RESISTANCE OF PARTICLEBOARD PANELS MADE OF AGRICULTURAL RESIDUES AND BONDED WITH SYNTHETIC RESINS OR PVC PLASTIC TO WOOD-ROTTING FUNGI[1]

Divino Eterno Teixeira[2], Alencar Garlet[3], Keila Lima Sanches[4]

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ABSTRACT: This study aims to evaluate the resistance of three types of particleboard panels to biodeterioration, two of which bonded with synthetic resins and one bonded with PVC plastic. Composite panels were made using sugar cane straw particles as raw material which were bonded together with urea-formaldehyde (UF), tannin-formaldehyde (TANI) and PVC plastic (PVC) resins. Decay tests were performed following procedures outlined in the ASTM D2017-81/1994 standard, whereby sample specimens were subjected to attack by white rot fungus *Trametes versicolor* and brown rot fungus *Gloeophyllum trabeum* using pine (*Pinus* sp.) and embaúba (*Cecropia* sp.) as reference timber. Panels bonded with PVC resin were rated 'resistant' to attack by both fungi while those bonded with UF and TANI resins were rated 'slightly resistant' to their attack.

Key words: Particleboard panels, biodeterioration, synthetic resins, agricultural residues.

RESISTÊNCIA DE PAINÉIS AGLOMERADOS DE RESÍDUOS AGRÍCOLAS COLADOS COM RESINAS SINTÉTICAS E PLÁSTICO PVC A FUNGOS APODRECEDORES

RESUMO: *O presente estudo avaliou a resistência à biodeterioração de três tipos de chapas de aglomerado; duas com resinas sintéticas e uma com plástico PVC. Painéis foram produzidos usando partículas de palha de cana-de-açúcar como matéria-prima, colados com resinas de uréia-formaldeído (UF), tanino-formaldeído (TANI) e plástico PVC (PVC). Os ensaios de deterioração foram conduzidos segundo a norma ASTM D2017-81/1994, onde corpos-de-prova foram submetidos ao ataque dos fungos Trametes versicolor (podridão-branca) e Gloeophyllum trabeum (podridão-parda), usando como referência amostras de pinus (Pinus sp.) e de embaúba (Cecropia sp.). Os painéis colados com PVC foram classificados como "resistentes" ao ataque de ambos os fungos, enquanto os com UF e TANI apresentaram-se pouco resistentes ao ataque dos fungos testados.*

Palavras-chave: Painéis aglomerados, biodeterioração, resinas sintéticas, resíduos agrícolas.

1 INTRODUCTION

Several tons of agricultural residue such as rice husk, straw (corn, sugar cane) and cane bagasse are generated every year by agribusiness activities. A portion of these residues has simply been burned, although the agricultural sector has been using much of the rice husk waste available while the sugar and alcohol sector has been using virtually the entire bagasse waste available. Environmental legislation is becoming increasingly stricter, with the burning of crop residues posing a major problem for agribusinesses seeking alternative use for their generated waste (Center for Environmental Studies - CEAM 2004).

Sugar cane bagasse has been used in the past to make particleboard panels using three types of resin – two tannin-based and one urea-based resin – and results met or even exceeded the relevant set standards (SANTANA & TEIXEIRA 1996). Following exposure to attack by white rot fungus *Pycnoporus sanguineus* and brown rot fungus *Gloeophyllum trabeum*, these panels were rated 'moderately resistant' (TEIXEIRA et al. 1997). In other countries, using agricultural residues such as wheat straw and sunflower hulls as raw material for the manufacture of reconstituted panels is common practice, generating income, ensuring suitable discharge of waste and being a source of fiber for the local economy (DAPROMA 2009, SORM 2009).

