Resistance of *Eucalyptus* and *Corymbia* Treated Woods against Three Fungal Species

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The genera *Eucalyptus* and *Corymbia* are widely used in Brazil. Although they present remarkable applicability, they manifest substantial end-splitting and surface checks, which allows wood decay organisms to penetrate the wood. Thereby, the resistance of *Eucalyptus grandis* x *Eucalyptus urophylla* (EU) and *Corymbia citriodora* (CT) treated with chromated copper arsenate type-C (CCA-C) against fungi decay was evaluated. Seventy-two fence posts were assessed; for each species, there were 18 posts treated with CCA-C and 18 non-treated posts. The posts were 2.20 m long and classified into three classes of diameter. The 2% active ingredient was used with a vacuum-pressure cycle. On each fence, disks measuring 2.0 cm thick were cut at the outcrop zone. Two sets of depths were analyzed: the edge at 0 cm to 1.5 cm as well as the inner part at 1.5 cm to 3.0 cm. The samples were subjected to *Postia placenta*, *Gloeophyllum trabeum*, and *Trametes versicolor* attack. The treatment was effective against all fungi, but for CT, the diameter range of 8 cm to 12 cm was optimal. The treated wood from EU samples reached the lowest weight loss for all fungi. Heartwood-sapwood ratio played a major role. By comparing the non-treated woods, EU yielded the highest mass loss.

Keywords: Treated wood; Chromated copper arsenate tolerant fungi; Biological assay; Radial protection

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INTRODUCTION

Molds and stains are among the fungi that attack wood. These fungi have the lowest degrading potential by only attacking superficial layers of wood. However, the Basidiomycetes attack wood deeply by disrupting the cellular structure (cellulose, hemicellulose, and lignin), and thus worsen its physical and mechanical properties (Clausen 2010; Stangerlin *et al.* 2013).

Mechanisms of brown and white rot of wood derive primarily from the possibility of fungi to produce enzymes and low-molecular weight catalytic systems needed for degradation of wood. Brown rot fungi attack hemicellulose and cellulose, but lignin only at a minimum rate. In white rot, the fungi destroy all components of wood cell walls (Reinprecht 2016).

One of the most important advances in the wood preservation industry was the development of chromated copper arsenate, CCA (Richardson 1993). CCA preservatives are highly effective against fungi and termites and are chemically fixed in wood by the formation of insoluble materials, which are not leached out by water (Wilkinson 1979).

Recently, the Brazilian preservation industry has grown substantially, mainly in production of fence posts, stakes, and poles with *Eucalyptus* and *Corymbia* genera. The adaptability of the *Eucalyptus* in the Brazilian soil is impressive, with growth reaching 39 $m^3\ ha^{-1}\ yr^{-1}$ to 80 $m^3\ ha^{-1}\ yr^{-1}$ depending on the soil conditions (Stape *et al.* 2004). Although its growth is extraordinary, it shows drastic seasoning defects, such as end splitting, surface checks, shake, tangential shrinkage, and collapse (Klitze and Batista 2008).

End splitting and surface checks are the seasoning defects associated with wood deterioration. This happens because ports of entry are created with the release of tension due to growth stress in either living or felled trees. The attack occurs generally in the radial direction for surface checks and in the longitudinal direction for end splitting, and it often goes unnoticed (Yasin and Raza 1992; Yang and Fife 2002).

The hypothesis of this study is that preservative treatment parameters are sufficient to ensure wood protection against *Trametes versicolor*, *Postia placenta*, and *Gloeophyllum trabeum* fungi, when analyzing radial depth from fence post's edge up to 3 cm in *Corymbia torelliana* (CT) and *Eucalyptus grandis* x *Eucalyptus urophylla* (EU) woods treated with chromated copper arsenate type-C (CCA-C).

EXPERIMENTAL

Materials

Thirty-six fence posts of 11-year-old *Corymbia torelliana* (CT) and 36 of nine-year-old *Eucalyptus grandis* x *Eucalyptus urophylla* (EU) were obtained from the market in Pinheiros, Southern Brazil, and classified into 8 cm to 10 cm, 10 cm to 12 cm, and 12 cm to 14 cm diametric classes.

