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FUNGAL DECAY RESISTANCE OF 16 TROPICAL WOOD SPECIES EMBEDDED WITH METAL SCREWS

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Decay resistance was assessed for 16 wood species, with metal screws embedded, against five fungal species. Wood species differed significantly in decay resistance. The three most resistant species, *Azadirachta indica, Castanopsis tunggurut* and *Turpinia sphaerocarpa,* lost 1.7–4.0% weight (resistance class, R II). *Gironniera subaequalis, Lindera polyantha* and *Hymenaea courbaril* were moderately resistant to decay (7.3–9.3% loss, R III) and the remaining species were designated R IV. Screw-embedded specimens lost significantly more weight (14.2 ± 4.0%) than the control (11.0 ± 3.4%). *Polyporus* sp. and *Pycnoporus sanguineus* caused significantly more wood weight loss than *Schizophyllum commune,* which in turn was greater than that for *Chaetomium globosum* and *Dacryopinax spathularia.* Screws from wood inoculated with *Polyporus* sp. lost significantly less weight (3.9 ± 0.7%) than with other fungi. *Hymenaea courbaril* and *A. indica* showed the highest and lowest corrosive activity respectively towards screws in the presence of fungi. Screws exposed to *C. globosum* in culture media lost significantly more weight (10.2%) than with the other fungi. Regression analysis showed that wood weight loss was negatively correlated with wood density of control specimens but not with screw-embedded specimens. Other wood properties including extractives were not found to significantly correlate with wood decay.

Keywords: Wood-decaying fungi, resistance class, rust discoloration, wood properties, metal corrosion

INTRODUCTION

In Indonesia, as high-value trade timber species have become limited in natural forests, there has been a shift to plantation forests using fast-growing exotic tree species and also utilisation of as substitutes for trade timber species (Sumarni et al. 2009). Many aspects of silviculture, growth performance and management of these exotic tree species in relation to local conditions are not well documented, as are their post-harvest properties as timber in civil and structural applications. Even far less understood is the wood properties of lesser-known timber species LKTS, e.g. decay resistance to fungi and interactions with commonly associated materials such as metal fasteners, screws and hinges. Wood can corrode metal fasteners under the right conditions of ambient moisture (Baker 1980). Most metals and their compatibility with wood are critical for the durability and safety of structural joints in wood-frame buildings (Li et al. 2011).

The objectives of our study were (1) to determine the decay resistance of selected lesser-known timber species LKTS and important plantation species against fungi, and of wood specimens with metal fasteners attached, and (2) to examine wood decay and metal corrosion.

MATERIALS AND METHODS

The 16 timber species used in our study were harvested from natural forest in West and East Java (Table 1). Wood specimens were cut from the heartwood (4 cm beyond the pith) of wide boards sawn from the bottom portion of logs. Specimens were cut along the anatomical directions of the wood to 5 cm length and 1.5 cm (radial) × 2.5 cm (tangential) following Suprapti and Djarwanto (2014).

The decay test employed the Kolle-flask method described in the Indonesian National Standard (SNI 2014). Specimens with or without screws embedded were exposed for 12 weeks to one of five fungi: *Dacryopinax spathularia*, *Polyporus* sp. HHBI-209 (brown rot), *Pycnoporus sanguineus* HHBI-8149, *Schizophyllum commune* HHBI-204 (white rot) and *Chaetomium globosum* (soft rot). The screws were bright, mild steel ½” wood screws bearing the SIP trademark, and sold in markets