The decay resistance of composite panels is influenced, among other things, by particle durability, type and concentration of resin used, and fungi species used in testing them. Okino et al. (2007) evaluated biodegradation

[1]Work conducted at Laboratório de Produtos Florestais/LPF of IBAMA – SCEN, Trecho 2, Edifício Sede do IBAMA – 70818-900 – Brasília, DF

[2]Forest Engineer, PhD, Environmental Analyst with Laboratório de Produtos Florestais/LPF of IBAMA – SCEN, Trecho 2, Edifício Sede do IBAMA – 70818-900 – Brasília, DF – divino.teixeira@florestal.gov.br

[3]Forest Engineer, Environmental Analyst with Laboratório de Produtos Florestais/LPF of IBAMA – SCEN, Trecho 2, Edifício Sede do IBAMA – 70818-900 – Brasília, DF – alencar.garlet@florestal.gov.br.

[4]MSc. in Forest Sciences – Departmento de Engenharia Florestal/EFL – Universidade de Brasília/UnB – 70919-970 – keila.sanches@gmail.com

in oriented strand board panels (OSB) made of pine, eucalyptus and cypress, bonded with urea-formaldehyde and phenol-formaldehyde resins at 5% and 8% of resin solids, and subjected to accelerated decay test by the soil-block method. The authors observed that panels bonded with phenol-formaldehyde were more resistant than those bonded with urea-formaldehyde, and also that increasing resin contents reduced mass loss in the panels.

An alternative way for interpreting results of decay resistance in wood panels is using the *Decay Susceptibility Index* (DSI). According to Okino et al. (2006), DSI is the ratio of mass loss percentage of sample to mass loss percentage of reference timber used in the accelerated laboratory test. For calculation of this index, hardwood blocks are used as reference timber for white rot fungi and softwood blocks are used as reference timber for brown rot fungi.

The growing interest in the use of wood composites bonded with thermoplastic resins, such as high and low density polyethylene, polypropylene (PP) and polyvinyl chloride (PVC), has indicated that different residual sources can be used for a variety of applications that include flooring, decking, sheathing and car parts, among other things. While studying wood-plastic composite panels made of particles of hardwood limba (*Terminalia superba*) and PVC in the proportion of 30/70 (wood/plastic), Labat et al. (2000) found that the panels had better performance than the relevant solid wood. After six weeks of exposure to fungus *Coriolus versicolor* using the agar-block test (EN 113), samples had a mass loss of only 0.3% which, according to the authors, is due to the resin coating on the wood particles, while the solid wood had a mass loss of 22.9%. The authors suggest that panel durability is shortened when the wood content exceeds 60% due to insufficient coating of fibers by the plastic resin.

The wood of the pine tree has low density and is the most commonly used for the manufacture of particleboard panels in Brazil. Sugar cane straw has even lower density (91 kg/m³) and thus greater compaction rate, having potential use as an alternative raw material in the upcoming future. Yet particleboard from this material needs to be evaluated for decay resistance prior to recommending its use.

This work aims to evaluate the decay resistance of particleboard panels made from cane straw particles and bonded with urea-formaldehyde, phenol-formaldehyde and PVC resins, and subjected to attack by white rot fungus *Trametes versicolor* and brown rot fungus *Gloeophyllum trabeum*.

2 MATERIAL AND METHODS

The study was conducted at the Laboratory of Forest Products (LPF) of IBAMA, in Brasília, Distrito Federal. The particleboard panels were manufactured at the Products division and the biodeterioration test was conducted at the Wood Preservation and Biodegradation division.

2.1 Making of particleboard panels

The sugar cane straw used in this experiment was obtained from a sugar mill in Jaú, an inland town in São Paulo state, and then processed at the Laboratory of Forest Products using a CREMASCO agricultural grinder. The material was then sorted for the making of three types of particleboard panel – two bonded with synthetic resins and one bonded with PVC plastic resin. Once sorted, the straw was dried at 3.5% and 5% humidity for making the synthetic resin panels, and at 1% maximum humidity for making the thermoplastic panels. The resins used were urea-formaldehyde (UF) and tannin-formaldehyde (TANI) emulsions, and powdered PVC plastic (PVC). Panel characteristics (resin type and content, straw granulometry and apparent specific mass) are illustrated in Table 1. Panels were hot pressed at 195ºC.

