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Effect of burgundy solid extracted from Eastern Red Cedar heartwood on subterranean termites and Wood-decay fungi*

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ABSTRACT

Eastern red cedar (ERC) is an abundant natural resource in the U.S. and has been investigated for the extraction of cedarwood oil (CWO) and CWO bioactivity, particularly its use to protect wood against termites and decay fungi. Methanol extraction of ERC sawdust gives a burgundy-colored oil (BO) that is comprised of both CWO and a burgundy solid (BS). The BO was significantly more inhibitory against two species of white-rot decay fungi than CWO alone, suggesting the BS itself might have inhibitory bioactivity. This study investigated the wood preservation properties of the BS alone, in combination with CWO and in conjunction with an amylose inclusion complex (AIC) against termites, brown-rot decay fungi and white-rot decay fungi. Wood was treated by vacuum/pressure impregnation and tested for resistance to subterranean termites and four species of decay fungi. The AIC alone made wood less palatable (16% mass loss versus 32% for H_2O) and more toxic (32% mortality versus 26% for H_2O) to termites but did not inhibit either brown-rot fungi nor the white-rot *Trametes versicolor* but did inhibit the white-rot *Irpex lacteus* (49% mass loss versus 65% for H_2O). The CWO led to both lower wood mass loss by termites and higher termite mortality as well as having an inhibitory effect on the white-rot decay fungi. However, a combination of AIC and CWO was necessary to have an inhibitory effect on the brown-rot fungi. The addition of BS to the AIC had a minor inhibitory effect on wood mass loss by termites (11% versus 16% for AIC) but did not inhibit either brown-rot fungi nor the white-rot *I. lacteus*. The addition of BS to the AIC decreased wood mass loss by the white-rot *T. versicolor* (38% versus 49% for AIC). Wood blocks impregnated with the combination of the AIC, CWO and BS resulted in the highest termite mortality (i.e., 100%), lowest percentage wood mass loss for the termites (i.e., 6%) and lowest percentage wood mass losses for all four species of wood decay fungi studied (less than 20% overall).

1. Introduction

Because of potential adverse effects of some wood preservatives on the environment and human health, there is considerable interest in safer alternative wood protection methods (Barbero-López et al., 2019; Bi et al., 2019). Transferable durability is a promising technique that uses extractives from naturally resistant materials to preserve susceptible wood (Kirker et al., 2013; Tascioglu et al., 2013). This method is particularly efficient if the extracts originate from a material that is a sustainable by-product or waste (Saha Tchinda et al., 2018). Our laboratory has been investigating the potential of using extracts of Eastern red cedar (ERC) (*Juniperus virginiana* L.) (Cupressaceae) sawdust as a preservative for other less durable woods.

In the United States, ERC is an abundant (Schmidt and Leatherberry, 1995) but underutilized natural resource with potentially great economic opportunities (Eller et al., 2010). Previous research has demonstrated that ERC heartwood is resistant to subterranean termites (Carter and Smythe, 1974; Arango et al., 2006; Kard et al., 2007; Kose

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and Taylor, 2012; Konemann et al., 2014). In addition, extracts of ERC heartwood have been reported to be toxic to termites (Adams et al., 1988; Carter, 1976; McDaniel et al., 1989) or to reduce termite attack when used to treat southern pine (McDaniel and Dunn, 1994).

Our laboratory has investigated several aspects of the chemistry of ERC including the extraction of cedarwood oil (CWO) by supercritical and liquid carbon dioxide (Eller and King, 2000; Eller and Taylor, 2004; Eller et al., 2010; Eller and Teel, 2019), pressurized solvent extraction (Eller et al., 2010; Tumen et al., 2013) and Soxhlet extraction (Eller, 2018). In addition, we have studied the bioactivity of ERC extracts in numerous systems including as a wood preservative against subterranean termites (Eller et al., 2010, 2018) and brown-rot and white rot decay fungi (Eller et al., 2010; Tumen et al., 2013; Eller et al., 2018), as an ant repellent (Eller et al., 2014, 2015) and as an pesticide against ticks, houseflies and mosquitoes (Eller et al., 2014; Eller, 2018). Cedarwood oil contains over 30 sesquiterpene hydrocarbons and alcohols (Heide et al., 1988). Several flavonoid compounds (i.e., quercetin, taxifolin, and naringenin) have been identified from a methanol extract of ERC and shown to stimulate oviposition by ladybird beetles (Riddick et al., 2018a, b).