Methods

For each of the fence posts, 2.0 cm thick disks were removed at 0.50 m from the base to be used as samples for decay testing (Fig. 1). The samples marked with the number one represented the radial depth at 0 cm to 1.5 cm, and the number two samples represented radial depth at 1.5 cm to 3.0 cm for each fungi. On each disk, 8 samples were analyzed. Namely, there were two for each of the fungi and two for CCA retention analysis.

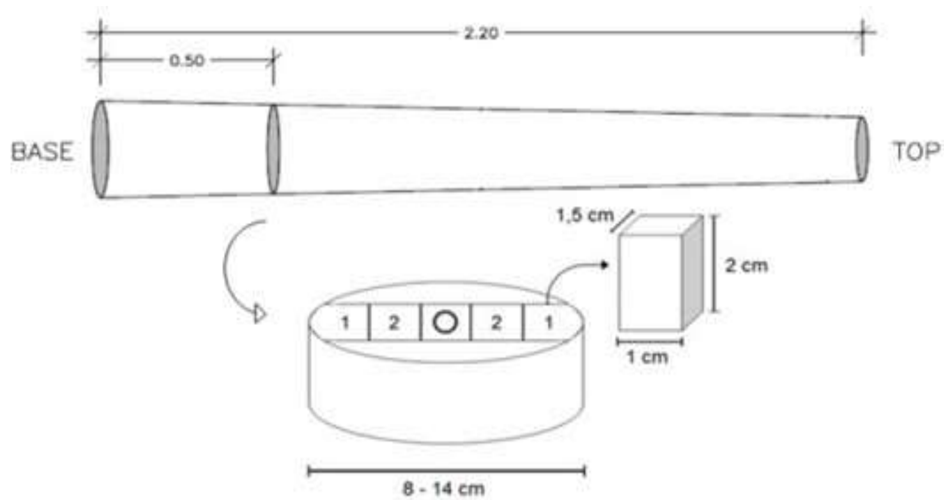

Fig. 1. Region of the fence post where the disk was taken and sample dimensions

Eighteen fence posts of each species were subjected to a modified full cell process with 2% of CCA-C. Full initial and final vacuum were applied for 15 min each, and 11 kgf/.cm^{-2} of pressure was applied for 1 h.

The target retention was at least 6.5 kg.m^{-3}, which is the threshold for wood in ground contact, and its determination followed the recommendations from Brazilian standard ABNT 9480 (2009). After the impregnation process, the fences were transported to Federal University of Espirito Santo, Brazil, located in Jeronimo Monteiro. The fence posts were stacked in a dry place and sheltered with air circulation to provide salt fixation into wood for 90 days.

The heartwood/sapwood ratio (HSR) on each wood disc was measured. The measurements were carefully taken with a 10x magnifying glass to separate heartwood from sapwood as well as to identify the change in color in accordance with Pereira *et al.* (2013).

Evaluation of the biologic assay

The experiment followed the procedures of the AWPA E10 (2014) standard, with the exception that the samples were sized 1.5 cm x 1.0 cm x 2.0 cm (radial x tangential x longitudinal) from both treated and untreated wood, from two positions in the disk (Fig. 1). Firstly, the samples were oven dried to obtain the initial weight at 102±3^{o}C, until constant weight.

The samples were subjected to the attack of *Postia placenta* (Fr.), M. Larsen et Lombard, *Gloeophyllum trabeum* (Pers. ex. Fr.), and *Trametes versicolor* (Linnaeus ex Fries) Pilat. Each flask was fulfilled with 300 g of soil with pH 7.2 and water capacity retention of 25.71%. The soil was moistened with 74 mL of distilled water. The samples were subjected to fungi attack for 12 weeks. After this period, samples were removed, and the final oven-dried weight was obtained for each sample at 102±3 °C, until constant weight. Weight loss was then calculated according to AWPA E10 (2014).

