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A novel wood preservative with plant extracts in a cypermethrin mixture protects envelope-treated tropical kempas hardwood against *Coptotermes* termites when exposed to an above-ground indoor situation after evaporative ageing

Photo 1.
Two top-covered rectangular zinc containers were positioned upright on the ground at the forest test site for the aboveground termite field test against *Coptotermes curvignathus*. Test wood blocks were held above ground inside the containers in between abundant termite-susceptible baitwood and corrugated cardboard material. Termites invade the contents from below the ground inside the containers.
Photo A. H. H. Wong.

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RÉSUMÉ

Un nouveau produit de préservation du bois à base d'extraits végétaux mélangés à de la cyperméthrine protège le bois tropical de kempas, traité par imprégnation, contre les termites *Coptotermes*, en situation intérieure, hors-sol, après vieillissement par évaporation

Dans un contexte d'initiatives de l'industrie de la protection du bois visant à développer des solutions de traitement du bois économiquement viables et écologiquement compatibles pouvant remplacer les biocides conventionnels, cet article rend compte d'un essai hors sol de protection contre les dégâts de termites souterrains sur des blocs de duramen de kempas (*Koompassia malaccensis*), un bois dur tropical (malaisien) sensible aux termites. Les blocs ont été traités par imprégnation (brossage) avec un nouveau produit de préservation du bois à base d'extraits de plantes dans un mélange de cyperméthrine (Biocide 1 : 0,16 % de cyperméthrine, 0,08 % de tébuconazole, 2 % d'extraits végétaux). Un traitement disponible à la vente, à base de solvant organique (LOSP) et de perméthrine (Biocide 2 : 0,2 % de perméthrine, 1,8 % de naphténate de tributylétain, 0,1 % de dichlorofluanide) en trempage de 3 mn a servi de traitement de référence. Les blocs de kempas séchés à l'air libre ont subi une fragilisation de type H2 dans le cadre d'un régime rigoureux de volatilisation en laboratoire (représentant un vieillissement long par évaporation du bois traité pour une utilisation hors sol en intérieur dans des situations à risque H2 prolongé). Les blocs ont ensuite été exposés pendant 6 mois en surface, à l'intérieur d'un conteneur d'essai conçu pour les termites souterrains *Coptotermes curvignathus*, sur un site forestier humide (représentant une situation à risque H2 sévère pour bois traité hors contact avec le sol et isolé de l'humidité et des conditions météorologiques). Les résultats ont montré de manière irréfutable que le duramen de kempas non traité était sévèrement attaqué par *C. curvignathus* (perte de masse moyenne : 70,4 % et 20 416 mg), l'indice visuel moyen de présence de termites étant faible (2,4). À l'inverse, le bois de kempas traité était bien protégé avec une très faible rétention en surface du Biocide 1 (perte de masse moyenne négligeable : 0,66 % et 207 mg) et une très faible rétention en surface du Biocide 2 de référence (perte de masse moyenne négligeable : 1,01 % et 306 mg). Les deux traitements ont produit l'indice visuel de présence de termites le plus élevé (10) pour tous les échantillons de kempas répliqués. Les performances des deux biocides sont ainsi semblables, mais diffèrent de manière significative (P < 0,05) de celles des homologues non traités et attaqués. Le biocide 1 a donc un potentiel anti-termites considérable et pourrait remplacer le biocide 2 LOSP conventionnel pour protéger les bois exposés à un environnement à risque H2 à long terme.

Mots-clés : *Coptotermes curvignathus*, pyréthrinoïde, traitement par imprégnation, expérimentation termites, kempas, bois dur tropical, solvant organique, LOSP, additif non-biocide, classe de risque H2, protection du bois.

