REVISTA FLORESTA
Engenharia Florestal
ISSN 1982-4688
Edição 54
Universidade Federal do Paraná
Setor de Ciências Agrárias

# POTENTIAL USE OF *Pinus patula* WOOD FOR THE PRODUCTION OF PURE AND IN COMBINATION WITH *Eucalyptus* PLYWOOD PANELS

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Received for publication: 24/01/2024 – Accepted for publication: 01/08/2024

**Resumo**

*Potencial de utilização da madeira de Pinus patula para a produção de painéis compensados puros e em combinação com Eucalyptus.* Os painéis compensados são produtos de grande importância no mercado global, e o Brasil é um grande produtor de compensados de coníferas, o que alavanca as atividades industriais do Sul do país e consequentemente contribui para o PIB brasileiro. *Pinus patula* é uma espécie não convencional que demanda estudos para esta finalidade. Assim, esta pesquisa teve como objetivo avaliar o potencial de utilização da madeira de *Pinus patula* para a produção de painéis compensados puros e em combinação com *Eucalyptus grandis* e *Eucalyptus dunnii*. Foram produzidos 8 tratamentos, puros e em combinação de espécies, os quais foram colados com adesivo fenol formaldeído em gramatura de 180 g/m$^2$ e teor de sólidos da batida de cola de 34%, e prensados com temperatura de 140°C por 13 minutos à pressão específica de 11 kgf/cm$^2$. *Pinus taeda* foi utilizado como espécie referência. As propriedades físicas e mecânicas foram avaliadas segundo as normas ABNT NBR 17002 e ABNT ISO 12466. Os resultados demonstraram que, para a maioria das propriedades avaliadas os painéis de *Pinus patula* foram estatisticamente iguais ou superiores em relação ao *Pinus taeda*. Os painéis do tipo "*combi''* mostraram que as espécies de *Eucalyptus* contribuíram para melhorar a propriedade de flexão estática. Conclui-se, portanto, que o *Pinus patula* possui potencial para a produção de painéis compensados, permite o aumento da disponibilidade e diversidade de matéria prima para os processos industriais, e ainda, a propriedade de flexão estática pode ser melhorada com a produção de painéis do tipo "*combi''* utilizando lâminas de *Eucalyptus*.
*Palavras-chave*: Colagem da madeira, painéis *"combi",* fenol formaldeído.

**Abstract**

Plywood panels are products of great importance in the global market, and Brazil is a large producer of conifer plywood, which boosts industrial activities in the south of the country and consequently contributes to the Brazilian GDP. *Pinus patula* is an unconventional species that requires study for this purpose. Thus, this research aimed to evaluate the potential for using *Pinus patula* wood for the production of pure plywood panels and in combination with *Eucalyptus grandis* and *Eucalyptus dunnii*. 8 treatments were produced, pure and in combination of species, which were glued with phenol formaldehyde adhesive, in a grammage of 180 g/m$^2$ and a solids content from the adhesive formulation of 34%, and pressed at a temperature of 140°C for 13 minutes at a specific pressure of 11 kgf/cm$^2$. *Pinus taeda* was used as a reference species. The physical and mechanical properties were evaluated according to the ABNT NBR 17002 and ABNT ISO 12466 standards. The results demonstrated that, for the majority of the properties evaluated, the *Pinus patula* panels were statistically equal or superior in relation to *Pinus taeda*. The "*combi*" type panels showed that the *Eucalyptus* species contributed to improving the static bending property. It is concluded, therefore, that *Pinus patula* has potential for the production of plywood panels, allowing an increase in the availability and diversity of raw materials for industrial processes, and that the static bending property can be improved with the production of panels of the *"combi"* type using *Eucalyptus* veneers.
*Keywords*: Wood bonding, "*combi*" panels, phenol formaldehyde.

