NATURAL DURABILITY OF *Eucalyptus dunnii* Maiden, *Eucalyptus robusta* Sm., *Eucalyptus tereticornis* Sm. AND *Hovenia dulcis* Thunb. WOOD IN FIELD AND FOREST ENVIRONMENT[1]

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ABSTRACT – This study aimed at evaluating the natural durability of *Eucalyptus dunnii*, *Eucalyptus robusta*, *Eucalyptus tereticornis* and *Hovenia dulcis* woods submitted to a deterioration test in two environments, field and forest. The test samples were buried until half of their length (150 mm). Evaluations were carried out each 45 days, totalizing a 405-day period, with three-repetition withdrawal of each species for environment, totalizing nine samples from each environment, making up 24 test samples for evaluation. After percentage calculations of mass loss and resistance degree classification, the deterioration index was adopted for decomposition evaluation and fungal decay potential determination of test samples. The study has been carried out in completely randomized design (CRD), evaluated through analysis of variance (ANOVA) with subsequent comparison of means by Turkey's test, in a 5%-level of probability of error, along with regression analysis. *Eucalyptus tereticornis* wood presented lesser mass loss in both environments. *Hovenia dulcis* presented lesser deterioration probability in both environments. Forest environment test samples presented greater mass loss percentages and lesser deterioration index.

Keywords: Mass loss; Deterioration index; Fungal decay potential.

DURABILIDADE NATURAL DE MADEIRA DE *Eucalyptus dunnii* Maiden, *Eucalyptus robusta* Sm., *Eucalyptus tereticornis* Sm. E *Hovenia dulcis* Thunb. EM AMBIENTE DE CAMPO E FLORESTA

*RESUMO – O estudo teve como objetivo avaliar a durabilidade natural das madeiras de **Eucalyptus dunnii**, **Eucalyptus robusta**, **Eucalyptus tereticornis** e **Hovenia dulcis** submetidas a ensaio de deterioração em dois ambientes, campo e floresta. Os corpos de prova foram enterrados até metade de seu comprimento (150 mm). As avaliações foram feitas a cada 45 dias, totalizando um período de 405 dias, com retirada de três repetições de cada espécie por ambiente, totalizando nove amostras de cada ambiente, perfazendo 24 corpos de prova por avaliação. Após calculadas as porcentagens de perda de massa e classificadas quanto ao grau de resistência, adotou-se o índice de deterioração para avaliação da decomposição dos corpos de prova e determinação do potencial de ataque fúngico. O estudo foi conduzido em delineamento inteiramente casualizado (DIC), avaliados por análise de variância (ANOVA), com posterior comparação de média pelo teste de Tukey, em nível de 5% de probabilidade de erro, juntamente com análise de regressão. A madeira de **Eucalyptus tereticornis** apresentou menor perda de massa em ambos os ambientes. A madeira de **Hovenia dulcis** apresentou menor probabilidade de deterioração em ambos os ambientes. Os corpos de prova do ambiente de floresta apresentam maiores percentuais de perda de massa e menor índice de deterioração.*

Palavras-chave: Perda de massa; Índice de deterioração; Potencial de ataque fúngico.

1. INTRODUCTION

The use of wood in contact with soil depends on external agents resistance that can cause wood damage and consequently interfere in its durability. Costa (2003) states that among the different wood properties, the natural deterioration resistance stands out, which is the species, intrinsic ability to resist the action of spoilage agents, referring to the mechanical, physical, chemical and biological ones. However, Willeitner (1984) states that because of economic value, natural resistance is normally seen as referring to biological agents.

According to Oliveira (1997), some particular wood will have preference for use in relation to others when its natural durability is longer, because if we avoid inconveniences arising from the use of chemical products, some very toxic, utilized in the treatment of low durability wood in order to provide it with a satisfactory performance in service. Besides environmental restrictions to the products that currently dominate preserving industry, some technical aspects related to the wood itself to be preserved are relevant. Such aspects are related to resistance to impregnation of wood from certain species, as in the case of eucalyptus heartwood. Cookson (2000) confirmed the difficulty penetration by preservatives in eucalyptus heartwood, proving the great importance of choosing species from this genus that have some natural durability to xylophagous organisms.