ABSTRACT

A novel wood preservative with plant extracts in a cypermethrin mixture protects envelope-treated tropical kempas hardwood against *Coptotermes* termites when exposed to an above-ground indoor situation after evaporative ageing

In keeping with sustainability initiatives in the commercial wood protection sector to develop cost-effective, environmentally acceptable wood treatment alternatives to traditional biocides, this paper reports on an above-ground test for protection against subterranean termite damage to blocks of termite-susceptible heartwood of tropical (Malaysian) kempas hardwood (*Koompassia malaccensis*). The blocks were envelope-treated (brush-on) with a novel wood preservative based on plant extracts in a cypermethrin mixture (Biocide 1: 0.16% cypermethrin, 0.08% tebuconazole, 2% vegetal extracts). A commercial permethrin-based LOSP (Biocide 2: 0.2% permethrin, 1.8% tributyltin naphthenate, 0.1% dichlorofluanid) applied in 3-minute dips served as the control treatment. The air-dried kempas blocks were H2-weathered under a rigorous laboratory volatilization regime (representing long-term evaporative ageing of treated wood for above-ground indoor use in prolonged H2-hazard class situations). The blocks were then exposed for 6 months above ground, inside a containerised test design targeting subterranean *Coptotermes curvignathus* termites, at a humid forest site (representing a severe H2-hazard class situation with treated wood isolated from wetting, soil contact, and weather). The results showed irrefutably that untreated kempas heartwood was severely attacked by *C. curvignathus* (mean mass loss: 70.4% and 20,416 mg) with a low mean visual termite rating (2.4). However, the treated kempas wood was well protected at very low surface retention of Biocide 1 (mean negligible mass loss: 0.66% and 207 mg) and very low surface retention of the control Biocide 2 (mean negligible mass loss: 1.01% and 306 mg), with both treatments similarly yielding the highest mean visual termite rating for all replicate kempas specimens (rating 10). The performances of the two biocides were similar but varied significantly (P < 0.05) from the attacks against their untreated counterparts. Biocide 1 therefore has considerable anti-termite potential and could replace conventional LOSP Biocide 2 treatments to protect wood exposed to a long-term H2-hazard class environment.

Keywords: *Coptotermes curvignathus*, pyrethroid, envelope treatment, termite test, kempas, tropical hardwood, LOSP, non-biocidal additive, H2 hazard class, wood protection.

RESUMEN

Un nuevo tratamiento superficial de la madera consistente en una mezcla de extractos de plantas con cipermetrina protege la madera dura de kempas tropical ante las termitas *Coptotermes* cuando se expone a un ambiente interior en superficie después de un envejecimiento evaporativo

Para continuar con iniciativas sostenibles en el sector de la protección de la madera comercial, se desarrollan soluciones de tratamiento de la madera rentables y medioambientalmente aceptables que puedan sustituir a los biocidas tradicionales. Este artículo describe un ensayo de protección en condiciones de superficie contra los daños de termitas subterráneas en bloques de duramen de madera dura de kempas tropical malayo (*Koompassia malaccensis*), vulnerables a las termitas. Los bloques se trataron superficialmente (cepillado) con un nuevo protector de la madera basado en una mezcla de extractos de plantas con cipermetrina (biocida 1: 0,16 % cipermetrina, 0,08 % tebuconazol, 2 % extractos vegetales). Un LOSP (conservante a base de disolventes orgánicos ligeros) comercial basado en el permetrín (biocida 2: 0,2 % permetrín, 1,8 % naftenato de tributilestaño, 0,1 % diclofluanido) aplicado en una inmersión de tres minutos se utilizó como tratamiento control. Los bloques de kempas secados al aire se sometieron a un envejecimiento climático H2 en un riguroso régimen de volatilización de laboratorio (que equivale a un envejecimiento evaporativo a largo plazo de la madera tratada en un ambiente interior sobre una superficie en situaciones de peligro de clase H2 prolongadas). Los bloques se expusieron a continuación durante seis meses en superficie, dentro de contenedores diseñados para ensayos con termitas subterráneas *Coptotermes curvignathus*, en una zona de bosque húmedo (que representa una situación de peligro de clase H2 severa con la madera tratada aislada de la humedad, del contacto con el suelo y de la climatología). Los resultados mostraron irrefutablemente que el duramen de kempas no tratado era gravemente atacado por las *C. curvignathus* (pérdida de masa media: 70,4 % y 20 416 mg) con una valoración visual media de termitas (2,4). Sin embargo, la madera de kempas tratada estaba bien protegida con una retención superficial muy baja del biocida 1 (pérdida de masa media negligible: 0,66 % y 207 mg) y una retención en superficie muy baja del biocida 2 de control (pérdida de masa media negligible: 1,01 % y 306 mg). Ambos tratamientos proporcionaron una clasificación visual media de termitas elevada similar para todas las muestras de kempas replicadas (10). El rendimiento de ambos biocidas fue similar, aunque se diferenció significativamente (P < 0,05) de los equivalentes no tratados atacados. Por lo tanto, el biocida 1 tiene un considerable potencial antitermitas y puede sustituir a los tratamientos convencionales con LOSP biocida 2 para proteger a la madera expuesta a un ambiente con peligro de clase H2 a largo plazo.