2.2 Preparation of samples for the biodeterioration test

Solid wood samples of *Eucalyptus grandis* (eucalyptus), *Cecropia* sp. (embaúba) and *Pinus* sp. (pine) were collected in Distrito Federal region and cut into chips each measuring 25x25x9 mm, the latter measurement running parallel to fiber direction. The eucalyptus samples were cut from the heartwood of three trees aged eight years, while the pine and embaúba samples were cut from the sapwood.

Particleboard samples were obtained by cutting panels into pieces each measuring 25x25cm x10 mm, with 12 replicates per type of panel / treatment for each fungus. This material was placed in an environmental chamber at 20±3°C and 65±5% RH, to constant weight. Then samples were weighed and measured. The apparent specific mass (A.S.M.) of each treatment was estimated by the arithmetic mean values of A.S.M. of 12 sample specimens.

2.3 Wood-boring fungi and decay test

Two species of wood-boring fungi were used: *Gloeophyllum trabeum* (Pers. Ex Fr.) Murril (brown rot) and *Trametes versicolor* (Linnaeus ex Fries) Pilát (white rot), as obtained from the Laboratory of Forest Products.

Table 1 – Treatments subjected to biodeterioration test.

***Tabela 1** – Tratamentos submetidos ao ensaio de biodeterioração.*

Treatments	Resin	Granulometry	A.S.M. (kg/m^3)	% of resin
		Wood		
CE	*Cecropia* sp.	Solid wood	475	-
EG	*Eucalyptus grandis*	Solid wood	612	-
PIN	*Pinus* sp.	Solid wood	476	-
		Straw particles		
TANI	Tannin-formaldehyde	3 mm	811	8%
UF	Urea-formaldehyde	1.5 mm + 1.0 mm	721	12%
PVC	Powdered PVC plastic	Powder	891	60%

CE = *Cecropia* sp. solid wood; EG = *Eucalyptus grandis* solid wood; PIN = *Pinus* sp. solid wood; TANI = Tannin-formaldehyde particleboard; UF = Urea-formaldehyde particleboard; PVC = PVC plastic particleboard; A.S.M. = apparent specific mass (particleboard/wood).

CE = madeira maciça de Cecropia sp.; EG = madeira maciça de Eucalyptus grandis; PIN = madeira maciça de Pinus sp.; TANI = aglomerado de Tanino-formaldeído; UF = aglomerado de Uréia-formaldeído; PVC = aglomerado de Plástico PVC; M.E.A. - Massa Especifica Aparente do material (aglomerado/madeira).

The fungi were introduced in a malt medium and taken to an incubator set at (26.7±1)°C temperature and (70±4)% RH, until the surface was fully covered by mycelial growth (3 weeks). At the time of inoculation, the mycelium was fragmented using a domestic blender in order to facilitate the process. All handling procedures were carried out in a laminar flow hood under aseptic conditions.

2.4 General experimental conditions

The experiment followed procedures outlined in the ASTM D2017-81 standard (ASTM 1994). Wide mouth, 190 ml, screw cap jars were used, containing 70g of B horizon soil, free from organic matter. A limestone pretreatment was applied in order to raise soil pH to 6.0.

Soil moisture was adjusted to 130% of field capacity, with 31 ml of deionized water being added to each test jar. One feeder strip measuring 33x29x3 mm was placed in each jar, pinewood for cultivation of *G. trabeum* and embaúba for cultivation of *T. versicolor*. The jars were placed in an autoclave at 121°C for 45 minutes, and each jar was then inoculated with 2 ml of the culture medium containing fragmented mycelium and taken to an incubation chamber set at (26.7±1)°C and (70±4)% RH to allow mycelium to fully cover the feeder strips (4 weeks). After colonization of the feeder strips, one sample specimen was added to each jar.