Oliveira et al. (1986) affirmed that temperature, humidity and precipitation conditions are important in the determination of microorganisms capable of invading wood and decay it and these conditions have great impact over decomposition rate and other factors related to wood. According to Santini's statement (1988), the content of parenchyma cells of certain species like starches, proteins and sugars, etc., are very sought by fungi and insects as food, which explains its greater susceptibility to attack. Under favorable humidity, temperature and pH conditions, all woods become susceptible to attack by xylphagous organisms (TEXEIRA, et al. 1997).

In the face of this situation, the present study aimed at evaluating the natural durability of *Eucalyptus dunnii*, *Eucalyptus robusta*, *Eucalyptus tereticornis* and *Hovenia dulcis* woods, submitted to a deterioration test in two environments, field and forest.

2. MATERIAL AND METHODS

In order to carry out the present study, the *Eucalyptus dunnii* Maiden, *Eucalyptus robusta* Sm, *Eucalyptus tereticornis* Sm and *Hovenia dulcis* Thunberg heartwoods, approximately aged 35, have been used. The wood samples were originally from the Fundação Estadual de Pesquisa Agropecuária-Centro de Pesquisa em Recursos Florestais (State Foundation of Agricultural Research – Research Center in Forest Resources) (FEPAGRO FLORESTAS), located at the District of Boca do Monte in the City of Santa Maria, RS. Test samples, with dimensions of 20 x 20 x 300 mm in thickness, width and length, respectively, have been made for the tests. Defect-free test samples have been selected, such as no wane presence, cracks and knots.

The apparent wood mass in 12% of humidity has been determined from mass and volume of samples taken after stabilization of their equilibrium humidity in climate chamber at the temperature of 20±2ºC and relative humidity of 65±5%.

The dry mass of each sample has been determined with the assistance of a 0,01g precision electronic scale. The samples have been buried until half of their length (150 mm) in environments of open field and forest. Evaluations have been conducted each 45 days, totalizing a 405-day period, with three-repetition withdrawal of each species for environment, totalizing nine samples from each environment, making up 24 test samples for evaluation. After each collection, the material has gone through a cleansing process for aggregated soil removal from samples with the assistance of a brush. Then, the material has been taken again to the greenhouse at the temperature of 103ºC for dry mass obtainment and, through the difference between the initial and final dry mass, the mass loss has been achieved and the material was classified in resistance classes according to the norm ASTMD-2017(ASTM, 2005).

Besides being classified as for its resistance, the deterioration index adapted by Lepage et al. (1986) has been adopted for evaluation of decomposition in test samples where, through damage cause on them, notes have been assigned to the generation of the deterioration average index.

Complementarily, climate information on the site has been obtained, as maximum, minimum and average daily temperature, precipitation and relative humidity

during the whole experiment period. Based on climate information, it was possible to determine fungal decay potential (FDP), estimated index (Equation 1), initially developed by Scheffer (1971) and adapted to Brazil by Martins et al. (2003). The FDP estimates the risk of incidence by decay fungi due to two important environmental variables for the development of these xylophagous agents, temperature and precipitation.

$$FDP = \sum \frac{[(T - 2)] * [(D - 3)]}{16,7} \qquad (1)$$

In which: *FDP*=Fungal Decay Potential; *T* = average temperature (ºC); *D* = number of days in month with precipitation equal to or greater than 0.3 mm.

In order to complement, soil collection at two experiment environments and a subsequent analysis at the Department of Soil at the Federal University of Santa Maria (UFSM) have been carried out, aiming at the determination of mineral and organic constituents. The study has been conducted in completely randomized design (CRD), evaluated through analysis of variance (ANOVA) with subsequent comparison of means by Turkey's test, in a 5%-level of probability of error, along with simple linear regression analysis (Equation 2). All statistical analyses have been carried out with the assistance of Statgraphics Centurion XV.II software program.

$$\hat{y} = b_0 + b_1 t + e \qquad (2)$$

In which: $\hat{y}$ = dependent variable (mass loss % or deterioration index); t = time in days; e = random error.