Palabras clave: *Coptotermes curvignathus*, piretroide, tratamiento superficial, ensayo con termitas, kempas, madera dura tropical, LOSP, aditivo no biocida, clase de peligro H2, protección de la madera.

Introduction

The wood protection industry in many progressive economies of the world is faced with stringent regulations and environmental pressures and has to develop more environmentally acceptable wood treatment/protection strategies accommodating a fit-for-purpose treatment rationale to protect the wood at low levels of biocide to reduce consequent chemical wastage and environmental contamination normally attributed to excess use of treating solutions. Sustainability and carbon footprint issues are also driving a change in wood preservation, aimed at securing a low-environmental impact wood protection activity at the workplace while securing quality-treated wood products. Traditionally, wood preservation using hazardous heavy metals, creosote, and other organo-metals, either as various forms of water-based solutions, heavy oils or organic solvents that often require high preservative retentions in pressure-treated wood, has raised serious concerns about the workplace safety and environmental safety of such treated wood (UNEP 1994; Freeman et al. 2003). This has spurred wood protection research and development in favour of safer non-arsenical, chromium-free, other non-metallics, organic-based, and bio-based, water-borne wood preservative systems (Barnes 1993; Green III and Schultz 2003; Schultz and Nicholas 2003; Coggins 2008).

Envelope wood treatment technology (using simple dipping, deluging, spray-on or brush-on) with novel formulations has thus emerged and is partly focused on wood protection against termites and decay fungi of solid wood or wood composites. Presumably, these formulations would be superior to traditional emulsifiable concentrates, suspension concentrates, or light organic solvent formulations often using pyrethroid and other organic termiticides at high dosages (Sornnuwat et al. 1994; Peters and Creffield 2003; Donath et al. 2008; Sukartana et al. 2009; Tawi and Wong 2016). Termite testings of these traditional termiticides were also evaluated as pressure-treated wood when increased termiticide penetration into the wood was desired (Creffield et al. 2013; Scown and Creffield 2009). A new generation of bio-based microemulsion termiticidal (pyrethroid-based) formulation technology with KO@LIB antioxidant additive (Messaoudi et al. 2018) has now emerged from the laboratory of Groupe Berkem (France), popular in Europe for envelope (dip) – and pressure-treatment of wood and wood-based products – and has been recently considered in Indonesia using the lowest emission costs (eco-costs) Life Cycle Assessment (LCA) methodology (Siswanti et al. 2016). Also, such enveloped-treated wood from this technology even conferred up to 8 mm cypermethrin penetration into the wood (Ruel et al. 2015). With expertise and knowledge in biocidal formulations, especially for wood preservation, for over 50 years, Groupe Berkem patented the first microemulsion technology for dipping treatments in Europe. Such water-borne products can, with practical dipping or aspersion treatments and adequate dipping times and effective concentrations, also enhance the durability performance of tropical hardwoods against termites under Malaysian H2-H3 biological hazard class conditions (Wong 2004) found in the humid tropics, as was favourably reported in kempas, *Koompassia malaccensis*, dip-treated in a cypermethrin- and a permethrin-based patented microemulsion formulation (Messaoudi et al. 2020ab). The Malaysian biological hazard class selection guide (Wong 2004), broadly similar to that described by the Australian Standards AS1604.1 (AS 2005), classifies H2-hazard class situation where serviced wood such as framing, flooring, and furniture are exposed aboveground indoors and protected from wetting to avoid leaching of biocides from serviced wood (i.e. dry situations), while the test wood samples encountered natural evaporative ageing (i.e. H2-weathering) and termites (and wood borers) under prolonged exposures. H3-hazard class situation concerns wood exposed aboveground outdoors subjected to combined leaching and evaporative ageing (i.e. H3-weathering), termites, wood borers, and decay fungi risks. Pyrethroid-based treated woods are not suitable for use in the more severe, in ground-contact (H4- and H5-hazard class) and marine (H6-hazard class), environments.