After 12 weeks, the sample specimens were removed from the jars, cleaned of any adhering mycelium, and again placed in an environmental chamber under the same conditions as the initial step, before final weighing.

2.5 Determination of mass loss

With the initial mass (M_i) and final mass (M_f) values at hand, the mass loss percentage was calculated according to Equation 1:

$$ML(\%) = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

Where: ML = mass loss, M_i = initial mass in grams, and M_f = final mass in grams.

Based on mass loss, species are grouped into different categories of natural durability, according to the ASTM D2017 standard (ASTM 1994), as illustrated in Table 2:

Table 2 – Classes of resistance based on natural durability, according to the ASTM D2017 standard (ASTM 1994).

***Tabela 2** – Classificação do material conforme a classe de durabilidade natural, segundo a norma ASTM D-2017 (ASTM, 1994).*

Mass loss Mean (%)	Class of resistance
0 to 10	Highly Resistant
11 to 24	Resistant
25 to 44	Slightly Resistant
45 or above	Non-Resistant

2.6 Determination of the 'new' decay susceptibility index (DSI_{new})

Through their works, Curling & Murphy (2002) proposed a procedure to calculate a 'new' DSI which takes into account the specific mass of a sample exposed to a laboratory decay test, using the actual mass loss rather than the mass loss percentage. This 'new' DSI is thus calculated by dividing the linear, actual mass loss of a composite by the actual mass loss of the reference timber. Through this methodology, different materials with varying densities can be compared for susceptibility.

Based on the above procedure, as proposed by Curling & Murphy (2002), the 'new' decay susceptibility index, known as DSI_{new}, was calculated using embaúba (*Cecropia* sp.) as reference timber for fungus *T. Versicolor*, and pinewood (*Pinus* sp.) as reference timber for fungus *G. trabeum*. Equations 2 and 3 illustrate how the new index was calculated, taking into account the A.S.M. of the material and mass loss results.

$$DSI_{new} = \frac{AML_{sample}}{AML_{timber}} \times 100 \quad (2)$$

$$AML = A.S.M.(kg/m^3) \times \text{mass loss}\,(\%) \quad (3)$$

Where: DSI_{new} = 'new' decay susceptibility index, A.S.M. = apparent specific mass of sample in kg/m^3, AML_{sample} = actual mass loss of sample in kg, AML_{timber} = actual mass loss of reference timber in kg.

2.7 Analysis of results

A statistical analysis was performed using software SPSS plus-version 13.0 and the obtained results were analyzed using the means test (Tukey test) at the 5% significance level.

3 RESULTS AND DISCUSSION

Mean results of attack by fungi *T. versicolor* and *G. trabeum* are illustrated in Tables 3 and 4 and in Figures 1 and 2.

From Table 3 data it can be seen that *Pinus* sp. had better performance than *Eucalyptus grandis* and *Cecropia* sp. in relation to fungus *T. versicolor*. As regards attack by fungus *G. trabeum*, however, *Eucalyptus grandis* revealed stronger resistance to decay while *Pinus* sp. was the most severely attacked (Table 4).

Species *Cecropia* sp. constituting a highly perishable type of wood was severely attacked by both fungi, and although *T. versicolor* caused greater mass loss, no statistical significant difference was observed between the fungi (Figure 1).

Eucalyptus grandis wood presented a mass loss of 48.0% for fungus *T. versicolor* and 20.6% for fungus *G. trabeum*. This difference was significant according to the Tukey test at the 5% significance level. Based on criteria set out in the ASTM D2017 standard (ASTM 1994), the eucalyptus sample was rated 'non-resistant' to fungus *T. versicolor* but 'resistant' to fungus *G. trabeum*.

These data agree with existing literature since brown rot fungi cause greater mass loss in softwoods than it does in hardwoods. The reverse is true for white rot fungi in that they are particularly effective at deteriorating hardwoods (CURLING & MURPHY 2002).

