2 hours and 24 hours respectively. It is expected that majority of water absorbed by boards during the water immersion test should be in the voids inside the boards. The thickness swelling of the board is not affected by free water inside the voids. Only after some water within the voids diffuse into the wood particles, the boards then begin to swell. Essential oil treatment reduced hygroscopicity of the wood particles within the boards (reduction in EMC value as shown in Table 2). As a result, thickness swelling, therefore, decreased as loading content of essential oil increased. It is also worth mentioning that application of essential oils to the boards, apart from being fungal resistant, can reduce the amount of wax used to achieve the same level of thickness swelling. While the addition of 1% wax reduced thickness swelling of the boards after 24 hours immersion from 26 to 10%, thickness swelling of the 3.0% essential oil-treated boards was 16%. It is expected that for those essential oil-treated boards, only about 0.5% wax addition would be required to reduce further thickness swelling to the value of 10%.

Bending properties of essential oil-treated particleboards were not affected by the amounts of essential oils added. The MOE and MOR of essential oil-treated boards with average values of 3391 and 10.9 MPa respectively were in a range similar to those of controls and the 1%

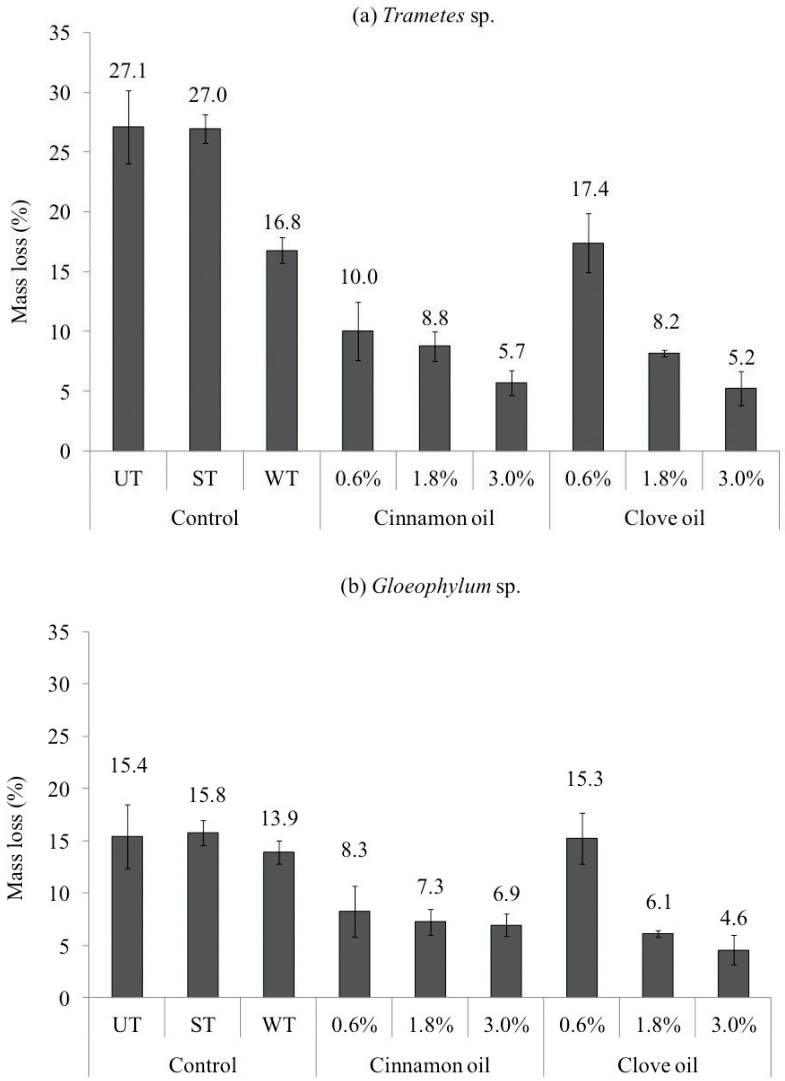

Figure 3 Mass losses of cinnamon oil- and clove oil-treated rubberwood particleboards exposed to (a) *Trametes* sp. and (b) *Gloeophylum* sp.; UT = untreated, ST = ethanol solvent treated, WT = wax treated

wax-treated boards. Both cinnamon and clove oils of up to 1.8% did not affect the IB (1.0 ± 0.1MPa) of particleboards. However, at 3.0% addition of cinnamon and clove oils, a reduction of 20 and 30% respectively in IB strength was observed. It was possible that essential oil reduced the performance of adhesives by changing the surface characteristics of wood, delaying moisture removal from the adhesive and also slowing the curing process (Eaton & Hale 1993).