Tumen et al. (2013) reported that the methanol extraction of ERC sawdust yielded a viscous burgundy-colored oil (BO) comprised of both the relatively non-polar CWO and a polar burgundy-colored solid (BS). The CWO can be extracted from ERC sawdust using a non-polar solvent like liquid carbon dioxide (L-CO_2), supercritical carbon dioxide (SC-CO_2), pressurized hexane extraction, and hexane Soxhlet (Eller, 2018). The BS can be extracted from ERC sawdust after first extracting the sawdust with CO_2 or hexane to remove the CWO then extracting with methanol. Tumen et al. (2013) reported the BO extract (containing both CWO and BS) was significantly more inhibitory against two species of white-rot decay fungi than an extract containing CWO alone (i.e., a hexane extract of ERC sawdust). However, the BO extract was not significantly more effective against either of two species of brown-rot decay fungi than the extract containing CWO alone.

Similarly, Eller et al. (2010) reported that an ethanol extract of ERC sawdust containing both the BS and CWO was not statistically more inhibitory than a CO_2 extract of ERC sawdust containing only CWO against either brown-rot fungi or subterranean termites. Only the ethanol extract of ERC sawdust conferred any significant inhibition against the brown-rot, *Rhodonia* (*Postia*) *placenta*, suggesting that the presence of the BS did inhibit this species of brown-rot fungus. Conversely, the CO_2 extract of ERC sawdust containing only CWO was significantly more inhibitory against the brown-rot fungus, *Gloeophyllum trabeum* than the ethanol extract of ERC sawdust containing both CWO and BS. It should be noted however, in that study, the total concentrations of extracts were held constant, meaning the concentration of CWO in the ethanol extract (i.e., BO) was approximately half the concentration of CWO in the CO_2 extract. The concentrations of CWO and BS in ERC sawdust are approximately equal at about 3 percent. This difference in CWO concentration and lack of BS inhibitory effect on brown-rot decay could explain why the CO_2 extract of ERC sawdust containing a higher concentration of CWO was significantly more inhibitory against the brown-rot fungus, *G. trabeum* than the ethanol extract of ERC sawdust containing both CWO and BS.

Recently, we have discovered that the use of an amylose inclusion complex (AIC), originally included as an emulsifier for CWO in pressure treating wood samples, by itself had significant bioactivity against termites but not wood decay fungi (Eller et al., 2018). The purpose of this study was to investigate the wood preservation properties of the BS alone, in combination with CWO and in conjunction with the AIC against termites, brown-rot fungi and white-rot fungi.

2. Materials and methods

2.1. Cedarwood oil

Sawdust from ERC heartwood was prepared as described by Eller et al. (2014) and CWO was extracted from this sawdust using SC-CO_2 (70 °C, 27.6 MPa) as described by Eller and King (2000). This CWO was used in the vacuum/pressure impregnation portion of this study.

2.2. Soxhlet extraction of burgundy solid

The ERC heartwood sawdust (100.0 g) was first extracted with refluxing *n*-hexane (Fisher Chemical, Fairlawn, NJ) in a Soxhlet extractor for ten cycles to remove the CWO. The *n*-hexane was separated from the resulting solution by rotary evaporation and the extracted CWO mass determined. This CWO was not used in the impregnation portion of this study. The residual hexane in the sawdust was allowed to evaporate from the sawdust and the sawdust was subsequently extracted with refluxing methanol (MeOH) (EMD Millipore Corp., Billerica, MA) in a Soxhlet extractor for ten cycles. The methanol was separated from the solution by rotary evaporation and the extracted BS residue scraped from the round-bottom flask to determine its mass. The residual methanol in the sawdust was allowed to evaporate from the sawdust and the sawdust was subsequently dried overnight in a vacuum oven (105^{0}C and −0.088 MPa). The percentage yields of the Soxhlet-derived CWO and BS are reported on a dry-wood mass basis. There were three replications of these Soxhlet extractions.