## INTRODUCTION

Plywood panels are a forest-based product widely sold and used on the global market. In 2021, global production reached approximately 60 million m³ of conifers and 55 million m³ of hardwood trees. Brazil is the fourth-largest producer of coniferous plywood panels and accounted for 3.4 million m$^3$, of which 2.6 million m$^3$ were exported, giving the country the status of the world's largest exporter. Regarding hardwood plywood panels, Brazil is more modest; the yearly production was 290 thousand m$^3$, with apparent consumption of 167 thousand m$^3$, and exports of 124 thousand m$^3$, but with imports of 833 thousand m$^3$ (ABIMCI, 2022).

In Brazil, coniferous plywood panels are produced with wood from the *Pinus* genus, mainly from the *Pinus taeda* species, whose plantations are concentrated in the South region, where most of the industries for this product are also located. For hardwood plywood, wood from native tropical species is predominantly used, as are, to a lesser extent, species of *Eucalyptus* and *Schizolobium amazonicum* from forest plantations. *Pinus taeda* stands out for its good adaptation and growth in the temperate regions of the south of the country, in addition to interesting chemical properties for the gluing process, such as a lower content of extractives or resin when compared to some of the other species of the genus.

However, in several regions, *Pinus taeda* plantations have suffered from attacks by capuchin monkeys (*Sapajus nigritus*), which remove the bark to feed on the elaborated sap. This damage can be of the "windowing" or "girdling" type. "Windowing" is characterized by the partial removal of the bark in one or more internodes, forming a rectangular opening in the trunk, while "girdling" occurs throughout its circumference, forming a ring. Girdling is the most severe form, and the crown above the damage tends to dry out, irreparably compromising growth and exposing the tree to the action of opportunistic fungi and pests (MIKICH; LIEBSCH, 2014; LIEBSCH *et al*., 2018).

Considering this context and the region covered by this research (Southern Brazil, especially Paraná), reforestation companies introduced the *Pinus patula* species. According to Liebsch and Mikich (2017), this species is only cultivated experimentally, and the choice has been associated with preliminary assessments that suggested that *Pinus taeda* is more frequently damaged and *Pinus patula* has been overlooked by the primate. This rejection of *Pinus patula* by the capuchin monkey may be associated with the chemical composition of the sap, which can be explained according to the study by Silva *et al.* (2022), who report that *Pinus patula* had a low (or lower) monosaccharide content and a high β-phellandrene contente (citrus odor), which is avoided by the monkeys. Another reason for the introduction of *Pinus patula* was to increase the availability and diversity of raw materials for forest-based industries, as well as to maximize the process, reduce costs or improve the quality of the final product.

*Pinus patula* is a species of Mexican origin that is of great value as a producer of wood for mechanical processing, its best development is observed in regions of higher altitude, and at altitudes above 1000 m, they develop straight trunks with thin branches and represent a large potential for producing high-quality wood, with growth and productivity superior to those of *Pinus taeda* (SHIMIZU, 2008). Its wood has a low density, ranging from 0.30 to 0.41 g/cm$^3$ (TAVARES *et al*., 2018; MODES *et al.*, 2019), contraction anisotropy of 1.43 to 2.44 (JUIZO *et al*., 2015), total content of extractives of 2.84% (RIOS *et al*., 2016), and mechanical properties that allow its application in light constructions (MODES *et al*., 2021).

In the production of plywood panels, light woods with a low content of extractives facilitates the lamination and gluing process.However, low-density woods can impair flexural strength, a very important property when the product is applied to floors or concrete forms, or products that require greater structural resistance. In this sense, industries have been producing "*combi*" type panels, that is, a combination of species, with *Eucalyptus* being the most used in the South region. Abimci (2022) reinforces that *Eucalyptus* species have been gaining significant share in recent years.

Based on the problems caused by capuchin monkeys in *Pinus taeda* plantations, the demand and diversity of wood for industrial processes, and improving the quality or resistance of the final product, this research aimed to evaluate the potential for using *Pinus patula* wood for the production of pure plywood panels and in combination with *Eucalyptus grandis* and *Eucalyptus dunnii.*

## MATERIAL AND METHODS

*Pinus patula* wood was used from an 18-year-old forest plantation located in Bituruna – PR (26°09'39"S 51°33'10"W and 900m altitude), belonging to Remasa Reflorestadora. In this region, the climate is subtropical (Cfb), with an average temperature between 15ºC and 18ºC, mild summers and winters with frequent frosts, an average annual precipitation between 1600mm, and 1700mm (NITSCHE *et al*., 2019).