Table 1 The wood species tested for resistance against wood-decaying fungi

Wood species	Local name	Family	Origin
Acer niveum	Ki endog	Aceraceae	Cempaka-Cianjur, West Java
Azadirachta indica	Mimba	Meliaceae	Tengos, Probolinggo, East Java
Calophyllum grandiflorum	Kilubang	Guttiferae	Lengkong-Sukabumi, West Java
Castanopsis tunggurrut	Tunggeureuk	Fagaceae	Cempaka-Cianjur, West Java
Diplodiscus sp.	Balobo	Euphorbiaceae	Surade-Sukabumi, West Java
Ehretia accuminata	Kendal	Boraginaceae	Surade-Sukabumi, West Java
Ficus variegata	Kundang	Moraceae	Surade-Sukabumi, West Java
Ficus vasculosa	Kikuya	Moraceae	Lengkong-Sukabumi, West Java
Gironniera subaequalis	Ki bulu	Ulmaceae	Lengkong-Sukabumi, West Java
Hymenaea courbaril	Marasi	Caesalpiniaceae	Cikampek, West Java
Lindera polyantha	Huru mentek	Lauraceae	Cempaka-Cianjur, West Java
Neolitsea triplinervia	Huru kacang	Lauraceae	Cempaka-Cianjur, West Java
Sloanea sigun	Beleketebe	Tiliaceae	Cempaka-Cianjur, West Java
Sterculia oblongata	Ki hantap	Sterculiaceae	Lengkong-Sukabumi, West Java
Tamarindus indica	Asam Jawa	Caesalpiniaceae	Karawang, West Java
Turpinia sphaerocarpa	Ki bancet	Staphyleaceae	Lengkong-Sukabumi, West Java

throughout the country. The test was conducted in a completely randomised design with 16 × 5 × 2 (wood) and 16 × 5 (screw) arrangement in six replicates. At the end of 12 weeks, the screws were carefully removed from the specimens. Weight loss of wood specimens was obtained from the difference between the initial and final oven-dry weight of the specimens. Screws were carefully cleaned using technical alcohol–acetone solution and nylon brushes, then allowed to dry, following a procedure previously described by Djarwanto and Suprapti (2015). Weight loss of the screws was obtained from the difference between the initial and final screw weights. Mean percentage weight loss for specimens with and without screws embedded was averaged across results for the five fungi, and assigned resistance classes I to V following the Indonesia National Standard (SNI 2014).

Fungal corrosiveness test had the screws exposed to one of the five fungi cultured on media in Kolle's culture flasks. The test was set up with fungi as the single factor in a completely randomised design with 10 replicates. Screws were inserted vertically into the growth medium and incubated for 12 weeks. In the control treatment, screws were inserted in the growth medium with no fungi inoculum. After 12 weeks, screws were carefully cleaned as in the decay test. Final screw weight was obtained and weight loss of the screws was obtained from the difference between the initial and final weights.

Discoloration that occurred on the wood surface due to screw corrosion was visually assessed and categorised using the scale established by Djarwanto and Suprapti (2015). Discoloration on the surface of the corroded screw head was also visually assessed and categorised using a colour-appearance scale as follows: - = no discoloration, +, ++, +++ and ++++ = discoloration up to 25, 50, 75 and 100% respectively (Djarwanto & Suprapti 2015).

The wood properties influencing wood decay were obtained from Sumarni et al. (2009) and Muslich et al. (2013) for each of the 16 timber species tested: wood density, flexural stiffness and strength (modulus of elasticity (MOE) and modulus of rupture (MOR)), and solubility in alcohol–benzene, 1% NaOH and hot water (chemical analyses). The pH of the specimens was measured from a 1:1 mixture (w/w) of sawdust and distilled water.

The data were analysed using SAS software version 6 (1997). For decay test, the percentage weight loss of specimens was analysed by two-way ANOVA with wood species, screw and fungi as factors, and means separated using Tukey (HSD) test ($p = 0.05$). The percentage weight loss of the screws was analysed by two-way ANOVA with wood species and fungi as factors, and means separated using Tukey (HSD) test (p = 0.05). For the fungal corrosiveness test, the percentage weight loss of the screws was analysed using one-way ANOVA with fungi as the factor, and means separated using Tukey (HSD) test (p = 0.05). The relationship between wood properties and specimen weight loss were evaluated using regression-equation analysis.

