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Natural resistance of plantation grown African mahogany (*Khaya ivorensis* and *Khaya senegalensis*) from Brazil to wood-rot fungi and subterranean termites

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ABSTRACT

African mahogany (*Khaya* spp.) has attracted the interest of the timber market in Brazil because of the quality of the wood and the similarity to the highly demanded, Brazilian mahogany (*S. macrophylla* King). The goal of this study was to examine natural resistance of plantation-grown African mahogany (*Khaya* spp.) to decay fungi and termite feeding, in order to better evaluate the potential use of this material as a suitable replacement for Brazilian mahogany wood. Heartwood and sapwood of two African mahogany species, *Khaya ivorensis* and *Khaya senegalensis*, were evaluated for resistance to decay by five wood-rot fungi as well as to feeding by subterranean termites in laboratory tests. In addition, density values were evaluated and examined for correlation to the observed natural durability properties. Overall, results showed heartwood of both species to be more resistant than sapwood to all fungi tested. *K. senegalensis* sapwood showed the lowest resistance to decay fungi, while *K. senegalensis* heartwood had the highest resistance to both brown- and white-rot fungi as well as to the dry-rot fungus tested. Both wood species showed some resistance to feeding by subterranean termites, with significantly higher resistance in heartwood compared to sapwood. In fungal and termite tests, durability was not found to be correlated to density values for either *Khaya* spp. tested. Results from this study suggest plantation-grown African mahogany exhibits similar natural durability properties as Brazilian mahogany, supporting the potential for its use as a suitable substitute to better meet the demands of the wood products industry.

1. Introduction

Native wood resources in Brazil have been exploited unsustainably for years largely due to the high demand for forest resources, resulting in vast areas of deforestation. Reforestation began with development of *Eucalyptus* spp. plantations, mainly to provide wood for railroad construction. In the 1960's, tax incentives prompted introduction of *Pinus* spp. in the southern region of Brazil as an additional alternative material to keep up with the demand for wood products. According to the Brazilian Association of Planted Forests - ABRAF (2013), *Eucalyptus* and *Pinus* plantations currently represent the two major plantation-grown wood species in Brazil. Other wood species, however, have also been grown in plantations to a lesser extent, including, *Acacia mearnsii*, *Hevea* spp., *Tectona grandis*, *Schizolobium amazonicum* Ducke and *Araucaria angustifolia*.

Currently, there is increasing interest in plantation-grown African mahogany (*Khaya* spp.) as a substitute for the high demand for native Brazilian mahogany (*Swietenia macrophylla* King). This commercial interest in African mahogany stemmed from the reduction of native Brazilian mahogany in the regions where it occurs. In 1976, five seedlings of African mahogany (*Khaya ivorensis* A. Chev.) were planted at the Brazilian Agricultural Research Corporation (EMBRAPA - Eastern Amazon). These specimens were eventually used to start up plantations in other regions of the country (Falesi and Baena, 1999). In 1993, Vale S.A. started another

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experimental plantation using seedlings of *Khaya senegalensis* A. Juss from Africa at the Vale Natural Reserve located in Linhares, Brazil. Most of these plantations, however, have not yet reached cutting age and scale for lumber production.

Native African mahogany species are desirable both in terms of color and grain patterns as well as for their physical and mechanical properties. Both species have similar characteristics and are considered resistant to fungal and termite attack. The color of *K. ivorensis* heartwood varies from yellowish-brown to reddish-brown, and has yellowish-brown sapwood (Wiemann, 2010). *K. senegalensis* heartwood varies from a pinkish to a reddish color, with yellowish sapwood (Zbonak et al., 2010). In addition to the favorable physical properties of African mahogany, *Khaya* spp. have also been shown to have some natural durability characteristics, such as resistance to the maggot, *Hypsiphyla grandella*, a common pest in many Brazilian mahogany plantations. These characteristics suggest that wood materials from these species have the potential to meet the needs of the solid wood market, as well as the quality standards of the wood industry (e.g. aesthetics, natural durability and strength) (Pinheiro et al., 2011).