Another patented formulation of Groupe Berkem, partly based on a cypermethrin-non-biocidal vegetal extracts mixture (SYNERKEM® technology), is developed as a brushed-on envelope treatment for likely permanent wood protection in aboveground (H2 and H3 hazard class) situations. This paper presents key findings from the accelerated tropical (Malaysian) H2-hazard class subterranean termite test of the performance of this novel bio-based formulation on H2-weathered envelope-treated Malaysian hardwood kempas (*K. malaccensis*) against subterranean termites *Coptotermes curvignathus*.

Experimental methods

The field trials were undertaken using an established H2-hazard class aboveground termite field test protocol (Wong 2005), meant to accelerate termite infestation (and exclude fungal mould growth and decay) and shielded from wetting by rainwater, by exposure of test wood specimens aboveground contact inside covered containers and sandwiched among termite-susceptible wooden baits. Containers were sited on a peripheral humid peat swamp forest area in Kota Samarahan, Sarawak, Malaysia, where subterranean termites *Coptotermes curvignathus* are prevalent (photo 1). *Coptotermes curvignathus* is representative of the aggressive *Coptotermes* subterranean termites found attacking the construction wood of urban buildings in Malaysia and much of Southeast Asia (Lee 2002; Sornnuwat et al. 1996). This termite test protocol (Wong 2005) represents an extreme Malaysian H2-hazard class situation whereby the initially dry situation (no wetting) inside the test assembly ultimately predisposes artificially H2-weathered test wood samples to potential termite risks under prolonged exposures.

The Malaysian hardwood selected for the envelope preservative treatment and termite testing was the structural commercial termite-susceptible kempas (*K. malaccensis*) heartwood material, widely used in Malaysia and abroad for medium to heavy construction indoors and outdoors (Wong 1982; Anonymous 1999). Replicated (n = 8) air-dried test blocks [2.5 × 4 × 5 (length) cm] of kempas (photo 2) heartwood were oven-dried (105 °C, 48 h), weighed, and then allowed to air dry at room temperature for 12 weeks before biocidal treatment. Then, immediately before biocidal treatment, the air-dried blocks were weighed and then dipped for 3 mn, in a reference proprietary nominal 0.2% permethrin-based light organic solvent preservative (LOSP) solution (Biocide 2), and the freshly treated wood was immediately weighed in order to measure weight gain denoting solution uptake (g) meant to estimate surface retention of permethrin expressed as oven dry weight basis (%g/g), wood surface area basis (g/m^2), and wood volume basis (g/m^3) of permethrin. Another replicated (n = 8) set of blocks was brushed-on with the candidate Biocide 1 paste (a cypermethrin-based water-borne preservative mixed with non-biocidal additive vegetal extracts) until the wood surfaces were coated, and then immediately weighed in order to measure weight gain due to coating uptake and hence estimate surface cypermethrin retention similarly as for Biocide 2 treatment. The descriptions of Biocide 1 and Biocide 2 are given in table I. Replicated (n = 8) untreated test blocks served as controls for the experiment. Freshly-treated blocks with Biocides 1 and 2 were then air dried for at least 8 weeks at room temperature to permit the adsorption of pyrethroid in the wood. To simulate the long-term weathered condition of treated wood used aboveground indoors, deemed as H2-hazard class situation (Wong 2004), treated and untreated blocks were next subjected to laboratory evaporative ageing (i.e. Induced H2-weathering) by oven drying at 40 °C for 18 days before termite testing. Such weathered, untreated, and treated wood blocks were exposed to subterranean termites *C. curvignathus* in the field for six months under severe H2-hazard class (i.e. abo-

Photo 2.
Two test blocks {2.5 x 4 x 5 (length) cm] of kempas (*Koompassia malaccensis*) heartwood representing structural medium density hardwoods used in Malaysia.
Photo A. H. H. Wong.