RESULTS AND DISCUSSION

Wood decay

The two-way ANOVA showed that wood weight loss was significantly affected by wood species, screw embedding and fungi ($p < 0.01$). Wood species differed significantly in their decay resistance (Tukey's, p = 0.05, Table 2). The three most resistant species, *Azadirachta indica*, *Castanopsis tunggurut* and *Turpinia sphaerocarpa* had significantly lower overall mean percentage of losses (1.6 to 4.0%, resistance class II) than the moderately resistant species, *Gironniera subaequalis*, *Lindera polyantha* and *Hymenaea courbaril* (7.3 to 9.3%, resistance class III). *Callophyllum grandiflorum*, *Tamarindus indica*, *Neolitsa triplinervia*, *Ehretia accumminata*, *Diplodiscus* sp., *Ficus vasculosa*, *Sterculia oblongata*, *Sloanea sigun* and *Ficus variegata*, in that order, showed progressively greater mean losses from 11.3 to 22.1% and all were designated resistance class IV. Our resistance class designations for *H. courbaril*, *Diplodiscus* sp., *A. niveum*, *N. triplinervia*, *S. oblongata* and *C. tunggurut* agreed with resistance classes reported by Oey (1990), but *C. grandiflorum*, *E. accuminata* and *T. indica* were reported as less resistant, and *A. indica*, *F. variegata*, *F. vasculosa*, *G. subaequalis*, *L. polyantha*, *S. sigun* and *T. sphaerocarpa* were reported as more resistant than our study results. Oey (1990) assessed the service life of wood species but did not specify the decay organisms. The wood species designated resistance classes I and II (strength and durability classes I and II in Martawijaya and Barly (2010)) are suitable for use as construction materials while those in classes III–V should first be preserved with fungicide to extend service life (Djarwanto et al. 2015).

Post-hoc analyses of the one-way ANOVA revealed that weight loss of screw-embedded specimens were significantly higher than the controls with mean weight loss values (± standard error) of 14.3 ± 4.0% and 11.0 ± 3.4% respectively (Tukey's, p = 0.05, Table 2). In line with our results, the decay intensity of screw-embedded wood was reportedly higher than that of whole (control) specimens of *Castanopsis acuminatissima, Cinnamomum iners, Litsea angulata, Ficus nervosa* and *Horsfieldia glabra* (Suprapti & Djarwanto 2015). Corrosion by-products of metal connectors fastened to wood may hasten wood decay over time by lowering decay resistance of wood around the fastener and locally accelerating degradation (Rammer et al. 2006). It is also possible that, in our study, screw insertion presented an access point for fungal mycelium to rapidly spread and hasten the decay process. Metal corrosion can be promoted by microorganisms including fungi, which release corrosive substances that break down both wood and metal into products utilised by these fungi (Kip & van Veen 2015). Fungi-driven reduction of Fe^{+3} ions in $FeCl_3$ solution to Fe^{+2} ions for uptake by these fungi were presumed to be responsible for decay of logs with metal fasteners attached (Noetzli et al. 2007).

Among the screw-embedded specimens, *Polyporus* sp. and *Pycnoporus sanguineus* caused the greatest weight loss (24.1 ± 3.7 and 22.9 ± 3.5% respectively), significantly higher and double that caused by *Schizophyllum commune* (12.5 ± 1.5%, Table 2). *Chaetomium globosum* and *Dacryopinax spathularia* had the least effect on decay of both screw-embedded and control specimens (4.9 to 7.2%). *Pycnoporus sanguineus* caused the greatest overall mean percentage loss of the five fungi tested, with deterioration recorded for both screw-embedded (22.9 ± 3.5%) and control specimens (24.2 ± 4.1%) indicating that this fungal species had the ability to attack whole wood equally well. Our results agree with previous studies reporting that *C. globosum* has low decaying ability (Takahashi 1978, Freas 1982, Suprapti & Djarwanto 2015, Djarwanto et al. 2018).

Screw corrosion in wood

Screws embedded in the wood specimens lost an average of 4.8 ± 0.5% of their original weight when exposed to fungi for 12 weeks (Table 3). Weight loss was significantly lower for screws from specimens innoculated with *Polyporus* sp. (3.9 ± 0.7%) than that inoculated with other fungi, where weight loss was 4.8 to 5.1% (Tukey's, $p < 0.05$). *Hymenaea courbaril* (class III) showed the highest corrosive activity towards screws in the

Table 2 Mean percentage weight loss (± standard deviation) and assigned resistance class of wood specimens 12 weeks after screw insertion and exposure to fungi