Despite what is known regarding the native African mahogany, there is still limited information about resistance to decay and insect damage, which is an important consideration for plantation-grown trees in novel environments. Additionally, knowledge about the natural durability of these wood species can provide useful information on their possible end-uses and may be important predictors of product service life (Gambetta et al., 2004). The goal of this study was to evaluate natural durability of *K. senegalensis* and *K. ivorensis* after exposure to decay fungi and subterranean termites, that would be useful for comparisons to the known properties of Brazilian mahogany.

2. Materials and methods

2.1. Test specimens

Wood samples were cut from three, 19-year-old trees of each species (*K. ivorensis and K. senegalensis*) from an African mahogany plantation located in southeastern Brazil. Five samples per fungus were used for evaluation of decay and a total of 10 samples of each species were evaluated in termite tests. Samples were taken from both sapwood and heartwood tissues and cut into 25 × 25 × 9 mm (longitudinal × tangential × radial) specimens for both decay and termite tests. The blocks were conditioned to a constant weight at 6% equilibrium moisture content (EMC) and then weighed again prior to testing.

2.2. Density

To obtain density measurements, blocks were conditioned to EMC at 6% and then weighed. Dimensions (cross section size and length) of each specimen were then measured using a caliper and the density of each specimen was calculated based on weight and volume at 6% EMC.

2.3. Decay test

Decay testing followed the ASTM D2017: Standard method for accelerated laboratory test of natural decay resistance of wood (ASTM, 2012. Specimens were exposed to total of five decay fungi, two brown-rot fungi (*Gloeophyllum trabeum* MAD-617 and *Postia placenta* MAD-698), two white-rot fungi (*Irpex lacteus* MAD-517 and *Trametes versicolor* MAD-697) and one dry-rot fungus (*Serpula lacrymans*). Southern pine sapwood (*Pinus* spp.) was used as a control for exposure to brown-rot and dry-rot fungi and sweetgum (*Liquidambar styraciflua*) sapwood was used as a control for exposure to white-rot fungi. Samples were exposed to fungi for four weeks. After this period, all blocks were removed from test, brushed free of mycelium and then allowed to air-dry overnight. Blocks were reconditioned to a constant weight at 6% EMC and percent mass loss was calculated.

2.4. Termite test

The experimental approach for the termite test followed the AWPA E1-09: Standard method for laboratory evaluation to determine resistance to subterranean termites (AWPA, 2013). Similar to the decay test, specimens of southern pine and sweetgum served as controls. Samples were placed at the bottom of a cylindrical plastic dish, covered with 50 g of sterile, sifted sand, and dampened to constant moisture content with 8.5 ml of sterile water. One gram of *Reticulitermes flavipes* (Kollar) (approx. 300 individuals) was then added to each dish and allowed to feed for four weeks. After the test period, samples were removed from the container, brushed free of debris, and air-dried overnight. Blocks were then reconditioned to a constant weight at 6% EMC to calculate percent mass loss. Termite mortality occurring at the end of the exposure period was also recorded.

2.5. Statistical analysis

For analysis of natural durability, three parameters were considered: density, percent mass loss of the test specimens from decay and termite exposure, and termite mortality. Statistics used for this analysis included the t-test ($\alpha = 0.05$), and comparisons of density were made using the f-test ($\alpha = 0.05$).

3. Results

3.1. Density

Statistical analysis showed a significant difference in density in the two *Khaya* spp. (p = <0.001). Both sapwood and heartwood of *K. senegalensis* were found to be significantly denser than the sapwood and heartwood of *K. ivorensis*. Heartwood of *K. ivorensis* was found to be denser than the sapwood of this species as opposed to *K. senegalensis*, where the sapwood was found to be denser than the heartwood. However, there is none of these values were found to be significantly different between sapwood and heartwood on each espécies. Average density measurements for both *K. ivorensis* and *K. senegalensis* are presented in Table 1.