Table I.
Partial composition of candidate Biocide 1 and reference Biocide 2.

Wood preservative product	Nominal composition of active (%g/g)	Solvent	Application
Biocide 1 (Xilix® 7000K)	Cypermethrin (0.16%) Tebuconazole (0.08%) Vegetal extracts (2%)	Water	Brush-on
Biocide 2 (Reference)	Permethrin (0.2%) Tributyltin naphthenate (1.8%) Dichlorofluanid (0.1%)	White spirit	Dipping 3 minutes

Table II.
AWPA E7-07 visual termite rating scale (AWPA 2008).

Rating	Description
10	Sound
9.5	Trace, surface nibbles permitted
9	Slight attack, ≤ 3% of cross-sectional area affected
8	Moderate attack, 3-10% cross-sectional area affected
7	Moderately severe attack and penetration, 10-30% of cross-sectional area affected
6	Severe attack, 30-50% of cross-sectional area affected
4	Very severe attack, 50-75% of cross-sectional area affected
0	Failure (destroyed)

veground contact, protected from wetting) situations inside the termite test assembly of Wong (2005). At the end of the termite field test, the test heartwood blocks were retrieved from the test assembly, cleaned, and visually rated for degree of termite attack (table II, AWPA 2007) using the AWPA E7-07 scale: 10 (sound),..., 6 (severe attack),..., until 0 (failure). The blocks were then re-weighed oven dry (105 °C, 48 h) so as to calculate oven-dry mass differences expressed as percent mass loss per unit before-test oven dry weight, and absolute mass loss (mg).

Data were interrogated by One-way ANOVA using MINITAB-14 software, with multiple comparison t-tests of mean values (for termite rating, percent mass loss, and milligramme mass loss) by Least Significant Difference (LSD, $P < 0.05$) to examine the relative hardwood protection from termites between Biocide 1 treated, Biocide 2 treated and untreated H2-weathered woods blocks.

Results and discussion

Synthetic pyrethroids in both Biocide formulations are of interest here concerning kempas heartwood protection against *C. curvignathus* as fungicides of these biocides are regarded as not effective against termites. The 3-minute dipping of air-dried kempas heartwood with reference Biocide 2 and the brush-on treatment of kempas heartwood with Biocide 1 yielded low mean retentions of each pyrethroid adsorbed onto the wood surfaces (calculated as either g/m^2, g/m^3, or %g/g) shown in table III. Notably, the low applied pyrethroid concentrations in these biocides (0.16% cypermethrin and 0.2% permethrin, table I) were considerably less or quite similar to those normally applied by others in the laboratory (e.g. Read and Berry 1984; Sornnuwat et al. 1994) and field termite tests (Tawi 2019), which expectedly yielded considerably low surface retention expressions shown (table III). Mean Biocide 1 cypermethrin retention in kempas (0.004%g/g, 24.76 g/m^3) differed from that found for kempas dip-treated with 0.16% cypermethrin in microemulsion solution (0.0047%g/g, 40.54 g/m^3) of Messaoudi et al. (2020b). Mean Biocide 2 permethrin retention in kempas (0.0042%g/g, 25 g/m^3) also differed from that in kempas dip-treated with 0.2% permethrin in microemulsion solution (0.0039%g/g, 36.21 g/m^3) of Messaoudi et al. (2020b). It is probable that the microemulsion solutions of Messaoudi et al. (2020ab) can yield slightly higher "g/m^3" retention of these pyrethroids than either Biocide 1 or the reference Biocide 2. Notably, despite the low kempas surface retention of these pyrethroids from Biocide 1 and Biocide 2, both severely H2-weathered treated kempas were nevertheless immune to termite attack compared to H2-weathered untreated kempas, based on mean wood percent mass loss, mean milligramme wood mass loss, and mean visual termite rating values (table IV). There were highly significant differences ($P < 0.05$) in mean termite attacks between treated and untreated kempas [mean termite rating of 10 (for Biocides 1 and 2) versus 2.4 (untreated); mean mass loss of 0.66%g/g (Biocide 1) or 1.01%g/g (Biocide 2) versus 70.4%g/g (untreated); mean absolute mass loss of 207 mg (Biocide 1) or 306 mg (Biocide 2) versus 20,416 mg (untreated)] while comparably excellent performance by Biocide 1 and Biocide 2 was hence confirmed (table IV). However, with pyrethroid formulations, the reference Biocide 2, containing white spirit solvent of LOSP, is increasingly not regarded as environmentally acceptable, unlike alternative pyrethroid biocides such as Biocide 1.