*Pinus patula* trees were collected to evaluate the quality of their wood for different applications, totaling 15 m$^3$. To study laminated panels, logs located close to the base of the trees (1st and 2nd logs) were selected, which went through the heating process by vaporization, followed by lamination by turning with a thickness of 2.7 mm. After this process, the veneers were dried in a roller dryer to a moisture content of approximately 8%. The lamination and drying stages were carried out on an industrial scale in a laminated panel, door, and molding factory also located in Bituruna – PR. The industrial-sized sheets were sectioned into dimensions of 500 x 500 mm and then used to produce laminated panels.

For reference (control) panels as well as for the production of *combi* type plywood panels, veneers from the species *Pinus taeda*, *Eucalyptus dunnii* and *Eucalyptus grandis* were used. The *Pinus taeda* veneers were donated by a plywood panel industry located in Clevelândia – PR, while the *Eucalyptus* species veneers were donated by the same company where the *Pinus patula* was laminated. The three species mentioned followed stages of heating, lamination, and industrial drying, specific to their characteristics, and under the control or research of the industries.

After receiving, all slides used in this experiment were stabilized and measured to determine the apparent density using the stereometric method. Then, they were placed in a drying oven with air circulation at 60ºC to adjust and maintain a moisture content of 8%.

The plywood panels were produced with dimensions of 500 x 500 x 13 mm (length, width, and thickness), 5 veneers, pure and in combination of species, with 3 replications per treatment, and in accordance with the experimental design presented in Table 1.

Table 1. Experimental design of plywood.
Tabela 1. Delineamento experimental dos painéis compensados.

| Treatment | Composition |
|---|---|
| **Pures** | |
| 1 - *Pinus patula* | Pp – Pp – Pp – Pp – Pp |
| 2 - *Pinus taeda* | Pt – Pt – Pt – Pt – Pt |
| 3 - *Eucalyptus dunnii* | Ed – Ed – Ed – Ed – Ed |
| 4 - *Eucalyptus grandis* | Eg – Eg – Eg – Eg – Eg |
| **Combi's** | |
| 5 - *Pinus patula* + *Eucalyptus dunnii* | Pp – Ed – Pp – Ed – Pp |
| 6 - *Pinus patula* + *Eucalyptus grandis* | Pp – Eg – Pp – Eg – Pp |
| 7 - *Pinus patula* + *Eucalyptus dunnii* | Pp – Ed – Ed – Ed – Pp |
| 8 - *Pinus patula* + *Eucalyptus grandis* | Pp – Eg– Eg – Eg – Pp |

Pp*: Pinus patula;* Pt*: Pinus taeda;* Ed*: Eucalyptus dunnii;* Eg*: Eucalyptus grandis.*

For gluing, phenol-formaldehyde (PF) resin was used with a solids content of 53%, Brookfield viscosity of 730 cP, and a pH of 12.8. The adhesive was formulated from 100 parts by weight of resin, 25 parts of flour, and 30 parts of water, generating a glue solids content of 34%, which was applied at a grammage of 180 g/m$^2$ (single line). After an assembly time of 40 minutes, the panels were pressed with a specific pressure of 11 kgf/cm$^2$ and a temperature of 140°C for 13 minutes.

The panels were conditioned at room temperature for 72 hours (3 days) and then air-conditioned at a temperature of 20±2°C and relative humidity of 65±5% for 15 days, being subsequently converted into test specimens for the evaluation of the physical and mechanical properties of apparent density, moisture content, water absorption, swelling and thickness recovery, and static bending, which followed the procedures of the ABNT NBR 17002 (2021) standard. The glue line shear test followed the methodology and requirements recommended by ABNT NBR ISO 12466 1 (2012) and ABNT NBR ISO 12466 2 (2012).