3.2. Decay test

Results showed some variation in decay resistance not only between the two *Khaya* spp., but also between the sapwood and heartwood specimens of each species. Heartwood and sapwood samples of *K. ivorensis* were only significantly different in terms of

Table 1
Density for *Khaya ivorensis* and *Khaya senegalensis*.

Species	Density (kg/m^3)		
	Sapwood	Heartwood	Average
Khaya ivorensis	(4.4)**	(5.9)	(5.8)
	467^{ns}	482	474
Khaya senegalensis	(1.3)	(2.7)	(2.8)
	693^{ns}	670	682*

*Significant difference between species in F test ($\alpha = 0.05$ level).
^{ns} Not significant.
**Coefficient of variation (%).

resistance to the white-rot fungus, *I. lacteus*. However, all heartwood specimens of *K. senegalensis* were shown to be significantly more resistant to fungal decay than the sapwood specimens, with the exception of resistance to the dry-rot fungus, *S. lacrymans*. In accordance with the classes of resistance to wood decay fungi as presented in ASTM D2017, the heartwood of *K. senegalensis* is considered highly resistant to decay caused by all the fungi tested (brown-, white- and dry-rot). Average percent mass loss and coefficient of variation for both *K. ivorensis* and *K. senegalensis* after fungal decay are presented in Table 2.

As specific gravity and density have been shown to correlate with decay resistance in previous studies (Arango et al., 2006; Panshin and de Zeeuw, 1980), this relationship was evaluated for both *Khaya* species (heartwood and sapwood) and for each decay fungus separately. Most of these results showed no significantly correlation between density and mass loss. However, results from the decay tests suggest a slightly positive correlation between mass loss and density for *K. ivorensis* sapwood ($p = 0.041$) after exposure to *P. placenta*, and a slightly negative correlation for *K. senegalensis* heartwood exposed to *G. trabeum* ($p = 0.011$) or *T. versicolor* ($p = 0.018$).

3.3. Termite test

Average percent mass loss and coefficient of variation for *K. ivorensis* and *K. senegalensis* are presented in Table 3 along with average density of the wood samples and termite mortality. Mass loss in specimens of the two *Khaya* spp. after termite exposure was low for both sapwood and heartwood specimens, compared to what can be seen in untreated Southern pine wood (average ~ 30%). Heartwood of *K. ivorensis* and *K. senegalensis* was shown to have significantly higher resistance to termite feeding compared to sapwood of that species. Heartwood of *Khaya ivoresis* also showed significantly higher termite mortality than in sapwood groups. In the *K. senegalensis* specimens, there was no significant difference in termite mortality among heartwood and sapwood, although mortality was high for both groups. Results from both *Khaya* spp. did not show a correlation between density and mass loss, but data did suggest an apparent inverse relationship between density and termite mortality, although this was not shown to be statistically significant.

4. Discussion

Overall, test specimens of *K. ivorensis* and *K. senegalensis* exhibited resistance both to feeding by subterranean termites as well as to the decay fungi selected. In general, heartwood of each species had higher natural durability properties than sapwood, although data showed this relationship not to be significant in many of the decay tests due to the high levels of variation observed among samples. For termites, results showed a positive associated between density and termite mortality, suggesting that species with a higher density may be more resistant to termite feeding.

Results from the present study are comparable to results from other researchers examining decay and termite resistance of *Khaya* species. Reilly and Robertson (2006) studied decay resistance of 17-year-old plantation grown *K. senegalensis* heartwood from Australia and found wood samples to be highly resistant to the wood-rot fungus *T. versicolor*, with an average of mass loss of 3.9%, which is close to the result found for heartwood of *K. senegalensis* in this study. Nzokou et al. (2005) studied the natural resistance of *K. ivorensis* planted in Cameroon against *I. lacteus*, *G. trabeum*, *T. versicolor* and *P. placenta* and found an average mass loss of 9.4%, 23%, 45% and 54%, respectively. In this study, *K. ivorensis* showed comparable values with slightly higher resistantance to *P. placenta*.