For comparison with previous applications of pyrethroids in traditional formulations, Read and Berry (1984) revealed that a 0.1% concentration of cypermethrin emulsion using surface application was sufficient against *Reticulitermes* termites. Zaidon et al. (2008) found that exposure of rubberwood particleboard, empty fruit bunch (EFB) particleboard, and Rubberwood-EFB particleboard

Table III.
Nominal surface retention of synthetic pyrethroid in wood determined by solution uptake of Biocide 1 (brush-on) and Biocide 2 (dipping).

Wood preservative	Nominal composition of pyrethroid (%g/g)	Mean retention (%g/g)	Mean retention (g/m^2)	Mean retention (g/m^3)
Biocide 1 (Xilix® 7000K)	Cypermethrin: 0.16	0.0040 (0.0002)	0.14 (0.006)	24.76 (1.05)
Biocide 2 (Reference)	Permethrin: 0.2	0.0042 (0.0004)	0.14 (0.008)	25.00 (1.51)

n = 8; ( ) = standard error of the mean.

Table IV.
Mean values of termite attack parameters comparing 2 treated and 1 untreated kempas, *Koompassia malaccensis*, heartwoods exposed to H2-hazard class situation.

Treatment	Percent mass loss (%g/g)	Absolute mass loss (mg)	Termite rating
Untreated, H2-weathered	70.4 (14.2)	20,416 (4110)	2.4 (1.2)
Biocide 1 (Xilix® 7000K) Surface-treated with cypermethrin/vegetal extracts mixture, H2-weathered	0.66a (0.04)	207a (10)	10a (0)
Biocide 2 Surface-treated with LOSP containing permethrin, H2-weathered	1.01a (0.41)	306a (125)	10a (0)
LSD values	24.21	6984	2.1

LSD values used for comparison within-column mean values: within-column means sharing the same letter "a" denotes that mean values do not differ at $P < 0.05$ sig. level; n = 8; ( ) denotes standard error of the mean.

sprayed with 0.2% permethrin solution yielded low mean mass loss (range: 7.2-12.1%) though failed to confer complete protection, with appreciable attacks on untreated susceptible counterparts (range: 17.8-31.1%) against *C. curvignathus*. Excellent protection was reported from a laboratory evaluation of 5-min dip-treated rubberwood blocks exposed to *C. gestroi* at 0.015, 0.25, and 0.5% cypermethrin and at 0.5, 1 and 2% permethrin (Sornnuwat et al. 1994). Perceivably, such laboratory screening test results, performed without prior evaporative ageing of treated wood blocks, are not necessarily reliable nor comparable with field termite tests, which are realistic for wood protection applications. Indeed, H2-hazard class termite field tests (Tawi 2019) on unweathered wood revealed instead that relatively higher levels of both emulsifiable concentrate-based permethrin (1.69-6.75%) and cypermethrin (1.68-3.35%) agropesticide were needed to fully protect hardwoods from *C. curvignathus* attack. Under similar conditions, traditional water-borne pyrethroid formulations (e.g. emulsifiable or suspension concentrates) could confer termite resistance to dip-treated wood either at longer dipping (steeping) durations, and/or increasing pyrethroid concentrations with consequent termiticide retentions in wood (Sornnuwat et al. 1994; Kamdem et al. 1996; Ma et al. 2013; Tawi 2019). By contrast, when testing weathered treated wood, which represents the true condition of treated wood in longer-term use, Messaoudi et al. (2020b) reported that a 3-minute dipping time protected severely artificially weathered treated kempas remarkably well against termites in the field under H2 and H3 hazard classes, even at their lowest pyrethroid concentrations of microemulsion formulation solution. Termite testing of weathered treated wood represents a realistic measure of longer-term preservative performance against termites in this case, performed also by others (e.g. Peters and Creffield 2003; Sukartana et al. 2009; Creffield et al. 2013). Also, the applied pyrethroid concentrations used with Biocide 1 and microemulsion solutions by Messaoudi et al. (2020ab) were comparably effective to those generally confirmed to be efficient against *Reticulitermes* termites (Adkalis 2018ab).