Wood species	*Chaetomium globosum*		*Dacryopinax spathularia*		*Polyporus* sp.		*Pycnoporus sanguineus*		*Schizophyllum commune*		Mean % loss		Overall mean % loss	R
	Screw	No	Screw	No	Screw	No	Screw	No	Screw	No	Screw	No		
Acer niveum	5.14 ± 0.78	4.70 ± 0.90	17.35 ± 4.83	19.90 ± 5.50	31.82 ± 7.28	8.97 ± 3.30	17.00 ± 3.20	42.40 ± 4.10	13.20 ± 3.40	14.60 ± 2.60	16.90 ± 3.90	18.11±3.28	17.5 ± 13.59^{cd}	IV
Azadiracta indica	1.48 ± 0.60	4.90 ± 2.10	0.60 ± 0.06	0.60 ± 0.30	0.59 ± 0.33	0.33 ± 0.16	1.27 ± 0.60	1.30 ± 0.60	4.04 ± 1.50	1.40 ± 0.60	1.60 ± 0.62	1.71±0.75	1.65 ± 0.69^{j}	II
Calophyllum grandiflorum	2.55 ± 0.90	2.40 ± 0.90	4.49 ± 2.38	4.60 ± 1.40	28.27 ± 5.40	8.70 ± 2.27	21.80 ± 3.60	24.30 ± 2.30	9.40 ± 1.50	6.30 ± 1.60	13.30 ± 2.76	9.26±1.69	11.28 ± 2.23^{g}	IV
Castanopsis tunggurut	1.47 ± 0.46	1.77 ± 0.80	0.76 ± 0.15	0.60 ± 0.40	6.36 ± 3.77	2.00 ± 0.80	1.90 ± 0.94	4.90 ± 1.20	7.89 ± 2.80	10.50 ± 3.40	3.68 ± 1.62	3.95±1.32	3.82 ± 1.47^{ij}	II
Diplodiscus sp.	8.87 ± 1.52	5.65 ± 1.50	8.45 ± 1.97	4.20 ± 1.40	38.10 ± 8.79	18.70 ± 5.98	31.30 ± 2.94	27.80 ± 6.80	15.80 ± 3.20	10.50 ± 1.80	20.50 ± 3.68	13.37±3.50	16.94 ± 3.59^{de}	IV
Ehretia accuminata	4.87 ± 1.14	3.75 ± 0.40	5.16 ± 1.53	1.30 ± 0.80	33.10 ± 5.31	15.10 ± 3.90	40.80 ± 1.80	22.30 ± 2.20	17.80 ± 5.60	11.70 ± 1.70	20.35 ± 3.08	10.83±1.80	15.59 ± 2.44^{def}	IV
Ficus variegata	8.46 ± 2.60	8.86 ± 2.40	12.54 ± 8.58	9.10 ± 5.70	50.90 ± 5.90	11.20 ± 2.70	45.20 ± 3.80	39.70 ± 2.70	23.10 ± 3.30	12.10 ± 3.60	28.04 ± 4.84	16.19±3.42	22.12 ± 4.13^{a}	IV
Ficus vasculosa	7.49 ± 1.12	5.25 ± 0.60	7.18 ± 1.64	6.80 ± 0.60	26.30 ± 3.60	14.70 ± 1.60	29.10 ± 4.30	47.20 ± 4.70	13.00 ± 2.50	13.30 ± 2.10	16.61 ± 2.63	17.45±1.92	17.03 ± 2.28^{cde}	IV