The results of the apparent density of the sheets, as well as the physical and mechanical properties of the panels were subjected to statistical analysis using the Bartlett and Analysis of Variance tests. Having rejected the null hypothesis, Tukey's comparison of means was applied. All tests were carried out using the *Statgraphics Centurion XVI* Program with a 95% reliability.

## RESULTS

### Apparent density of the veneers

The results of the apparent density of the veneers are presented in Table 2.

Table 2. Average results of the apparent density of veneers.
Tabela 2. Resultados médios da densidade aparente das lâminas.

| Species | Average density (g/cm$^3$) | Minimum density (g/cm$^3$) | Maximum density (g/cm$^3$) | CV (%) |
|---|---|---|---|---|
| *Pinus patula* | 0.426 c | 0.346 | 0.515 | 10.62 |
| *Pinus taeda* | 0.501 a | 0.448 | 0.581 | 7.81 |
| *Eucalyptus dunnii* | 0.467 b | 0.413 | 0.547 | 7.06 |
| *Eucalyptus grandis* | 0.496 a | 0.412 | 0.553 | 5.75 |

Means followed by the same letter are statistically equal according to the Tukey Test at a 5% probability of error.

**Physical properties of the panels**

Table 3 shows the average results of the panels' apparent density, moisture content, water absorption, swelling and thickness recovery, as well as the coefficients of variation and comparison of means.

Table 3. Average results of the physical properties of the plywoods.
Tabela 3. Resultados médios das propriedades físicas dos painéis compensados.

| Treatment | AD (g/cm³) | MC (%) | WA (%) | STR (%) |
|---|---|---|---|---|
| T1 - Pp | 0.532 A ab (4.92) | 10.89 A a (3.20) | 65.56 A bc (9.92) | 9.37 A ab (7.99) |
| T2 - Pt | 0.553 A a (7.27) | 10.69 A abc (2.57) | 66.44 A bc (7.61) | 8.25 A b (13.60) |
| T3 - Ed | 0.530 ab (4.81) | 10.91 a (1.54) | 70.42 b (8.59) | 9.42 ab (14.41) |
| T4 - Eg | 0.555 a (3.88) | 10.48 c (2.97) | 49.71 d (8.54) | 9.10 b (10.23) |
| T5 – Pp;Ed;Pp;Ed;Pp | 0.516 b (5.27) | 10.65 abc (2.60) | 76.97 a (6.77) | 9.40 ab (14.69) |
| T6 – Pp;Eg;Pp;Eg;Pp | 0.537 ab (7.29) | 10.51 c (1.90) | 69.69 bc (6.10) | 9.67 ab (11.46) |
| T7 – Pp;Ed;Ed;Ed;Pp | 0.541 ab (6.19) | 10.81 ab (2.82) | 70.81 ab (6.00) | 12.57 a (9.99) |
| T8 – Pp;Eg;Eg;Eg;Pp | 0.556 a (7.57) | 10.54 bc (2.04) | 63.34 c (13.49) | 8.39 b (18.60) |

*Pp: Pinus patula; Pt: Pinus taeda; Ed: Eucalyptus dunnii; Eg: Eucalyptus grandis.* Ad: Apparent density; MC: Moisture content: WA: Water absorption; STR: Swelling and thickness recovery Means followed by the same letter in the same column are statistically equal according to the Tukey Test at a 5% probability of error. Capital letters indicate comparison of means between the species *Pinus patula* and *Pinus taeda*; Lowercase letters indicate comparison of means between all treatments. Values in parentheses indicate the coefficient of variation in percentage.

**Mechanical properties of panels**

Tables 4 and 5 present the average results of the modulus of rupture and elasticity to static bending, and the resistance of the glue line to shear, respectively.