Statistical analysis

The results of weight loss and CCA retention were analyzed in an a x b x c factorial arrangement of treatments in a completely randomized design, with species (four levels – EU and CT treated and untreated), diameter classes (three levels), and radial depth on the disk (two levels) as factors with a total of 72 replicates; 36 for each species. In the analysis of the experiment, the least significant difference (LSD) test was used to group the means ($p \leq 0.05$) as a *post hoc* test. Factors and their interactions were determined to be significant by F- test ($p \leq 0.05$). HSR was only analyzed by standard deviation and overall mean for each species and diameter class. All data for this paper was generated using SAS/SAT™ software version 9.4 (Cary, NC, USA).

RESULTS AND DISCUSSION

Heartwood/Sapwood Ratio and Chromated Copper Arsenate type-C Retention

The HSR is a unitless measure widely used in preservation industries in Brazil. It roughly measures the percentage of treatable area. A high value of HSR indicates more heartwood present in a trunk, which may lead to lesser preservative absorption, unless incising were performed on the fence post, which was not the case. Rudman (2013) pointed out that fast-grown *Eucalyptus* trees have a greater percentage of non-durable wood. Furthermore, higher HSR increases wood susceptibility to decay.

Table 1 shows that CT yielded higher HSR with gradual increases as diameter increased, but this increase was not statistically significant (p-value = 0.70). The EU species behaved completely differently. The expected result was that as the diametric class increased, the HSR would increase for both species.

Table 1. Heartwood/sapwood Ratio for Diametric Class and Species

Diametric Class (cm)	Species	Heartwood/Sapwood Ratio (HSR)*
8 – 10	*C. torelliana*	2.45 (1.14)
	E. urograndis	1.92 (1.15)
10 - 12	*C. torelliana*	2.83 (1.07)
	*E. urograndi*s	1.88 (1.25)
12 – 14	*C. torelliana*	2.89 (1.67)
	*E. urograndi*s	1.46 (0.56)

*The value shown is the mean, with the standard deviation value between parentheses

The influence of the HSR is better understood when analyzing the CCA retention results. Statistical tests showed that both species*diameter class (p-value = 0.01) and species*radial position (p-value ≤ 0.0001) interactions were significant (Fig. 2). Specifically, there was no difference for EU species when analyzing species*diameter class interaction, although a small decrease was observed as diameter increases. In contrast, for CT there was a steep decrease according to increase in diameter class. Once again, this might have been influenced by HSR. In analyzing Table 1 for EU, the ratio was somewhat steady as the diameter increased, with values below 2; for CT, the values were close to 3 for diameter between 12 cm to14 cm. This result suggests that a lower HSR is needed to ensure full protection to the wood.

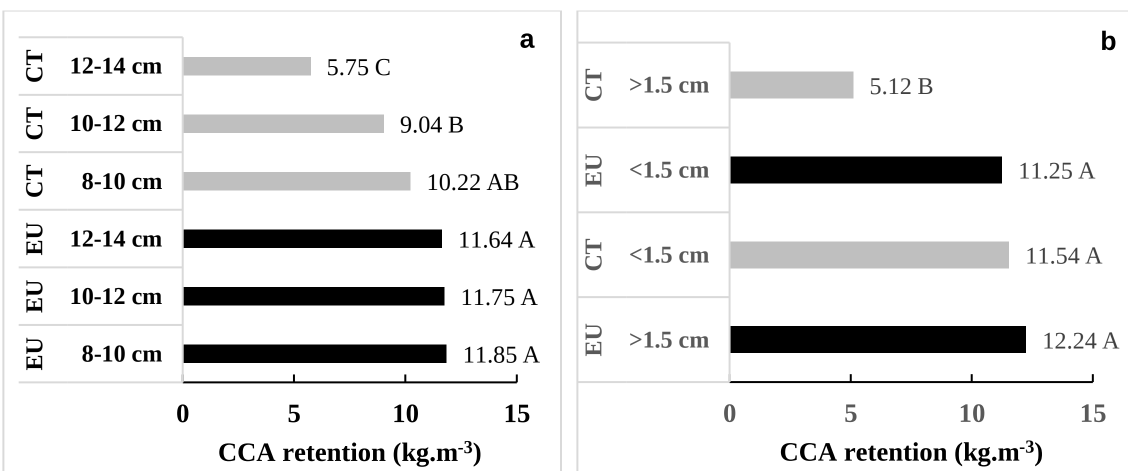

Fig. 2. CCA retention according to (a) diameter and (b) radial position. Similar capital letters on the same chart mean no statistical difference among the treatments by LSD test; p > 0.005.