2.3. Amylose inclusion complex (AIC)

Previously, the amylose inclusion complex (AIC) was originally used as an emulsifier for the CWO, however, in this study it was not used as an emulsifier but instead for its own observed wood preservation properties (Eller et al., 2018). The AIC contains a mixture of a high-amylose corn starch-hexadecylammonium chloride complex and polyvinyl alcohol in water. This mixture confers both emulsification properties and water resistance (Hay et al., 2019; Fanta et al., 2016). The AIC was prepared as previously described (Hay et al., 2017; Eller et al., 2018). Briefly, 100 g of high-amylose corn starch (~68% amylose, AmyloGel 03003, Cargill, Minneapolis, MN) was dispersed in 1800 mL water by high shear mixing and passed through a steam jet-cooker. A solution of hexadecylammonium chloride was prepared from 5.25 g of hexadecylamine (Sigma, St. Louis, MO) was dispersed in 217.42 g of 0.1 N HCl (from 37% HCl, Sigma, St. Louis, MO) and fully dissolved by heating to 90 °C and was added to the hot starch dispersion. This mixture was cooled and freeze dried. A final solution containing 2% amylose-hexadecylammonium chloride complexes and 2% polyvinyl alcohol (PVOH) (MW 133,000, 99 mol% hydrolyzed, Polysciences, Warrington, PA) was prepared as reported previously and this final mixture is referred to as the AIC.

2.4. Treatment descriptions

All treatments involved the vacuum/pressure impregnation of the test materials. The six treatments tested were: Water Only Control (H_2O); Water after Methanol (MeOH > H_2O); Amylose Inclusion Complex after Methanol (MeOH > AIC); Amylose Inclusion Complex after CWO in Methanol (CWO/MeOH > AIC); Amylose Inclusion Complex after BS in Methanol (BS/MeOH > AIC); and Amylose Inclusion Complex after CWO + BS in Methanol (CWO + BS/MeOH > AIC). These treatments were specifically designed to determine the separate effects of exposure to methanol, the inclusion of AIC, CWO, and BS individually as well as in binary and tertiary combinations.

The methanol solutions used for treatments CWO/MeOH > AIC and BS/MeOH > AIC were formulated to contain 5% CWO and 5% BS by weight, respectively. The methanol solution used for treatment CWO + BS/MeOH > AIC contained both 5% CWO and 5% BS by weight.

2.5. Vacuum/Pressure impregnation

Wood blocks were impregnated as described by Eller et al. (2018). After conditioning to a constant mass and weighing, blocks were submerged under a given treatment solution and held under vacuum (−0.088 MPa) for 30 min and then pressurized to 0.69 MPa for 60 min. Blocks were weighed immediately after vacuum/pressure impregnation. For treatments CWO/MeOH > AIC, BS/MeOH > AIC and CWO + BS/MeOH > AIC that included CWO and/or BS followed by AIC, the blocks were re-conditioned to a constant mass and re-weighed after treatment with the methanolic solution and again after treatment with the AIC. This allowed the determination of the incorporation rates of the separate components (i.e., CWO, BS and AIC). After re-conditioning, blocks were re-weighed before exposure to termites or wood-decay fungi.

2.6. Termite resistance

Resistance to eastern subterranean termites, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) was tested using Standard Method for Laboratory Evaluation to Determine Resistance to Subterranean Termites E1-06 (American Wood Protection Association, 2016) with details by Eller et al. (2018). Southern yellow pine blocks (2.54 cm × 2.54 cm × 0.64 cm) were prepared and conditioned to a constant mass at 25 °C and 50% relative humidity (RH) prior to and after impregnation. After a 4-week exposure to the termites, wood mass loss and termite mortality were recorded. There were six replications of each of the six treatments.

2.7. Wood-decay Fungi resistance

Resistance to wood-decay fungi was tested using Standard Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures 172 E10-06 (American Wood Protection Association, 2012) with details as described Eller et al. (2018). Southern yellow pine blocks (1-cm^3) were used for brown-rot (*Gloeophyllum trabeum* (Pers.: Fr.) Murr (MAD 617) and *Rhodonia* (*Postia*) *placenta* (Fr.) M. Lars., et Lomb (MAD 698) fungal tests and yellow poplar blocks (1-cm^3) were used for white-rot (*Trametes versicolor* (L. Fr.) Pil. (MAD 697) and *Irpex lacteus* (Fr.: Fr.) Fr. (HHB 7328) fungal tests. The 1-cm^3 blocks were conditioned to a constant mass at 25 °C and 70% RH and weighed prior to and after impregnation. After an 8-week exposure to the fungi, wood mass loss was determined. There were six replications of each of the six treatments per fungal species.