3. RESULTS

3.1. Soil analysis and climate conditions

Regarding the soil acidity diagnosis, the pH from both environments were similar, 4,5 and 4,9 for forest and field, respectively. The diagnosis for macronutrients pointed out that the forest soil had higher organic matter content, 3,3%, whereas the amount found in field was 1,9%. This indicates that the forest soil presented a higher propensity for the development of xylophagous microorganisms.

Figure 1 presents the relative humidity variation, the average temperature, the fungal decay potential and the number of days with precipitation equal to or higher than 0,30mm. It is possible to observe the relative humidity variation during the 405 days of experiment. It can be noted that relative humidity values oscillated between 69,9% and 79,6%. The average temperature oscillation was 14,4 °C, in the month of July, to 27,8 °C, in the month of March.

3.2. Specific mass, mass loss and deterioration index

Given the values for specific mass obtained in the study, the species *Hovenia dulcis* (0,66 g/cm³) and *Eucalyptus robusta* (0,75 g/cm³) can be classified as moderately heavy density woods, situated between 0,65 and 0,79 g/cm³. Meanwhile, *Eucalyptus dunnii* (0,88 g/cm³) and *Eucalyptus tereticornis* (0,90 g/cm³) can be classified as heavy woods, as light to dark heartwood eucalyptus, with densities between 0,80 and 0,95 g/cm³, according to Carvalho's classification (1996). A direct relation can be observed between specific mass and mass loss of species, with some variations.

Table 1 presents mass loss values of the species studied for field and forest environments due to time in days exposed to the decaying field. It can be noted that mass loss mostly increased along with exposure time of test samples.
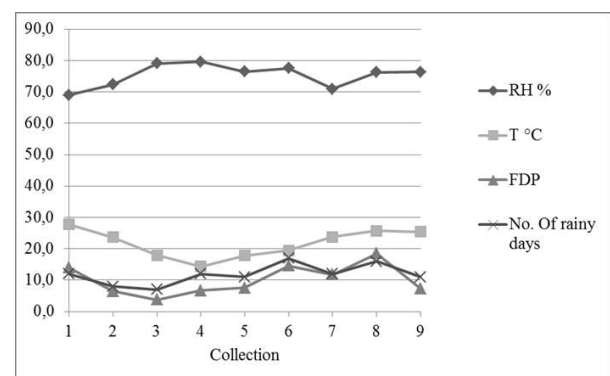

Figure 1 – Relative Humidity Variation (RH %); Temperature (T°C); Fungal Decay Potential (FDP) and No. of days with rain equal or higher than 0,30 mm during the experiment.

Figuras 1 – *Variação da Umidade Relativa (UR %); Temperatura (T°C); Potencial de Ataque Fúngico (PAF) e Número de dias com chuva igual ou superior a 0,30 mm durante o experimento.*

Table 1 – Mass Loss (%) of species submitted to decaying field.
Tabela 1 – *Perda de Massa (%) das espécies submetidas ao campo de apodrecimento.*

Collection	Days	E. tereticornis		H. dulcis		E. robusta		E. dunnii	
		Field	Forest	Field	Forest	Field	Forest	Field	Forest
1	45	7,8	7,6	11,0	11,7	12,6	12,8	9,0	9,0
2	90	8,4	10,8	13,3	10,9	13,0	11,7	11,1	15,6
3	135	9,2	14,4	13,4	12,8	13,1	13,8	14,7	20,2
4	180	15,1	13,9	11,9	12,6	12,5	13,1	11,1	24,8
5	225	11,8	22,7	13,0	14,4	12,9	14,1	11,6	21,5
6	270	7,1	14,1	15,3	15,8	13,1	14,2	13,3	22,8
7	315	6,0	20,8	18,8	18,0	13,7	16,5	14,1	31,1
8	360	7,4	21,9	14,4	22,8	13,9	19,8	19,0	43,1
9	405	18,5	13,0	17,4	27,5	14,4	27,1	15,2	46,2
Average		10,14	15,47	14,28	16,28	13,24	15,90	13,23	26,03

Results from the forest environment presented a higher mass loss tendency in relation to the open field environment, which can be explained by more adequate conditions for the development of wood biodeterioration agents, as previously mentioned, due to the microclimate present in the forest.