Gironniera subaequalis	0.91 ± 0.34	1.64 ± 0.50	4.24 ± 1.02	2.70 ± 1.50	12.30 ± 4.50	5.97 ± 1.40	13.60 ± 4.20	19.20 ± 5.40	8.10 ± 2.40	4.60 ± 1.80	7.83 ± 2.49	6.82±2.12	7.33 ± 2.31^{h}	III
Hymenaea courbaril	3.80 ± 0.40	2.05 ± 0.60	4.46 ± 1.22	2.10 ± 0.90	24.10 ± 10.11	4.00 ± 1.80	13.80 ± 2.10	10.40 ± 2.30	19.80 ± 4.60	8.50 ± 3.10	13.19 ± 3.69	5.41±1.74	9.30 ± 2.71^{gh}	III
Lindera polyantha	1.79 ± 0.98	1.45 ± 0.50	1.70 ± 0.68	0.90 ± 0.50	13.40 ± 4.24	10.80 ± 3.30	42.20 ± 8.00	1.80 ± 0.60	1.70 ± 0.80	0.70 ± 0.20	12.16 ± 2.94	3.13±1.02	7.64 ± 1.98^{h}	III
Neolitsea triplinervia	4.99 ± 0.99	3.89 ± 1.40	3.87 ± 1.49	3.00 ± 1.00	36.10 ± 14.20	24.10 ± 7.70	14.90 ± 6.00	28.20 ± 2.90	15.70 ± 7.60	15.25 ± 4.30	15.11 ± 6.06	14.89±3.46	15.00 ± 4.76^{ef}	IV
Sloanea sigun	8.31 ± 0.99	7.82 ± 0.90	17.69 ± 5.25	24.30 ± 6.70	37.42 ± 6.38	7.90 ± 2.40	33.40 ± 0.80	41.70 ± 2.20	13.80 ± 1.60	15.60 ± 4.40	22.12 ± 3.00	19.46±3.32	20.79 ± 3.16^{ab}	IV
Sterculia oblongata	7.35 ± 4.47	4.28 ± 1.10	6.69 ± 3.31	29.20 ± 2.60	18.70 ± 6.10	7.30 ± 4.50	35.90 ± 7.90	50.10 ± 3.20	17.20 ± 1.90	15.27 ± 1.30	17.17 ± 4.74	21.23±2.54	19.20 ± 3.64^{bc}	IV
Tamarindus indica	8.00 ± 1.23	7.26 ± 2.30	7.50 ± 2.30	5.40 ± 1.70	35.20 ± 6.45	18.80 ± 7.80	15.50 ± 3.30	16.50 ± 3.50	14.40 ± 4.70	9.70 ± 4.20	16.12 ± 3.60	11.53±3.90	13.83 ± 3.75^{f}	IV
Turpinia sphaerocarpa	2.74 ± 0.25	2.55 ± 0.40	1.12 ± 0.39	1.30 ± 1.00	4.41 ± 1.17	1.40 ± 1.00	9.00 ± 3.60	9.60 ± 0.90	5.90 ± 2.70	2.20 ± 0.40	4.63 ± 1.62	3.41±0.74	4.02 ± 1.18^{i}	II
Mean % loss	4.89 ± 1.17	4.26 ± 1.08	6.49 ± 2.30	7.25 ± 2.00	24.82 ± 5.85	10.00 ± 3.16	22.92 ± 3.57	24.21 ± 2.85	12.55 ± 3.13	9.51 ± 2.32	14.33 ± 3.20	11.05±2.28	12.69 ± 2.74	
Overall mean % loss	4.58 ± 1.13^{e}		6.87 ± 2.15^{d}		17.41 ± 4.50^{b}		23.56 ± 3.21^{a}		11.03 ± 2.73^{c}					