Table 4. Average results of the modulus of rupture and modulus of elasticity to static bending of the plywood.
Tabela 4. Resultados médios do módulo de ruptura e módulo de elasticidade à flexão estática dos painéis compensados.

| Treatment | MOR (MPa) | | MOE (MPa) | |
|---|---|---|---|---|
| | Parallel | Perpendicular | Parallel | Perpendicular |
| T1 – Pp | 41.54 A b (25.16) | 26.56 A b (18.08) | 5567.54 A b (11.13) | 2073.70 A b (23.42) |
| T2 – Pt | 48.22 A ab (15.25) | 26.40 A b (17.74) | 5583.24 A b (17.09) | 1600.61 B b (17.59) |
| T3 – Ed | 57.57 a (6.06) | 31.42 ab (11.55) | 8028.72 a (5.68) | 2677.33 a (14.06) |
| T4 – Eg | 57.74 a (15.71) | 32.24 ab (11.43) | 8021.65 a (8.61) | 2711.88 a (14.29) |
| T5 – Pp;Ed;Pp;Ed;Pp | 46.11 ab (23.40) | 30.07ab (9.78) | 5700.13 b (16.73) | 2940.34 a (8.84) |
| T6 – Pp;Eg;Pp;Eg;Pp | 45.10 ab (19.37) | 34.03 a (9.83) | 5791.02 b (12.53) | 2750.40 a (11.81) |
| T7 – Pp;Ed;Ed;Ed;Pp | 52.64 ab (19.58) | 34.56 a (15.47) | 5987.47 b (17.01) | 3247.90 a (20.13) |
| T8 – Pp;Eg;Eg;Eg;Pp | 47.55 ab (26.78) | 31.06 ab (9.55) | 5818.83 b (24.36) | 2954.08 a (10.47) |

Pp: *Pinus patula;* Pt: *Pinus taeda;* Ed: *Eucalyptus dunnii;* Eg: *Eucalyptus grandis;* MOR: Modulus of Rupture; MOE: Modulus of Elasticity. Means followed by the same letter in the same column are statistically equal according to the Tukey Test at a 5% probability of error. Capital letters indicate comparison of means between the species *Pinus patula* and *Pinus taeda*; lowercase letters indicate comparison of means between all treatments. Values in parentheses indicate the coefficient of variation in percentage.

Table 5. Average results of glue line shear resistance of plywood.
Tabela 5. Resultados médios da resistência da linha de cola ao cisalhamento dos painéis compensados.

| Treatment | Dry | | 24h | | Boil Cycle | |
|---|---|---|---|---|---|---|
| | $R_{cis}$ (MPa) | Failure (%) | $R_{cis}$ (MPa) | Failure (%) | $R_{cis}$ (MPa) | Failure (%) |
| T1 - Pp | 1.98 A a (12.31) | 68 | 1.00 A ab (15.47) | 60 | 0.90 A abc (18.95) | 60 |
| T2 - Pt | 1.67 B ab (16.94) | 57 | 0.92 A b (24.02) | 65 | 0.74 B c (15.17) | 58 |
| T3 - Ed | 1.54 b (17.61) | 36 | 1.02 ab (20.16) | 51 | 0.82 bc (23.22) | 23 |
| T4 - Eg | 1.47 b (21.67) | 44 | 1.11 ab (15.71) | 26 | 0.83 bc (26.87) | 47 |
| T5 – Pp;Ed;Pp;Ed;Pp | 2.00 a (18.76) | 63 | 1.06 ab (28.91) | 52 | 0.90 abc (20.31) | 42 |
| T6 – Pp;Eg;Pp;Eg;Pp | 1.99 ab (21.03) | 51 | 1.23 a (13.84) | 53 | 1.05 a (13.94) | 31 |
| T7 – Pp;Ed;Ed;Ed;Pp | 1.52 b (17.85) | 41 | 0.99 ab (21.97) | 54 | 0.78 c (26.62) | 41 |
| T8 – Pp;Eg;Eg;Eg;Pp | 1.72 ab (13.21) | 41 | 1.18 a (19.64) | 55 | 0.96 ab (17.63) | 43 |

Pp*: Pinus patula;* Pt: *Pinus taeda;* Ed: *Eucalyptus dunnii;* Eg: *Eucalyptus grandis;* Rcis: glue line shear resistance; Means followed by the same letter in the same column are statistically equal according to the Tukey Test at a 5% probability of error. Capital letters indicate comparison of means between the species *Pinus patula* and *Pinus taeda*; Lowercase letters indicate comparison of means between all treatments. Values in parentheses indicate the coefficient of variation in percentage.