2.8. Statistical analyses

Single-factor analyses of variance (ANOVA) were performed on the percentage wood mass loss for the termites, percentage termite mortality and percentage mass loss for each of the four fungal species tested. A Levene's homogeneity of variance test was performed to determine if values needed to be transformed in order to satisfy ANOVA assumptions. Additionally, Box and Whisker plots were examined and used for outlier removal when a suitable transformation could not be found. Statistical analyses were performed on transformed data where needed but untransformed means are presented for ease of interpretation. If a significant F-test value was obtained from an ANOVA at $P \leq 0.05$, then Differences of Least Squares Means (DLSM) was used for pairwise comparisons of treatments at $P \leq 0.05$. PROC Mixed and INSIGHT in SAS Version 9.2 were used for all analyses.

3. Results and discussion

3.1. Soxhlet extraction of burgundy solid

The dry wood basis mean percentage Soxhlet extraction yields of the CWO (*n*-hexane) and BS (methanol) were 3.5% and 3.1%, respectively. The mean moisture content of the ERC heartwood sawdust was 8.7%.

3.2. Vacuum/Pressure impregnation

After re-conditioning to a constant mass, the mean percentage mass gains for the treated wood samples were as follows: H_2O 0.6%; MeOH > H_2O 0.2%; MeOH > AIC 6.4%; CWO/MeOH > AIC (3.7% CWO and 5.7% AIC); BS/MeOH > AIC (4.8% BS and 5.8% AIC); and CWO + BS/MeOH > AIC (7.5% CWO + BS and 5.2% AIC). Because the all aspects of the block conditioning were held constant throughout the study, the measured changes are considered reliable. The small mass gain observed for H_2O (i.e., 0.6%) may just be sampling error. The slightly lower mass gain for MeOH > H_2O (i.e., 0.2%) than for H_2O (i.e., 0.6%) suggests the MeOH may have extracted something from the wood leading to its lower mass gain, especially given the termite resistance results described below. Although the MeOH > AIC treatment had a mass increase of 6.4% attributable to the AIC, treatments CWO/MeOH > AIC, BS/MeOH > AIC and CWO + BS/MeOH > AIC only had mass increases of 5.7%, 5.8% and 5.2% attributable to the AIC, respectively. These slightly lower mass increases may be result of the CWO and/or BS occupying some space within the blocks during the first impregnation and leading to a reduction in the amount of AIC that can subsequently be added during a second impregnation.

3.3. Termite resistance

Percentage mass loss for the termites was identified as needing a transformation and Arcsin*√ (Proportion Mass Loss/10) was found to stabilize the variance. A significant F-test ($P < 0.0001$) was obtained from the ANOVA. Percentage termite mortality also was identified as needing a data transformation, but none could be found that stabilized the variance. A Box & Whisker plot identified one outlier replication in MeOH > H_2O with 100% termite mortality. After this outlier replication was removed, the variance was stable with no further data transformation necessary. A significant F-test ($P < 0.0001$) was obtained from the ANOVA.

The mean percentage mass losses by termites and termite mortalities are shown in Fig. 1. The MeOH > H_2O treatment had significantly greater wood mass loss and lower termite mortality (32% and 26%, respectively) than did the H_2O only control (23% and 49%, respectively). This suggests that the methanol extracted something from the wood making it both more palatable and less toxic. In addition, the slightly lower mass gain for the MeOH > H_2O treatment (i.e., 0.2%) than for the H_2O only control treatment (i.e., 0.6%) supports the hypothesis of a small mass of some inhibitory materials being extracted by exposure to the methanol. Similarly, Eller et al. (2018) reported that wood exposed to ethanol had higher wood mass loss by termites and lower termite mortality than wood exposed to water. This is further evidence that polar solvents like methanol and ethanol can remove materials that would otherwise inhibit termites. This specific effect will be the subject of a future study.