According to the norm ASTMD-2017 (2005), results from *Eucalyptus tereticornis* field and forest environments were classified as very resistant to resistant. For *Hovenia dulcis*, results from field were classified as resistant, as well as in forest, carrying out the value of the last collection, classified as moderately resistant. A similar behavior has also been observed in *Eucalyptus robusta*, with small variations in values obtained. *Eucalyptus dunnii* was classified as resistant for field environment, whereas for forest, it was classified as resistant to moderately resistant wood, with the last collection being classified as non-resistant. Resistance variation has occurred due to material exposure time

at the decaying field and consequent susceptibility to attack by xylophagous organisms.

The state of sanity of the species studied has been analyzed by the deterioration index, submitted to open field and forest environments, whose values can be observed in Table 2. It can be verified that the highest indices were in the first collections, tending to decrease along with exposure time, with some oscillations between collections. These highest values indicate lesser probability of attacks.

It can be observed that the values for the deterioration index tended to be more reduced in forest environment, presenting a higher degradation than samples from open field.

In Table 3, it can be observed that the comparative average values among species and environment, species, environment and evaluations. For the evaluation of species and environment, it can be noted that mass loss inversely varied in relation to the specific mass

Table 2 – Deterioration Index of species submitted to decaying field.
Tabela 2 – *Índice de deterioração das espécies submetidas a campo de apodrecimento.*

Collection	Days	E. tereticornis		H. dulcis		E. robusta		E. dunnii	
		Field	Forest	Field	Forest	Field	Forest	Field	Forest
1	45	93,3	86,7	100,0	93,3	100,0	90,0	90,0	76,7
2	90	80,0	70,0	93,3	93,3	90,0	90,0	90,0	43,3
3	135	76,7	76,7	90,0	93,3	83,3	76,7	70,0	26,7
4	180	90,0	50,0	96,7	96,7	83,3	70,0	70,0	13,3
5	225	90,0	50,0	90,0	93,3	90,0	76,7	40,0	83,3
6	270	90,0	70,0	83,3	76,7	83,3	90,0	76,7	26,7
7	315	90,0	50,0	90,0	60,0	90,0	70,0	70,0	0,0
8	360	70,0	36,7	90,0	60,0	90,0	70,0	50,0	0,0
9	405	70,0	0,0	83,3	13,3	13,3	60,0	26,7	0,0
Average		83,33	54,46	90,73	75,54	80,36	77,04	64,82	30,0

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of species in field environment, whereas, in forest environment, the same behavior was not noticed only for *Eucalyptus dunnii*, because it presented more likely to mass loss. By analyzing the values of field environment, it can be verified that *Eucalyptus tereticornis* presented the lowest average mass loss, statistically differing from the other species, which did not differ among themselves. In forest environment, *Eucalyptus dunnii* statistically differed from the other species, presenting the highest mass loss.

By analyzing the difference between environments, it can be noted that the species *Hovenia dulcis* did not present statistical difference between open field and forest. It can still be perceived that the forest environment presented higher mass loss than field environment for all species.

As for the deterioration index, it can be perceived that the species *Eucalyptus dunnii* presented higher probability to attack by biodeterioration agents, statistically differing from the other species. The species *Eucalyptus tereticornis* did not statistically differ from *Eucalyptus robusta*, but the latter presented difference

in relation to *Hovenia dulcis*. A similar behavior has been observed in forest environment, but in this environment, *Eucalyptus tereticornis* and *Eucalyptus robusta* differed between themselves.