## DISCUSSION

### Apparent density of the veneers

The results of the apparent density of the veneers showed that the *Pinus patula* species presented the lowest apparent density. This value allows it to be classified as a light wood or wood with low density (< 0.50 g/cm$^3$), as well as suitable for lamination, according to Walker (1993), who reports that wood for this purpose has a density variation range of 0.38 to 0.70 g/cm$^3$.

Regarding the production of laminated panels, some inferences can be made about gluing and according to Sellers (1994). According this author, low density woods are easier to glue, do not require high-resistance adhesives, do not require special procedures such as high pressures, and have thinner cells with larger lumens, which facilitates adhesive mobility. However, due to the greater porosity, they can consume a greater volume of adhesive, making it necessary to control viscosity, especially using more viscous adhesive formulations to avoid starving glue lines and, consequently, low glue line strength.

### Physical properties of the panels

The average results of the apparent density of the panels (Table 3) indicated that in the comparison between *Pinus patula* and *Pinus taeda*, no statistically significant difference was found between the species of this genus. When comparing all the proposed treatments, there was a significant statistical difference, which can be explained by the variation in the wood density, especially of the species of the Eucalyptus genus. Furthermore, despite the pairing of veneers between the different treatments being carried out to eliminate density variation when evaluating product performance, it is worth highlighting that wood is a biological material with considerable heterogeneity, and the elimination of this influencing factor is often difficult.

In comparison with the density values of *Pinus* plywood panels presented in the Abimci Technical Catalog (2002) it is noted that for phenolic panels with 12 and 15 mm thickness and 5 veneers, the average density values are 0.532 and 0.512 g/cm$^3$, respectively, values similar to those found in this research.

For the equilibrium moisture content of the panels, no statistically significant difference was found between *Pinus patula* and *Pinus taeda*, indicating similar behavior between these two species for this application. In the analysis of this property among all treatments, the occurrence of a statistical difference was verified, showing that, despite the small difference in average values between treatments, the physical, chemical, and anatomical characteristics of the species and their combinations of veneers in the composition of the panels exerted significant influence.

The Abimci Technical Catalog (2002) presents an average value of 10% for the moisture content property of 12 mm panels and 5 veneers, with a variation of 9% to 12%, therefore, the values determined in this research are within the range of variation found and recommended industrially.

The water absorption values also showed that between the target species of this study and its control (*Pinus taeda*), no statistically significant difference was observed, and in the same way as already observed in the density and moisture content, when all treatments were compared between themselves, a significant statistical difference was noted, probably due to the reflection of the physical, chemical, and anatomical properties of each species and their consequent influence on each panel composition. *Eucalyptus grandis* panels were those that showed the best performance, and on the other hand, *Eucalyptus dunnii* panels were those that had the highest absorption.

Regarding swelling and thickness recovery, the average results varied from 8.25% to 12.57%, with no statistically significant difference being found between *Pinus patula* and *Pinus taeda*. As observed in the other physical properties in Table 3, when all treatments were evaluated together, a significant statistical difference was identified, and for this property, treatments 2 (100% Pt), 4 (100% Eg), and 8 (Pp;Eg;Eg;Eg;Pp) were the most stable, differently from treatment 7 (Pp;Ed;Ed;Ed;Pp), which was the one with the lowest stability. No effects of density on the swelling and thickness recovery of the panels were found.

**Mechanical properties of panels**

Static bending

The average results of the modulus of rupture (MOR) in flexion, both in the parallel and perpendicular directions (Table 4), showed that no statistically significant difference was observed between *Pinus patula* and *Pinus taeda*. In relation to the modulus of elasticity (MOE), a significant statistical difference was found only for the perpendicular direction, with *Pinus patula* being superior compared to the control species.