The MeOH > AIC treatment had significantly less wood mass loss (16%) and higher termite mortality (80%) than did the MeOH > H_2O treatment (i.e., 32% and 26%, respectively). This suggests the AIC itself makes the wood less palatable and perhaps more toxic. Although unlikely, it is possible the AIC renders the wood sufficiently less palatable to cause death by starvation. Previously, Eller et al. (2018) reported very similar subterranean termite results for an AIC treatment (i.e., ca. 10% mass loss and 95% mortality).

The BS/MeOH > AIC treatment had significantly less wood mass

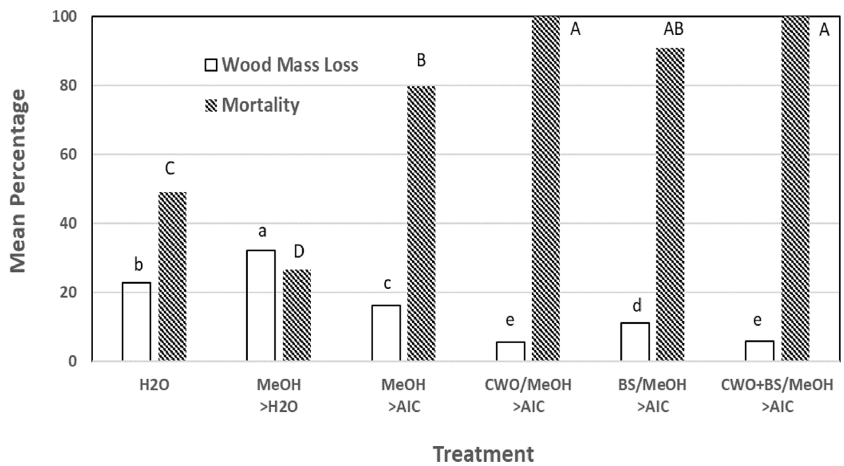

Fig. 1. Mean percentage mass losses (open bars with lower case letters) and termite mortalities (shaded bars with upper case letters) for treated southern pine samples exposed to subterranean termites. Means without letters in common differ significantly using DLSM (P ≤ 0.05).

loss (11%) than did the MeOH > AIC treatment (16%), indicating that the BS had a slight inhibitory effect on termites. Although the BS/MeOH > AIC treatment had numerically higher mortality (91%) than the MeOH > AIC treatment (80%), termite mortality was not statistically higher for the BS/MeOH > AIC treatment. In addition, the BS/MeOH > AIC treatment had twice as much mass loss as did the CWO/MeOH > AIC (i.e., 11% versus 5.5 %, respectively). Together, these results suggest only a relatively minor inhibitory effect of BS on termites. Similarly, Adams et al. (1988) reported that both hexane and methanol (sequential) extracts of *J. virginiana* heartwood showed termiticidal activities. These hexane and methanol extracts contain CWO and BS, respectively.

The CWO/MeOH > AIC and CWO + BS/MeOH > AIC treatments had both the lowest wood mass losses (both 6%) and the highest termite mortalities (both 100%), and these two treatments were statistically equivalent for both wood mass loss and termite mortality. For both wood mass loss and mortality, both the CWO/MeOH > AIC and CWO + BS/MeOH > AIC treatments were significantly different than the MeOH > AIC treatment, but statistically equivalent to one another. This indicates the CWO alone is largely responsible for both the lower mass loss and the higher termite mortality seen in these treatments. Earlier, a termite wood mass loss of 5% and termite mortality of 100% were reported for a CWO/AIC treatment (Eller et al., 2018) demonstrating the effectiveness of these two components against termites. Zhu et al. (2001) reported that CWO was repellent to Formosan subterranean termites, *Coptotermes formosanus* Shiraki. The observed effects of CWO on termites is likely a combination of repellency and toxicity. Carter and Smythe (1974) stated that subterranean termites did not feed on ERC heartwood, but instead covered it over to seal off volatiles. Similarly, Konemann et al. (2014) reported that subterranean termites fed preferentially on ERC sapwood and plastered frass and substrate over only the heartwood portion of the ERC. This behavior appears to be an adaptive response to the negative effects of ERC heartwood on termites.

3.4. Brown-rot decay Fungi resistance

No data transformation was needed for the *G. trabeum* data. However, the *R. placenta* data was identified as needing a data transformation. The transformation (Percentage mass loss)^7 stabilized the variance. Significant F-tests were obtained for both *G. trabeum* (P = 0.0482) and *R. placenta* (P = 0.0267).