The interaction between species*radial position showed interesting results. EU and CT were protected against wood decay when the fence posts were in contact with the ground, because the retention values, independently of the radial position, showed exceptionally strong values, except for CT at radial depth > 1.5 cm.

Although the CCA retention for CT at radial depth > 1.5 cm showed values below recommended (5.12 $kg.m^{-3}$, the recommendation is 6.5 $kg.m^{-3}$), the weight loss for this species and position were below 10% (Fig. 3). This observation suggested that CCA penetration and distribution were deep into the wood, thus inhibiting the decay. Thus, even though the EU and CT species showed seasoning defects, such as checking and end splitting, they were likely protected against wood decay. Furthermore, all three diameters could be used as fence posts for EU, whereas only those diameters ranging between 8 cm and 12 would be acceptable for CT.

In general, both species reached CCA retention values higher than the recommended standard (6.5 $kg.m^{-3}$), with some cases where the values reached almost twice the recommended, despite the radial position of CT at >1.5 cm reaching only 5.12 $kg.m^{-3}$. Based on this finding, further studies are recommended so that an optimal treatment cycle can be found to achieve economically feasible results. The results showed for both species are reasonable. Modified Full-cell process is used when the retention of a maximum quantity of preservative is desired. Values below the recommended by the standard might be influenced by wood anatomy, in this case heartwood presence. The penetration and retention of CCA could be improved by using incising technique; however, it is not common in Brazil.

Deterioration by Fungi

The F-test was significant for the interaction between species*radial position (p-value $\leq$ 0.0001) for the three fungi analyzed. Furthermore, Fig. 3 must be analyzed carefully. The chart displays the weight loss caused by *Trametes versicolor*, *Postia placenta*, and *Gloeophyllum trabeum.*

The weight loss for untreated samples ranged from 10.3% for CT at radial depth > 1.5 cm and 41.56% for EU at radial depth < 1.5 cm, which confirms the destructiveness of each fungi in degrading the wood. However, for the three fungi and untreated samples, the same pattern was observed. With an increase in radial depth of 1.5 cm, there was a significant decrease in weight loss. A possible explanation for this is that the heartwood holds fungicidal properties and thus effectively protects the tree against microbiological attack (Panshin and De Zeeuw 1980).

Sjöström (1981) claimed that the biosynthesis of extractives is controlled by genetic factors; each wood species tends to produce specific substances responsible for heartwood natural durability. In particular, flavonoids, phenolics, lignans, stilbenes, and tropolones are of interest for the natural durability, and the genera *Acacia*, *Pinus*, and *Eucalyptus* produce those specific substances. Furthermore, the origin of the wood may influence the trend in weight loss for untreated samples.

With respect to natural durability, *Eucalyptus* wood decays easily. The weight loss of EU wood reported in this study corroborates this statement. However, Oliveira *et al.* (2005) studied the heartwood's natural durability of seven *Eucalyptus* species. They found for *Gloeophyllum trabeum* a weight loss of 3.4% in *Eucalyptus grandis*, with the highest weight loss of 8.3% in *E. maculata*. In comparison, in this work, for untreated samples at radial depth > 1.5 cm, the weight loss was 10.3% for CT.

Vivian *et al.* (2015) reported for untreated *Eucalyptus grandis* a weight loss of 58.20% for the *Trametes versicolor* fungus. For untreated *Eucalyptus cloeziana*, the weight loss was 28.82%. They also analyzed the weight loss caused by *G. trabeum*. For untreated *E. grandis* the weight loss was 33.45%, and for untreated *E. cloeziana* it was 15.23%.