CONCLUSIONS

Major constituents responsible for antifungal activities of cinnamon and clove oils (cinnamondehyde and eugenol respectively) were found in particleboard after hot pressing. Addition of cinnamon and clove oils at 3.0% was capable of providing complete protection against growth of *Aspergillus* sp. and *Trichothecium* sp. on particleboards for 9 weeks at 25 °C and 100% RH.

Table 2 Physical and mechanical properties of the cinnamon oil- and clove oil-treated rubberwood particleboards

Essential oil content (%, mass of oil/mass of board)		Density (kg m^{-3})	EMC (%)	TS (%)		WA (%)		MOE (MPa)	MOR (MPa)	IB (MPa)
				2 hours	24 hours	2 hours	24 hours			
Control	Untreated	722 ± 23 a	8.6 ± 0.1 a	19 ± 2 a	26 ± 1 a	60 ± 4 a	80 ± 2 a	3337 ± 118 ab	11.9 ± 0.4 a	1.0 ± 0.1 a
	Ethanol	718 ± 29 a	8.4 ± 0.1 a	18 ± 2 a	24 ± 1 a	58 ± 5 a	72 ± 3 a	3295 ± 105 ab	11.8 ± 0.3 a	1.0 ± 0.1 a
	1.0% Wax	691 ± 40 a	8.1 ± 0.2 c	3 ± 1 d	10 ± 1 d	15 ± 1 b	36 ± 3 b	3392 ± 144 ab	11.2 ± 1.2 a	1.0 ± 0.1 a
Cinnamon oil	0.6%	702 ± 39 a	8.4 ± 0.1 a	16 ± 1 ab	20 ± 2 b	65 ± 6 a	82 ± 4 a	3407 ± 283 ab	12.3 ± 0.8 a	0.9 ± 0.1 abc
	1.8%	734 ± 53 a	8.1 ± 0.1 c	12 ± 1 c	17 ± 1 c	68 ± 1 a	80 ± 2 a	3381 ± 403 ab	11.0 ± 1.8 a	0.9 ± 0.0 abc
	3.0%	692 ± 42 a	7.8 ± 0.1 d	12 ± 1 c	16 ± 1 c	68 ± 3 a	81 ± 3 a	3622 ± 323 a	11.1 ± 2.2 a	0.8 ± 0.1 cd
Clove oil	0.6%	716 ± 51 a	8.3 ± 0.1 b	18 ± 2 a	27 ± 3 a	65 ± 3 a	81 ± 4 a	3085 ± 68 b	10.0 ± 0.7 a	1.0 ± 0.1 a
	1.8%	736 ± 46 a	8.1 ± 0.1 c	17 ± 1 a	19 ± 1 b	62 ± 4 a	82 ± 2 a	3492 ± 112 ab	10.7 ± 0.7 a	1.0 ± 0.1 ab
	3.0%	708 ± 33 a	7.8 ± 0.1 d	13 ± 1 bc	16 ± 1 c	71 ± 8 a	80 ± 4 a	3360 ± 341 ab	10.4 ± 1.9 a	0.7 ± 0.0 d

Means followed by the same letter in the same column of each treatment are not statistically different according to Duncan's multiple range test at $\alpha = 0.01$; EMC = equilibrium moisture content, TS = thickness swelling, WA = water absorption, MOE = modulus of elasticity, MOR = modulus of rupture, IB = internal bond

Percentage mass loss of particleboards caused by *Trametes* sp. and *Gloeophylum* sp. was also reduced to about 5%. Essential oil treatment also decreased WA and TS of particleboards without affecting their mechanical properties except for a slight reduction of IB strength above 1.8% of cinnamon and clove oils.

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