As for species, it can be noted that the species *Eucalyptus dunnii* proved to be more likely for both deterioration index and mass loss, differing from the other species. As for environment analysis, it can be perceived that there has been statistical difference between them, with wood from forest environment being more affected for both deterioration index and mass loss. As for the evaluations carried out accordingly to time in days, a deterioration index decrease and mass loss increase with the growth of exposure time is perceived. These facts indicate that the deterioration index along with mass loss are safe methods for the evaluation of species natural durability and indicate the attack by biodeterioration agents to wood.

In Table 4, linear equations adjusted for deterioration index and mass loss estimation from the woods studied can be observed, accordingly to the time in which samples remained exposed to environments.

Table 3 – Comparison of Averages for deterioration index and mass loss in relation to species, environments and evaluations.
Tabela 3 – Comparação de médias para o índice de deterioração e perda de massa em função das espécies, ambientes e avaliações.

Species	Mass loss (%)		Deterioration index	
	Field	Forest	Field	Forest
Eucalyptus tereticornis	10,1 A a	15,5 A b	83,3 B a	54,4 B b
Eucalyptus dunnii	13,2 B a	26,0 B b	64,8 A a	30,0 A b
Eucalyptus robusta	13,3 B a	15,9 A b	88,9 BC a	71,1 C b
Hovenia dulcis	14,3 B a	16,3 A a	90,7 C a	75,6 C b
Species	Mass loss (%)		Deterioration index	
Eucalyptus dunnii	19,63 a		48,15 a	
Eucalyptus tereticornis	12,80 b		68,89 b	
Eucalyptus robusta	14,57 b		81,48 bc	
Hovenia dulcis	15,28 b		84,63 c	
Environment	Deterioration index		Mass loss (%)	
Forest	59,26 a		18,42 a	
Field	82,31 b		12,73 b	
Evaluations (days)	Deterioration index		Mass loss (%)	
1 (45)	92,08 a		10,19 a	
2 (90)	80,42 ab		11,85 ab	
3 (135)	73,75 ab		13,96 ab	
4 (180)	72,08 ab		14,38 abc	
5 (225)	79,17 ab		15,27 abc	
6 (270)	72,92 ab		14,47 abc	
7 (315)	65,00 bc		17,37 bcd	
8 (360)	58,33 bc		20,29 cd	
9 (405)	43,33 c		22,38 d	

The averages followed by the same letter do not differ statistically (Turkey p > 0,05).

Table 4 – Prediction models of Deterioration Index and Mass Loss in relation to exposure time of woods to deterioration tests in field and forest.
Table 4 – *Modelos de predição do Índice de Deterioração e Perda de Massa em função do tempo de exposição das madeiras aos ensaios de deterioração em campo aberto e floresta.*

DETERIORATION INDEX						
Species	Environment	B_0	B_1	R^2_{aj} (%)	S_{yx} (%)	F
Eucalyptus dunnii	Field	95,5556	- 0,13333	44,6	17,19	21,93*
	Forest	70,463	- 0,176543	30,36	30,35	12,34*
Eucalyptus robusta	Field	24,5712	- 0,0246878	12,82	6,79	4,82*
	Forest	87,037	- 0,054321	28,20	9,79	11,21*
Hovenia dulcis	Field	28,5354	- 0,0334145	33,37	5,39	14,02*
	Forest	115,926	- 0,153086	70,4	11,66	62,84*
Eucalyptus tereticornis	Field	93,2407	- 0,0407407	18,06	9,48	6,73*
	Forest	94,4444	- 0,177778	52,87	19,54	30,17*
MASS LOSS						
Species	Environment	B_0	B_1	R^2_{aj} (%)	S_{yx} (%)	F
Eucalyptus dunnii	Field	89,8758	0,0180183	36,84	2,71	16,17*
	Forest	5,10258	0,093002	73,26	6,60	72,25*
Eucalyptus robusta	Field	12,2897	0,00426812	66,34	0,35	52,24*
	Forest	146,048	0,0254923	54,89	2,69	32,64*
Hovenia dulcis	Field	10,7195	0,0158873	47,68	1,93	24,70*
	Forest	6,92041	0,0415693	61,48	3,85	42,49*
Eucalyptus tereticornis	Field	8,02051	0,00939259	0,04	5,64	1,01[nm]
	Forest	9,85284	0,0249696	13,45	6,71	5,04*

In which: R²aj= adjusted coefficient of determination; Syx(%)= standard error of the estimate; F= value of F calculated; *= meaningful to 5% of probability.