The particleboard panel made from sugar cane straw and bonded with PVC presented the best result for both fungi. The mass loss in relation to total mass of sample was 18.4% for *T. versicolor* and 18.5% for *G. trabeum*. According to ratings in the ASTM D2017 standard (ASTM 1994), this panel is 'resistant' to both fungi tested.

The above results are consistent with the work of Mankowski et al. (2005). These authors observed a mass loss of 10%-20% in wood-plastic composites subjected to accelerated decay tests. Results obtained by Okino et al. (2006) were lower, around 8% for *T. versicolor* and 5.6% for *G. trabeum*, in composites containing 60% of LDPE plastic in their composition.

The good performance of the above panel is credited to the 60% PVC content in its composition. This high PVC content allows better coating of straw particles, reducing moisture absorption. According to Milagres et al. (2006), when PVC content is increased from 25% to 50% a significant reduction occurs in water absorption.

The sample panels bonded with tannin-formaldehyde presented a mass loss of 44.0% ('slightly

Table 3 – Mass loss and DSI_{new} results for treatments subjected to attack by *Trametes versicolor*.

Tabela 3 *– Resultados da perda de massa e DSI_{novo} dos tratamentos submetidos ao ataque de Trametes versicolor.*

Treatment	Mass loss (%) [1]	ASTM D2017 Class of resistance	DSI_{new}
CE	52.6 [b]	Non-Resistant	reference
EG	48.0 [b]	Non-Resistant	117.5
PIN	26.5 [a]	Slightly Resistant	50.4
TANI	55.7 [b]	Non-Resistant	180.8
UF	67.30 [c]	Non-Resistant	194.2
PVC	18.4 [a]	Resistant	65.6

TANI = Tannin-formaldehyde particleboard; PVC = PVC plastic particleboard; UF = Urea-formaldehyde particleboard; EG = *Eucalyptus grandis* solid wood; CE = *Cecropia* sp. solid wood; PIN = *Pinus* sp. solid wood.
([1]) Means followed by the same letter do not differ statistically by the Tukey test at the 5% significance level.

TANI = aglomerado de Tanino-formaldeído; PVC = aglomerado de Plástico PVC; UF = aglomerado de Uréia-formaldeído; EG = madeira maciça de Eucalyptus grandis; CE = madeira maciça de Cecropia sp.; PIN = madeira maciça de Pinus sp.
([1]) Médias com a mesma letra não diferem estatisticamente pelo teste de Tukey a 5% de significância.

Table 4 – Mass loss and DSI_{new} results for treatments subjected to attack by *Gloeophyllum trabeum*.

Tabela 4 *– Resultados da perda de massa e DSI_{novo} dos tratamentos submetidos ao ataque de Gloeophyllum trabeum.*

Treatment	Mass loss (%) [1]	ASTM D2017 Class of resistance	DSI_{new}
CE	46.9 [b,c]	Non-Resistant	78.9
EG	20.6 [a]	Resistant	44.7
PIN	59.2 [c]	Non-Resistant	reference
TANI	44.0 [b,c]	Slightly Resistant	126.7
UF	41.6 [b]	Slightly Resistant	106.5
PVC	18.5 [a]	Resistant	58.5

TANI = Tannin-formaldehyde particleboard; PVC = PVC plastic particleboard; UF = Urea-formaldehyde particleboard; EG = *Eucalyptus grandis* solid wood; CE = *Cecropia* sp. solid wood; PIN = *Pinus* sp. solid wood.
([1]) Means followed by the same letter do not differ statistically by the Tukey test at the 5% significance level.

TANI = aglomerado de Tanino-formaldeído; PVC = aglomerado de Plástico PVC; UF = aglomerado de Uréia-formaldeído; EG = madeira maciça de Eucalyptus grandis; CE = madeira maciça de Cecropia sp.; PIN = madeira maciça de Pinus sp.
([1]) Médias com a mesma letra não diferem estatisticamente pelo teste de Tukey a 5% de significância.

resistant') for fungus *G. trabeum* and 55.7% ('non-resistant') for *T. versicolor*, the difference being significant by the Tukey test at the 5% level (Figure 2). The sample panels bonded with urea-formaldehyde presented a mass loss of 41.6% ('slightly resistant') for fungus *G. trabeum* and 67.3% ('non-resistant') for *T. versicolor*, also significant at the 5% level. Unlike PVC resin, the urea-formaldehyde resin provides lower resistance to moisture, facilitating fungi attack.