The mean percentage mass losses for the brown-rot decay fungi are shown in Fig. 2. For the brown-rot decay fungi in this study, mass losses for the MeOH > H_2O and H_2O only treatments were statistically equivalent (ca. 30% and 50% for *G. trabeum* and *R. placenta*, respectively), indicating that, for these brown-rot fungi, wood block exposure to methanol did not lead to higher wood mass losses. Although wood mass losses for the MeOH > AIC treatments were slightly less than that for the MeOH > H_2O treatments, they were also statistically equivalent. Eller et al. (2018) reported a similar lack of inhibitory effect of the AIC towards brown-rot fungi. These results suggest the AIC alone does not inhibit these brown-rot fungi.

The MeOH > AIC and BS/MeOH > AIC treatments were also statistically equivalent, indicating the inclusion of the BS does not inhibit these brown-rot fungi. The CWO/MeOH > AIC and CWO + BS/MeOH > AIC treatments had the lowest observed wood mass losses (ca. 20% and 30% for *G. trabeum* and *R. placenta*, respectively). However, neither of these treatments were statistically different than the MeOH > AIC treatment but both were significantly lower than the MeOH > H_2O. This suggests that a combination of AIC and CWO is necessary to have a significant inhibitory effect on the brown-rot decay fungi studied. Eller et al. (2018) also reported that the combination of AIC and CWO resulted in lower wood mass losses for brown-rot fungi than either AIC or CWO alone. Previously, Mun and Prewitt (2011) reported that cedrol and thujopsene, two abundant components of CWO, showed high inhibitory effects against the brown-rot fungus *G. trabeum*. Bauch et al. (2004) also found that CWO sesquiterpenes were highly toxic against a brown-rot fungus, while the reddish-violet heartwood flavonoid compounds were not.

3.5. White-rot decay Fungi resistance

No data transformations were needed for the *T. versicolor* or *I. lacteus* data. Significant F-tests were obtained for both *T. versicolor* (P < 0.0001) and *I. lacteus* (P < 0.0001).

The mean percentage mass losses for the white-rot decay fungi are shown in Fig. 3. As observed for the brown-rot decay fungi, the MeOH > H_2O and H_2O only treatments resulted in relatively high mass losses (i.e., over 50%) and were statistically equivalent for the white-rot decay fungi also, indicating that, for all decay fungi studied, wood block exposure to methanol does not lead to higher mass losses.

For *T. versicolor*, the MeOH > AIC and MeOH > H_2O treatments were statistically equivalent (ca. 50%), indicating no inhibitory effect of the AIC on *T. versicolor*. However, for *I. lacteus*, wood mass loss was significantly less for wood treated with the AIC than wood treated with H_2O (i.e., 49% mass loss versus 65%, respectively), demonstrating an inhibitory effect of the AIC against *I. lacteus*.

For *T. versicolor*, the BS/MeOH > AIC treatment had significantly less wood mass loss (i.e., 38%) than did the MeOH > AIC treatment (i.e., 50%). However, for *I. lacteus*, the BS/MeOH > AIC treatment and MeOH > AIC treatment were statistically equivalent. This indicates