It can be observed that meaningful equations have been generated for the deterioration index, with higher determination coefficients for forest environment, the same fact did not occur for *Eucalyptus dunnii*. In equations generated for mass loss, only the field environment equation for *Eucalyptus tereticornis* was not meaningful, contrasting with the other equations that presented meaningful adjustments. As for *Eucalyptus robusta*, the determination coefficient was higher in field environment, differing from the other species. Conducting studies aiming at identifying extractives and other chemical compounds that affect wood natural durability is advisable.

4. DISCUSSIONS

4.1 Climate Conditions Analysis

The number of rainy days followed FDP variation, which presented variations from 3,8 to 18,5. The collection that presented the highest FDP value was in January, which presented the highest occurrence of rainy days, 16 days, with relative humidity of 76,2 % and temperature of 25,7 ºC, confirming Moreschi's statement (1980) that temperatures near 25ºC represent a higher risk of fungal attack in woods. Just like Silva et al. (2005), who stated that the ideal temperature for most xylophagous organisms is between 20 and 30ºC, similar to what was observed in the study, with average temperature of 21,8ºC for the whole data collection period.

The lowest FDP value has been found in the collection carried out in June, which was the period with less rainy days, 7 days, with relative humidity of 79,0% and average temperature of 17,9 ºC. The values fund corroborate studies carried out by Trevisan (2006), which affirm that environmental variations, mainly in relation to temperature and humidity, have fundamental importance in the development of microorganisms able to attack and in wood decomposition rate. The same author affirms that microorganism species present different ideal conditions of tolerances to the environment.

4.2. Specific mass, mass loss and deterioration index

The deterioration index values in this research corroborate what was found by Trevisan et al. (2008), studying wood behavior from five forest species according to deterioration in two environments (open field and forest), they also found the same tendency,

with higher mass loss in forest when compared to open field. For Melo et al. (2010), the analysis by attribution of notes is the main parameter for evaluation of wood durability in experiments at decaying fields. However, Lopez and Milano (1986) affirm that various researchers used, besides visual evaluations as the deterioration index, a second parameter, which can be mechanical testing or mass loss, as used in this study, in order to characterize wood natural durability in field experiment.

The forest environment presented a higher mass loss than open field environment for all species. Trevisan et al. (2008) found similar results and attributed the fact to a higher humidity existing in forest environment, which combined with the higher stability of environmental conditions (temperature and humidity) from that place are favorable factors to the higher incidence of termites and coleopterans (beetles) in these environments, when compared to the open field experiment.

In relation to mass loss among species, a lesser mass loss has been found for *Eucalyptus tereticornis* wood can be explained by the presence of some compounds with fungicide and insecticide action, minimizing wood damage, as stated by Paes et al. (2007), some extractives can be toxic to xylophagous organisms. The inverse behavior is attributed to *Eucalyptus dunnii* in forest environment that can be explained by the absence of some toxic extractives to biodeterioration organisms, to the highest organic matter content and consequently action by xylophagous agents.

Comparing the environments in which species have been submitted, a meaningful difference can be perceived among all species evaluated, which indicates that deterioration in forest environment was higher than in open field environment, corroborating the statement by Trevisan et al. (2007) that this fact happens because forest provides environmental conditions that benefit the development of biodeterioration organisms.

5. CONCLUSIONS

Based on results obtained, it can be concluded that:

The number of rainy days and temperature directly influence the fungal decay potential.

The *Eucalyptus tereticornis* wood presented a lesser mass loss in both environments.

The *Hovenia dulcis* wood presented a lesser probability of attack in both environments according to the deterioration index criterion

Test samples from forest environment presented higher percentages of mass loss and lesser deterioration index.

Exposure time considerably affected mass loss and deterioration index in the woods studied.

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