The results of comparing the two species of *Pinus* can be considered interesting and promising because, although *Pinus patula* has a lower wood density, it presented similar results to *Pinus taeda* in the bending test, indicating that it can be an alternative species for this purpose, as well as increasing the availability of wood.

In the analysis of all treatments, it was found that for the parallel MOR, the two species of *Eucalyptus* stood out and were statistically superior only in relation to *Pinus patula*. In the perpendicular direction, they were superior to the two *Pinus* species. In relation to MOE, the panels produced with the two species of *Eucalyptus* in pure form showed statistical superiority in relation to all other treatments when analyzed in the parallel direction. For the MOE in the perpendicular direction, the two *Pinus* species were classified as statistically inferior to the other treatments.

Considering the target species of this study and the treatments produced in combination of species (*combi*), it is noted that the use of *Eucalyptus* veneers in the core of the panels provides increased resistance and stiffness in both test directions. This can be an alternative or strategy to increase this property when necessary or to improve the quality of the panel. These results are explained by the higher densities of *Eucalyptus grandis* (0.496g/cm$^3$) and *Eucalyptus dunnii* (0.467g/cm$^3$) compared to *Pinus patula* (0.426g/cm$^3$), which results in greater resistance and stiffness.

Comparing the results in Table 4 with the values in the Abimci Technical Catalog (2002), it appears that for 12 mm panels and 5 veneers, the average values of parallel and perpendicular MOR are 45.36 and 32.05 MPa, respectively, values close to this work, whose variation was from 41.54 to 57.74 MPa in the parallel direction and from 26.40 to 34.56 MPa in the perpendicular direction. For the MOE, the Abimci document presents average values of 5139.78 MPa (parallel) and 2590.96 MPa (perpendicular), values compatible with those obtained in this research, which ranged from 5567.54 MPa to 8028.72 MPa for the parallel direction and from 1600.61 MPa to 3247.90 MPa for the perpendicular direction.

Glue line shear resistance

The average shear strength results indicated that *Pinus patula* presented statistically higher values in relation to *Pinus taeda* when compared with each other and in the dry and boiling cycle pre-treatment. In the test after immersion in cold water for 24h, the values were statistically equal. This result demonstrates that *Pinus patula* has a similar or superior gluing quality to the species traditionally used for this purpose, thus indicating its potential and the greater diversity and availability of raw materials for lamination and the production of plywood panels.

When all treatments were evaluated together, it was observed that significant statistical differences were found in all test conditions; however, in none of them, *Pinus patula* was statistically inferior to the others.

Considering the normative requirements of the ABNT ISO 12466-2 standard, except for the T3 treatment, produced with 100% *Eucalyptus dunnii* veneers and only in the boiling cycle pre-treatment, all others were approved in terms of bonding quality, meeting a minimum strength of 1 MPa or presenting shear strength values in the range of ≥ 0.60 to 0.99 MPa and with wood failure greater than 40%.

## CONCLUSIONS

The development of this research allows us to conclude that:

- The *Pinus patula* wood veneers presented an apparent density of 0.426 g/cm$^3$, classified as low, and statistically inferior to the *Pinus taeda* veneers.
- *Pinus patula* panels presented physical properties statistically equal to those of *Pinus taeda* panels and similar in relation to panels from *Eucalyptus* species or "*combi*" type panels.
- *Pinus patula* panels showed statistically equal or superior mechanical properties compared to *Pinus taeda* and similar to the other treatments produced in pure form or in combination of species.
- The use of *Eucalyptus* species to produce "*combi*" type panels with *Pinus patula* provided increased resistance to static bending.
- In general, *Pinus patula* presented similar properties to *Pinus taeda*, indicating that it is a suitable species for use in lamination and production of plywood panels, has similar behavior in the production process, and contributes to increasing the availability and diversity of raw materials for this purpose.

## ACKNOWLEDGEMENTS

The authors would like to thank the companies Randa and Remasa, located in the city of Bituruna.

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