In terms of termite resistance, Armstrong et al. (2007) determined *K. senegalensis* to be highly resistant against termite damage. In another study, Usher and Ocloo (1976) evaluated termite resistance to 85 different wood species from Africa, and showed mass loss in *K. ivorensis* and *K. senegalensis* to be 8.5% and 11.5% respectively, which are similar to the results found in this study. Interestingly, our results showed that exposure to heartwood of both *Khaya* spp. and the sapwood of *K. senegalensis* resulted in high levels of termite mortality, suggesting some type of secondary compounds are likely present in the wood that have anti-termitic properties. It is well known that numerous wood extractives, particularly those originating from the heartwood of certain species, can have a significant effect on resistance to subterranean termites in terms of toxicity or repellency (Fengel and Wegener, 1984; Panshin and de Zeeuw, 1980). Although the exact mechanisms of these extractives remains unknown, numerous researchers have noted that these extractives are often responsible for the natural durability properties of wood against termites (Ragon et al., 2008). In the present study, extractives may be responsible for the higher levels of termite mortality, particularly in the *K. ivorensis* heartwood groups. Termite mortality may have also influenced some of the trends observed between mass loss and density, such as the apparent positive relationship between mass loss and density in *K. senegalensis* heartwood. It is also possible that density cannot be directly correlated with natural durability without consideration of a number of other factors.

Overall, results from this study suggest African mahogany to have similar natural durability properties to decay and termites when compared to Brazilian mahogany (i.e. moderate resistance to brown and white-rot fungi (Carvalho, 2007; Chudnoff, 1984) as well as moderate resistance to termite feeding (Moses, 1955; Bultman and Southwell, 1976; Torelli and Cufar, 1994)). In addition, African mahogany has been shown to have similar physical and mechanical

Table 2
Mass loss (%) of *Khaya ivorensis* and *Khaya senegalensis* woods exposed to brown-, white- and dry-rot fungi.

Fungus	*Khaya ivorensis*				*Khaya senegalensis*			
	Sap.	Class	Heart.	Class	Sap.	Class	Heart.	Class
S. lacrymans	(9.7)** 18.5^{ns}	R	(4.9) 8.7	HR	(16.9) 13.4 ^{ns}	R	(2.1) 2.1	HR
I. lacteus	(19.6) 55.7*	NR	(13.4) 19.8	R	(26.5) 47.3*	NR	(4.6) −2.8	HR
G. trabeum	(21.1) 35.1^{ns}	MR	(12.4) 26.1	MR	(9.9) 46.4*	NR	(0.52) 2.6	HR
T. versicolor	(5.1) 53.0^{ns}	NR	(3.48) 53.8	NR	(2.97) 57.9*	NR	(3.2) 3.7	HR
P. placenta	(17.9) 24.3^{ns}	R	(12.4) 12.4	R	(8.7) 39.2*	MR	(3.5) 3.9	HR

*Significant difference between species in Tukey test ($\alpha = 0.05$ level).
^{ns} Not significant.
** Coefficient of variation (%).
Classes of decay resistance based on ASTM D2017 categories – HR: highly resistant; R: resistant; RM: moderately resistant; NR: not resistant.

Table 3
Results from *Khaya* spp. exposed to feeding by subterranean termites.

Category	*Khaya ivorensis*		*Khaya senegalensis*	
	Sapwood	Heartwood	Sapwood	Heartwood
Termite mortality (%)	(68.9)** 27.1b*	(5.8) 92.5	(18.6) 91.4^{ns}	(6.6) 80.7
Mass loss (%)	(41.7) 12.9*	(14.5) 4.7	(18.8) 7.9*	(16.9) 4.2

*Means for each category and each species differ at a 5% probability by t-test.
^{ns} Not significant.
**Coefficient of variation (%).

properties as Brazilian mahogany. These characteristics suggest plantation-grown African mahogany is a viable substitute wood resource for the over-exploited Brazilian mahogany.

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