Overall mean percentage loss values followed by the same letters are not significantly different for screw-embedded specimens across fungi, control (no screw) specimens across fungi and fungi-exposed specimens across wood species (Tukey's test, $p < 0.05$), R = Resistance class where I is most resistant and V is least resistant (SNI 2014)

Table 3 Mean percentange weight loss of screws (±standard deviation) embedded in wood exposed to fungi for 12 weeks

Wood species	*Chaetomium globosum*	*Dacryopinax spathularia*	*Polyporus* sp.	*Pycnoporus sanguineus*	*Schizophyllum commune*	Overall mean % loss
Hymenia caurbaril	8.4 ± 0.5	7.8 ± 1.9	7.8 ± 0.9	8.7 ± 1.4	8.7 ± 0.7	8.3 ± 0.2 [a]
Diplodiscus sp.	7.3 ± 1.5	7.1 ± 0.8	7.6 ± 1.1	8.1 ± 0.9	7.1 ± 0.7	7.4 ± 0.2 [ab]
Tamarindus indica	7.7 ± 1.5	7.3 ± 1.7	7.1 ± 1.1	7.0 ± 0.9	6.0 ± 1.7	7.0 ± 0.3 [bc]
Ehretia accuminata	3.7 ± 1.7	8.1 ± 1.2	8.9 ± 1.4	5.1 ± 2.6	7.9 ± 1.7	6.7 ± 1.0 [bcd]
Acer niveum	7.8 ± 1.6	7.5 ± 1.1	4.3 ± 1.1	7.4 ± 1.3	6.0 ± 1.1	6.6 ± 0.7 [bcd]
Sloanea sigun	7.1 ± 1.4	6.9 ± 2.1	4.6 ± 0.8	5.8 ± 0.6	5.6 ± 1.1	6.0 ± 0.5 [ef]
Gironniera subaequalis	8.7 ± 1.2	4.7 ± 0.8	4.1 ± 1.2	7.1 ± 2.8	4.6 ± 1.3	5.8 ± 0.9 [d]
Ficus variegata	5.5 ± 1.3	4.9 ± 0.9	3.7 ± 0.9	3.3 ± 0.9	4.6 ± 1.0	4.4 ± 0.4 [e]
Neolitsea triplinervia	1.8 ± 1.1	5.0 ± 1.1	2.6 ± 0.4	4.7 ± 1.3	4.9 ± 0.5	3.8 ± 0.7 [ef]
Sterculia oblongata	4.6 ± 1.8	4.1 ± 1.2	1.8 ± 0.8	3.7 ± 0.6	4.7 ± 0.6	3.8 ± 0.5 [cd]
Calophyllum grandiflorum	6.2 ± 2.5	4.2 ± 1.5	0.9 ± 0.7	3.1 ± 1.1	3.4 ± 0.4	3.6 ± 0.9 [ef]
Ficus vasculosa	4.5 ± 1.4	4.6 ± 0.9	1.2 ± 0.2	3.7 ± 0.6	3.4 ± 1.0	3.5 ± 0.6 [ef]
Azadiracta indica	2.9 ± 1.4	2.6 ± 0.7	2.9 ± 0.9	3.4 ± 1.0	3.9 ± 1.1	3.1 ± 0.2 [f]
Turpinia sphaerocarpa	1.1 ± 1.2	3.6 ± 1.4	1.6 ± 0.5	5.9 ± 0.9	3.3 ± 0.9	3.1 ± 0.8 [f]
Lindera polyantha	0.8 ± 0.2	1.6 ± 1.0	1.2 ± 0.4	2.7 ± 0.6	1.6 ± 0.8	1.6 ± 0.3 [g]
Castanopsis tunggurut	0.9 ± 0.7	0.5 ± 0.4	1.9 ± 0.5	2.2 ± 1.3	1.7 ± 0.9	1.4 ± 0.3 [g]
Overall mean % loss	4.9 ± 0.7 [a]	5.0 ± 0.6 [a]	3.9 ± 0.7 [b]	5.1 ± 0.5 [a]	4.8 ± 0.5 [a]	4.8 ± 0.5

Overall mean percentage loss values in column or row followed by the same letter are not significantly different (Tukey's test, p < 0.05)

presence of fungi, with mean loss of 8.3 ± 0.2% across the five fungi. *Diplodiscus* sp., *T. indicus, E. acuminata* and *A. nivum* (all resistance class IV species that lost from 13.8 to 17.5% of their weight in the decay test) exhibited fairly high corrosive activity that was significantly higher than the remaining species (Tukey's, p < 0.05). Among the arbitrary grouping of wood species that showed moderate corrosive activity towards the metal screws, *F. variegata, S. sigun* and *S. oblongata* (mean screw weight losses of 4.4 ± 0.4, 6.0 ± 0.5 and 3.8 ± 0.7% respectively) were resistance class IV species that experienced the three highest weight losses in the decay test while *T. sphaerocarpa* and *A. indica* were resistance class II species that caused mean losses in screw weight of 3.1 ± 0.8 and 3.1 ± 0.2% respectively. Weight loss of screws extracted from *L. polyantha* and *C. tunggurut* (1.6 ± 0.3 and 1.4 ± 0.3 respectively) was significantly lower than that from *A. indica* and *T. sphaerocarpa* (Tukey's test, p < 0.05). The variability in weight loss of metals in physical contact with different wood species has been attributed to wood extractives that can corrode metal (Krilov 1987) and react with iron subsequently increasing corrosion (Krilov 1986). Additionally, wood with high acidity (pH < 4.0) are likely to be highly corrosive to metals while those with pH > 5.0 are regarded as relatively safe (Cole & Schofield 2000).