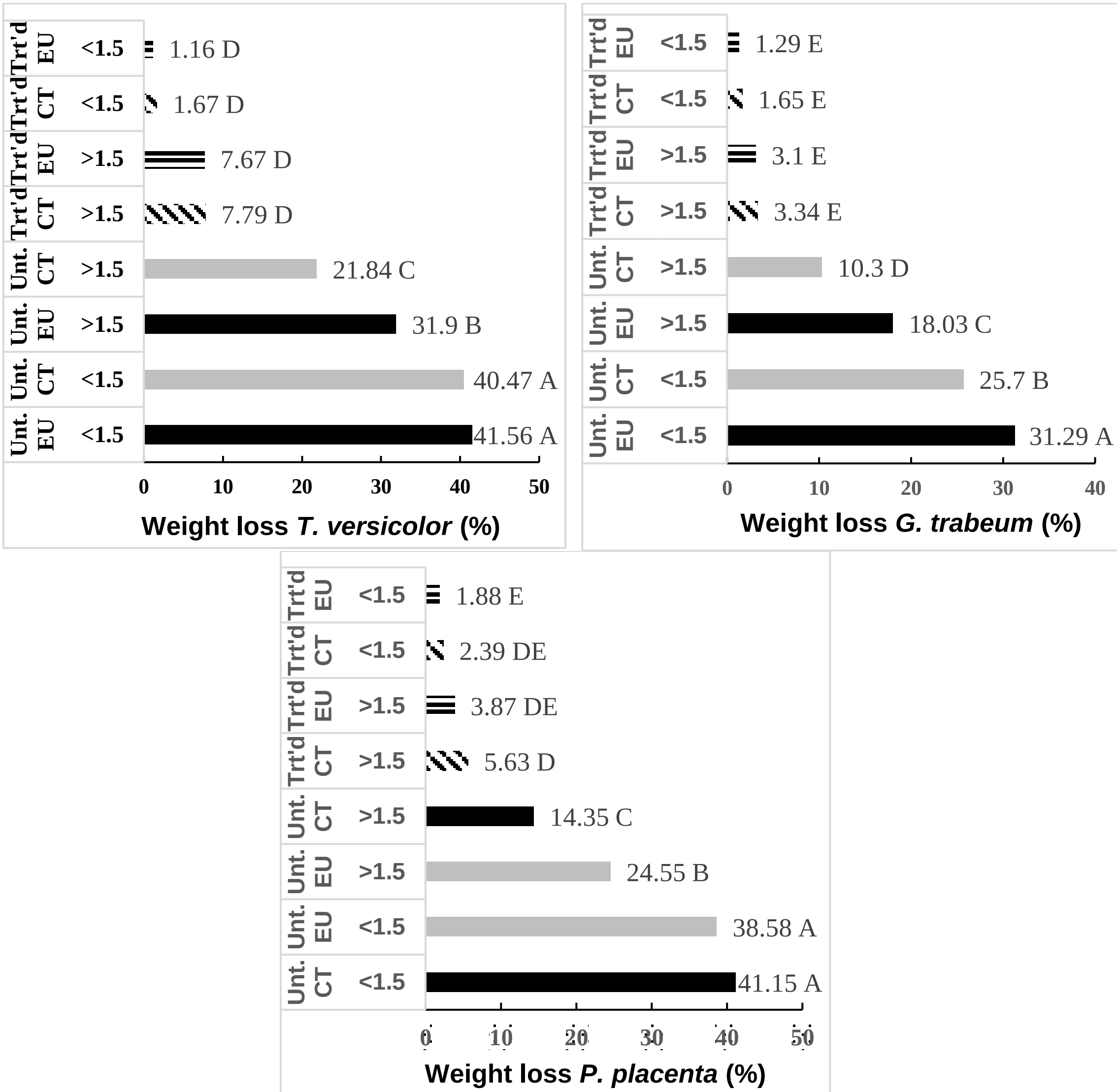

Fig. 3. Weight loss caused by *Trametes versicolor*, *Postia placenta*, and *Gloeophyllum trabeum*

Such differences, *i.e.*, between Oliveira *et al.* (2005) and Vivian *et al.* (2015), according to Panshin and De Zeeuw (1980), may be attributed to the tree's age and extractives nature. CT was 11, and EU was 9 years old. Compared with younger trees, the outer heartwood in older tree produces either more highly effective toxic extractives. For both studies mentioned above, the woods were 16 years old. Furthermore, the variation in weight loss in radial direction is due to the kind and the concentration of toxic chemical constituents of heartwood as well as its permeability, which causes oxygen level gradient and moisture content reduction in its interior.