Experimental results indicate that panels bonded with urea- and tannin-formaldehyde cannot be used in places with impending exposure to moisture and thus to fungi attack. For such panels, further studies are required to investigate the application of preservative products

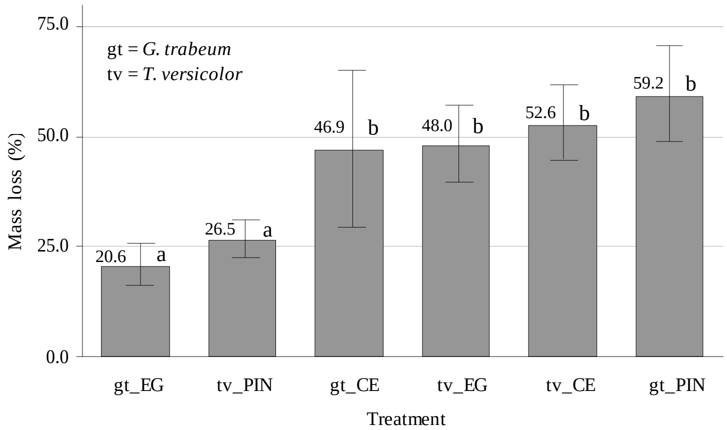

Figure 1 – Mass loss in wood samples used as control, as caused by fungi *Gloeophyllum trabeum* and *Trametes versicolor.* (Means followed by the same letter do not differ by the Tukey test at the 5% significance level).

***Figura 1** – Perda de massa das amostras de madeira, usadas como controle, causada pelos fungos Gloeophyllum trabeum e Trametes versicolor. (Médias com uma mesma letra não diferem entre si a 5% de significância, segundo o teste de Tukey).*

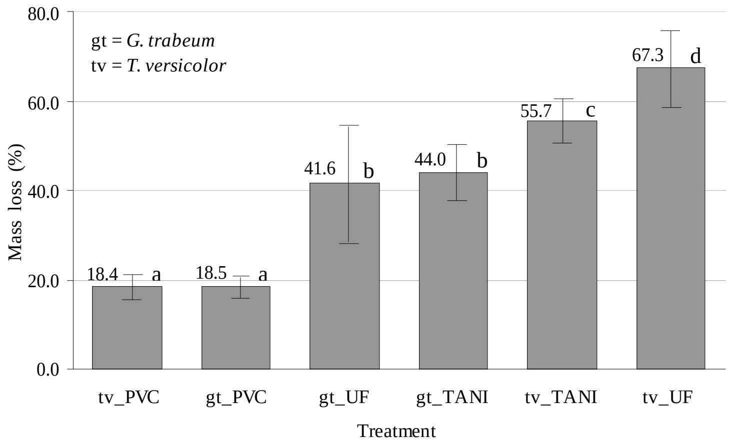

Figure 2 – Mass loss in reconstituted panels, as caused by fungi *Gloeophyllum trabeum* and *Trametes versicolor.* (Means followed by the same letter do not differ by the Tukey test at the 5% significance level).

***Figura 2** – Perda de massa dos painéis reconstituídos causada pelos fungos Gloeophyllum trabeum e Trametes versicolor. (Médias com uma mesma letra não diferem entre si a 5% de significância, segundo o teste de Tukey).*

capable of improving their resistance to attack by wood-boring fungi. By the same token, sugar cane straw panels bonded with PVC resin, being rated 'resistant' to both fungi, can be used in places subjected to continuous moisture though not in direct contact with soil or water.