Screw corrosion in fungal culture media

Chaetomium globosum in culture media caused a 10.2% screw weight loss, significantly higher than that of *D. spathularia* (5.9%), which was in turn significantly greater than weight loss of screws exposed to the other fungi in culture media (1.3 to 2.6%, Table 4). The weight loss of screws exposed to *C. globosum* in culture media in this test was double that of screws exposed to *C. globosum* in contact with wood (Table 3). However, screw weight loss was lower in culture media than in the decay test for the other four fungi. Screw corrosion occurs at above 20% wood moisture content (Freas 1982) and the humid environment in which the specimens were maintained in the decay test likely encouraged fungal growth and

Table 4 Screw weight loss and discoloration following exposure to fungi in culture media for 12 weeks

Species	Weight loss (%)	Extent of discoloration		Final pH of media
		Screw head	Screw body	
Chaetomium globosum	10.24[a]	-	++	8.0
Dacryopinax spathularia	5.94[b]	-	+	5.1
Polyporus sp.	2.63[c]	+	++	3.4
Pycnoporus sanguineus	1.30[c]	-	+	5.1
Schizophyllum commune	2.29[c]	+	+	4.2
Without fungi (control)	1.87[c]	-	+	6.3

Mean column values of screw weight loss followed by the same letters are not significantly different (Tukey's test, $p \leq 0.05$); - = no discoloration on the screw, + and ++ = discoloration up to 25 and 50% respectively

accelerated metal corrosion. Microorganisms produce corrosive metabolites, e.g. inorganic and organic acids, sulphide, ammonia, carbon dioxide and nitrogen oxides (Juzeliunas et al. 2007). Further, humid conditions in the decay test enhanced corrosiveness of wood, which is slightly acidic (Baker 1980) thus jointly corroding the screws.

While discoloration covering up to 50% of the screw body surface was recorded for all screws, the screw head discoloured only in *Polyporus* sp. and *S. commune* innoculated culture media, which had the two lowest final pH values (3.4 and 4.2, Table 4). It was notable that pH of 8.0 was measured for *C. globosum*, being the only alkaline medium that also gave the greatest screw weight loss.

Wood and screw discoloration in decay test

Discoloration on the surface of the wood specimens occurred around the area of screw insertion and ranged in colour from greenish to blackish brown, in line with previous observations by Djarwanto (2009). The extent of discoloration on the wood surface (Table 5) appeared to correspond with how corroded were the screws in the decay test (Table 3). *Pycnoporus sanguineus* and *S. commune*, both of which caused the least weight loss from screws in the fungal culture test (Table 4), were associated with discoloration on all the wood species tested (Table 5) while *C. globosum*, which caused the highest weight loss from screws in the fungal culture test (Table 4), was associated with extensive discoloration only on *E. accuminata* and *A. indica* (Table 5). The surface of *A. indica* was extensively discoloured across all fungi (Table 5), even though screw weight loss was small (Table 3). Discoloration was not seen at all on half of the 16 wood species tested against *Polyporus* sp. (Table 5). While all screw heads showed an evenly brown colour 12 weeks into the decay test, screw heads were observed to turn a greenish white colour on *H. courbaril, E. accuminata* and *F. variegata* with *D. spathularia, T. indica* with *C. globosum* and *F. variegata* with *S. commune.* For these wood species, wood surface discoloration was greenish brown.

Regression analysis

Weight loss of wood was significantly correlated with wood density in the control wood specimens ($r = -0.642$, $p < 0.01$, Table 6) and decay resistance against fungi has been attributed to greater density (Takahashi & Kishima 1973). Dense wood tends to have more compact structure that fungi cannot easily penetrate, thus lowering the wood decay rate (Mori et al. 2013). While previous studies have found that wood extractives are positively correlated with decay resistance (e.g. Freas 1982, Li 2004, Li et al. 2007), our analysis found no significant correlations of the other wood properties with decay rate. Weight loss of screws however was negatively correlated with alcohol–benzene-soluble wood extractives ($r = -0.638$, $p < 0.01$) and positively correlated with MOR of the wood ($r = 0.583$, $p < 0.05$), but with MOE there was no significant correlation ($r = 0.036$).