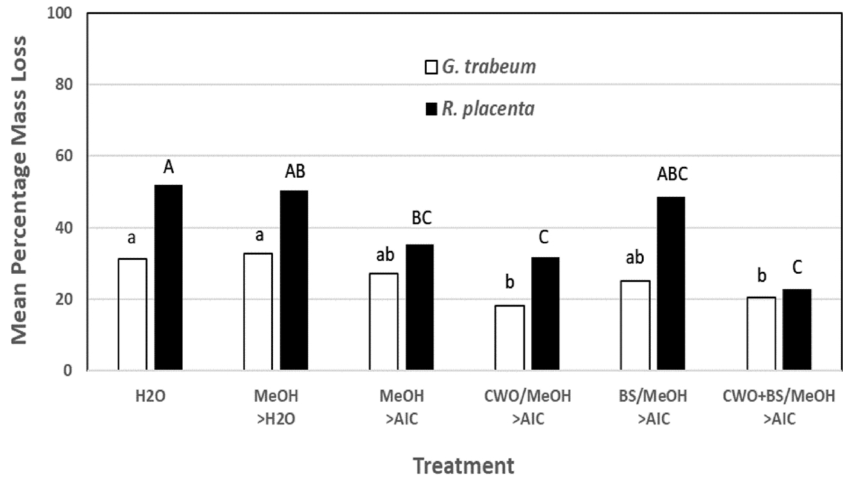

Fig. 2. Mean percentage mass losses for treated southern pine samples exposed to brown-rot decay fungi *Gloeophyllum trabeum* (open bars with lower case letters) and *Rhodonia placenta* (solid bars with upper case letters). For a given fungal species, means without letters in common differ significantly using DLSM (P ≤ 0.05).

that the BS inhibited *T. versicolor* more than *I. lacteus*. For both species of white-rot decay fungi, the CWO/MeOH > AIC and CWO + BS/MeOH > AIC treatments had significantly lower mass losses than did the MeOH > AIC, suggesting that the inclusion of CWO inhibits both species of white-rot decay fungi. Eller et al. (2018) also reported that the combination of AIC and CWO resulted in lower wood mass losses for white-rot fungi than either AIC or CWO alone. Mun and Prewitt (2011) reported that cedrol and thujopsene, major components of CWO, showed high inhibitory effects against the white-rot fungus *T. versicolor*. The inclusion of BS with CWO only increased the inhibition of *T. versicolor* but not *I. lacteus*.

4. Conclusions

Wood blocks impregnated with the tertiary combination of the AIC, BS and CWO resulted in the highest termite mortality, and the lowest percentage wood mass losses for the termites and all four wood decay fungi species studied. Compared to controls, this tertiary combination resulted in more than 70% less mass loss by termites, more than double termite mortality, and between 30 and 80% less mass loss by wood-decay fungi, depending on the species. The CWO, AIC and BS have both separate and additive wood preservation activity. Although the CWO and BS extracts did not provide complete protection, CWO and BS are natural materials that could be used to treat wood and help protect wood from these wood destroying organisms. The effectiveness of these materials might be enhanced by incorporating a different ammonium chloride in the AIC in place of hexadecylammonium chloride. This will be investigated in a planned experiment. The impregnation of the BS required the use of a polar solvent that had an adverse effect on the wood's resistance to termites in addition to the potential hazards of using a flammable toxic solvent. If BS is to be used in impregnation of treated wood, a better method without methanol would be preferred. When used alone, CWO can be formulated in an aqueous emulsion which is both safer and less expensive. In addition, the BS imparts the burgundy color to the treated wood, which may or may not be desirable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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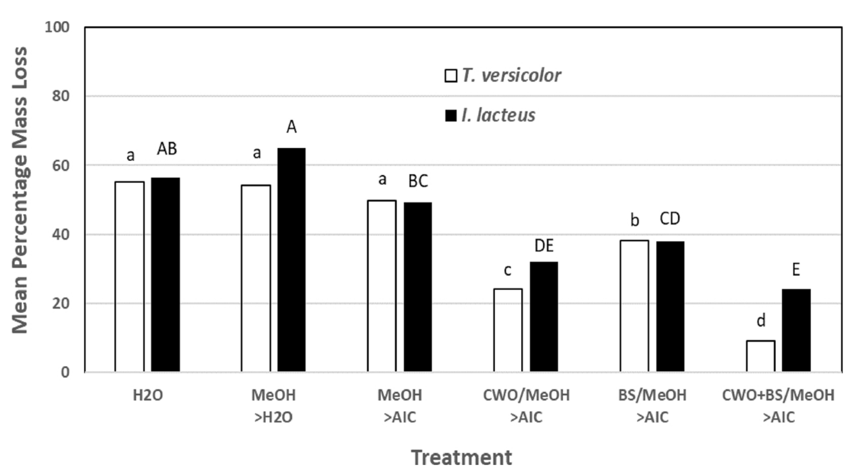

Fig. 3. Mean percentage mass losses for treated yellow poplar samples exposed to white-rot decay fungi *Trametes versicolor* (open bars with lower case letters) and *Irpex lacteus* (solid bars with upper case letters). For a given fungal species, means without letters in common differ significantly using DLSM (P ≤ 0.05).

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