Since preservative performance against wood-degrading organisms obviously depends mainly on wood species, target preservative retention, treating concentrations and treatment methods, and penetration of the preservative into the wood, the unique envelope treatment microemulsion technology reported by Messaoudi et al. (2020ab) can provide up to 8 mm pyrethroid penetration into wood (Ruel et al. 2015) for termite durability performance in aboveground contact, when adequate wood treatment parameters are applied. There may also be good pyrethroid penetration into kempas shown by the excellent termite resistance performance of Biocide 1 (present study) based on the SYNERKEM® technology, where the component non-biocidal additive vegetal extracts are claimed to act as a booster for cypermethrin efficacy for wood protection and enhancing the fixation of cypermethrin in Biocide 1 into wood cell walls even after evaporative ageing treatment (Ruel et al. 2015). Applying mixtures of non-biocidal additives and organic biocides here represents a novel environmentally friendly concept in wood protection that enhances both the bioefficacy and cost-effectiveness of such a wood preservative system (Green III and Schultz 2003).

Some national wood preservation standards in various regions traditionally specify a high minimum pyrethroid retention with penetration of the active in the wood used in construction, deem as adequately treated wood, and that pyrethroid penetration is achieved via a low-pressure impregnation process. Notably, the Australian Standard AS1604.1 (AS 2005) for preservative treatment of sawn and round timber specifies a relatively higher minimum retention of cypermethrin (0.03%g/g) and permethrin (0.02%g/g) within the 5-8 mm penetration zone, especially for microemulsion or LOSP-based double-vacuum-treated wood for H2-hazard class uses. The exception in AS1604.1 is the use of permethrin, bifenthrin, and imidacloprid for solid wood envelope treatment, albeit at high retention (respectively 0.02%g/g, 0.02%g/g and 0.0078%g/g retention) at the 2 mm penetration zone. However, the present termite test on Biocide 1, as with that of microemulsion-based pyrethroids reported in Messaoudi et al. (2020ab), at considerably lower cypermethrin surface retention (comparable to the reference Biocide 2 LOSP) from envelope treatment, was sufficient to protect kempas against termites as a “fit-for-purpose” wood preservative system. Thus, envelope wood protection of long-lived structures with such innovative formulations (e.g. Messaoudi et al. 2020ab; present study) would certainly befit an environmentally conscious society.

Conclusion

The patented water-borne Biocide 1 formulation (comprising cypermethrin, tebuconazole, and vegetal extracts) provided excellent protection of H2-weathered treated kempas, *Koompassia malaccensis,* from *Coptotermes* subterranean termites aboveground contact indoors exposure, comparable to the reference LOSP Biocide 2 (comprising permethrin, tributyltin naphthenate, and dichlorofluanid), while preliminary observations (to be reaffirmed) even suggest that Biocide 1 could be used to protect wood from termites under H3-weathered situations (treated wood exposed aboveground, outdoors), while the response of the biocide aboveground outdoors to fungal decay threats should also be ascertained. Thus, Biocide 1 is a promising eco-friendly and cost-effective new generation wood preservative for aboveground wood protection against termites, and its use in envelope treatment leads to a greener future for wood protection.

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Access to data

The detailed data obtained through this study and presented in this article can be asked to Groupe Berkem.

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