Table 5 Rust discoloration on the surface of wood embedded with screws after exposure to fungi for 12 weeks

Wood species	*Chaetomium globosum*	*Dacryopinax spathularia*	*Polyporus* sp.	*Pycnoporus sanguineus*	*Schizophyllum commune*
Acer niveum	++	++++	-	+++	++
Azadiracta indica	++++	+++	++++	+++	+++
Calophyllum grandiflorum	-	+	-	+	+++
Castanopsis tunggurut	+	-	++	+	++
Diplodiscus sp.	++	+++	+	++++	+++
Ehretia accuminata	++++	++ §	++++	+++	++++
Ficus variegata	++	+++ §	+	+++	+++ §
Ficus vasculosa	+++	++	-	++	++
Gironniera subaequalis	+++	+++	-	+++	++++
Hymenaea caurbaril	+++	+++ §	+++	+++	++++
Lindera polyantha	-	+	++	+++	+
Neolitsea triplinervia	+	+++	-	++	+
Sloanea sigun	+++	+++	-	++	+++
Sterculia oblongata	+	++	-	+	+++
Tamarindus indica	- §	++	+	++++	++++
Turpinia sphaerocarpa	+	++++	-	++++	++++

- = no wood discoloration; + to ++++ = slight, moderate, rather widespread and extensive discoloration around the screws respectively; § = greenish white colour on screw surface

Table 6 Relationship between wood properties (X) and weight loss of wood and screws (Y)

Wood properties	Regression equation (Y = a + bX)	Coefficient of determination (r^2)	Correlation coefficient (r)
Control wood specimens (no screw embedded)			
Solubility in alcohol–benzene	Y = 7.74 + 1.33X	0.052	0.227^{ns}
Solubility in hot water	Y = 7.63 + 0.56 X	0.035	0.186^{ns}
Solubility in 1% NaOH	Y = 9.61 + 0.09X	0.002	0.044^{ns}
Wood density	Y = 24.43 – 21.67X	0.412	-0.642^{**}
MOE	Y = 15.62 – 0.00X	0.047	-0.218^{ns}
MOR	Y = 17.35 – 0.02X	0.098	-0.314^{ns}
pH (1:1)	Y = -6.77 + 3.43X	0.078	0.279^{ns}
Wood specimens with screw embedded			
Solubility in alcohol–benzene	Y = 16.06 – 0.69X	0.012	-0.125^{ns}
Solubility in hot water	Y = 17.71 – 0.55X	0.028	-0.166ns
Solubility in 1% NaOH	Y = 27.01 – 0.76X	0.122	-0.350^{ns}
Wood density	Y = 24.10 – 17.27X	0.214	-0.462^{ns}
MOE	Y = 15.31 – 0.00X	0.002	-0.042^{ns}
MOR	Y = 17.37 – 0.01X	0.019	-0.137^{ns}
pH (1:1)	Y = -19.61 + 4.98X	0.201	0.448^{ns}
Screws extracted from wood			
Solubility in alcohol–benzene	Y = 7.79 – 1.21X	0.407	-0.638^{**}
Solubility in hot water	Y = 6.19 – 0.23X	0.057	-0.239^{ns}
Solubility in 1 % NaOH	Y = 8.40 – 0.22X	0.116	-0.341^{ns}
Wood density	Y = 4.04 + 1.17X	0.011	0.106^{ns}
MOE	Y = 3.46 + 0.00X	0.036	0.191^{ns}
MOR	Y = 0.95 + 0.01X	0.340	0.584^{*}
pH (1:1)	Y = 2.01 + 0.45X	0.015	0.124^{ns}

MOE = modulus of elasticity, MOR = modulus of rupture; ** = highly significant, * = significant, ^{ns} = not significant

CONCLUSIONS

Based on the wood resistance against fungi, *Azadirachta indica, Castanopsis tunggurut* and *Turpinia sphaerocarpa* could be classified as resistant species (resistance class, R II). *Gironniera subaequalis, Lindera polyantha* and *Hymenaea courbaril* were moderately resistant to decay (R III), and *Callophyllum grandiflorum, Tamarindus indica, Neolitsa triplinervia, Acer niveum, Ehretia accumminata, Diplodiscus* sp., *Ficus vasculosa, Sterculia oblongata, Sloanea sigun* and *Ficus variegata,* were classified as resistance class IV. The decay screw-embedded wood was greater than wood without screw. *Hymenaea courbaril* wood was more corrosive to metal screw than the rest of the tested wood. Screw-embedded wood exposed to *Polyporus* sp. had the lowest corrosive activity, while *Chaetomium globosum* had the highest corrosive activity on screw when exposed in culture media. There was negative correlation between wood weight loss and wood density of control specimens. Wood weight loss was positively correlated with MOR of wood. Wood extractives, MOE were not significantly correlated with wood decay and corrosion of screw.

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