Regarding treated wood, the treatment with CCA type-C provided sufficient protection against fungi to both woods with significant changes in weight loss, which was expected. Similar trends were observed for all fungi and species. With an increase in radial depth to 1.5 cm, there was not a significant decrease in weight loss. EU yielded the smallest weight loss for all fungi tested, which probably occurred due the lower HSR and higher CCA retention exhibited by EU. Although the CCA retention for CT at radial depth >1.5 cm showed values of 5.12 $kg.m^{-3}$ (Fig. 2), it yielded low weight loss for all fungi tested.

As previously explained, the preservative penetration and distribution may have played a major role in the result. Even with an effective preservative, good protection cannot be expected only with preservative retention (Ibachi 1999).

Vivian *et al.* (2015) showed that treated wood from *E. grandis* yielded weight loss for *T. versicolor* and *G. trabeum* fungi of 37.73 and 31.18%, respectively. They also tested *E. cloeziana*, and the results showed weight loss of 5.10 and 0.51% for *T. versicolor* and *G. trabeum*, respectively. Notably, they worked with lumber where the heartwood and sapwood content were not described, and the CCA retention requirement from ABNT 9480 (2009) was not met.

Different fungi were tested in this work, and they should produce different weight losses due to their individual attacking mechanisms. *T. versicolor* is a white-rot fungus and well recognized as a hardwood-degrading organism, whereas *P. placenta* and *G. trabeum* are brown-rot fungi with tolerance to copper and arsenic compounds, respectively.

Cowling (1961) has shown that considerable differences exist in the manner of degradation of the cell wall by the brown and white-rot fungi. Brown-rot fungi liberate enzymes that diffuse from the cell lumen, where the hyphae are located. They appear to attack carbohydrates in the S2 layer of the secondary wall first, followed by the S1 and finally the S3 layers. In contrast, white-rot fungi produce a gradual erosion of all cell wall constituents from the lumen outward by attacking S3 layer first, followed progressively by the other layers. This leads to some correlation between the amount and characteristics of the available carbohydrates and the decay resistance of the cell walls.

Finally, the importance of having treated wood from a reforested source, as *Eucalyptus* trees, is the possibility of reducing the harvesting pressure over native species with high natural durability. Brazil is recognized for having highly durable woods.

Paes *et al.* (2007) investigated the natural durability of nine species from Brazilian semiarid region against *Postia placenta*. The treated woods in this work could be compared to either *Myracrodruon urundeuva* or *Schinopsis brasiliensis*, where the highest weight loss were 0.99% and 1.35%, respectively.

In research developed by Alves *et al.* (2006), the natural durability of six species from Amazon rain forest were assessed against *Gloeophyllum trabeum*. *Eucalyptus* treated wood in this work could also be compared to *Astronium* sp. wood, in terms of weight loss, where it reached only 1.97%. Furthermore, the studies from Paes *et al.* (2007) and Alves *et al.* (2006) corroborate the statement that both treated *Eucalyptus* and *Corymbia* trees would be suitable to replace native species as adequate species against wood decaying organisms.

CONCLUSIONS

1. The untreated wood of EU produced higher weight losses for all fungi tested in which HSR played a major role on its natural durability.
2. The woods showed protection against wood fungi decay organisms for both radial depths (at edge to 1.5 cm and 1.5 to 3.0 cm); hence, they may be used as fence posts even if they manifest seasoning defects with long lifetime service.
3. Although the treated wood with CCA-C became effectively more resistant to decay, additional tests should be carried out to find out the best treatment cycle parameters to make the treatment economically feasible.

4. Treated woods of both *Eucalyptus* and *Corymbia* could be used as supply for replacement of native species of high natural durability.

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