Figures 3 and 4 illustrate DSI_{new} values. Panels bonded with tannin-formaldehyde, urea-formaldehyde and PVC presented values of 180.8, 194.2 and 65.6 respectively for *T. versicolor,* and 126.7, 106.5 and 58.5 respectively for *G. trabeum*. PVC resin showed greater resistance to decay. According to Curling & Murphy (2002), indices above 100 denote that the sample is less resistant than the reference timber used to each type of fungus. Thus, panels bonded with urea-formaldehyde or tannin-formaldehyde are less resistant than *Pinus* sp. sapwood to attack by *G. trabeum*, and less resistant than *Cecropia* sp. sapwood to attack by *T. versicolor*.

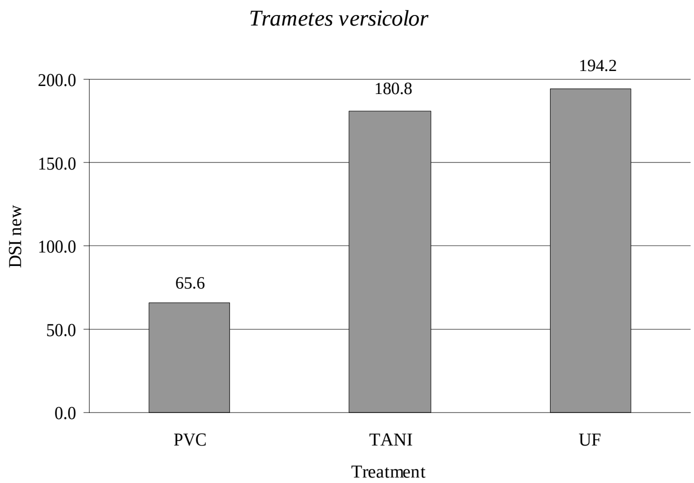

Figure 3 – Decay Susceptibility Index (DSI_{new}) of particleboard treatments to attack by wood-rotting fungus *Trametes versicolor*.

***Figura 3 –** Decay Susceptibility Index (DSI_{novo}) dos tratamentos de aglomerado diante do ataque do fungo apodrecedor Trametes versicolor.*

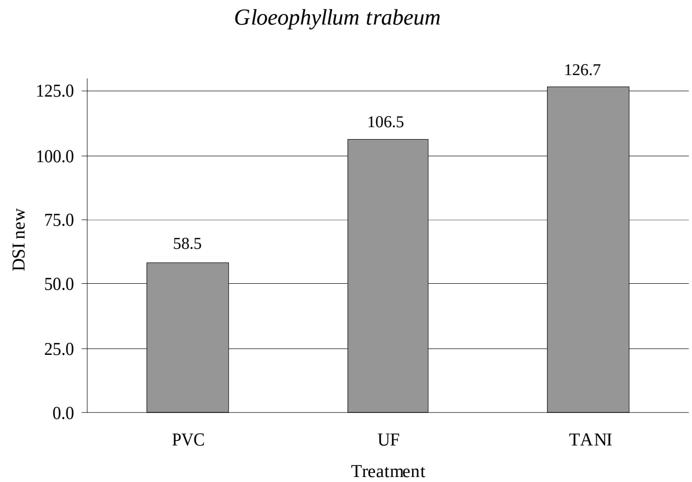

Figure 4 – Decay Susceptibility Index (DSI_{new}) of particleboard treatments to attack by wood-rooting fungus *Gloeophyllum trabeum*.

***Figura 4 –** Decay Susceptibility Index (DSI_{novo}) dos tratamentos de aglomerado diante do ataque do fungo apodrecedor Gloeophyllum trabeum.*

4 CONCLUSIONS

Panels composed of sugar cane straw particles and PVC resin were rated 'resistant' to attack by *T. versicolor* and *G. trabeum*, according to the ASTM D2017 standard.

Panels composed of sugar cane straw particles and tannin-formaldehyde or urea-formaldehyde were rated 'slightly resistant' to attack by the above fungi.

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