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# Juvenile Wood from *Pinus patula* Schltdl & Cham for Multilaminated Panel Production

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## ABSTRACT

Wood scarcity, attacks by primates and insects, and fungal damage in forest plantations make the introduction of new species necessary. Given this, it is important to understand the potential uses of wood in the production chain. *Pinus patula* Schltdl & Cham presents good adaptation to Brazilian conditions and is a candidate for wood supply. Its juvenile wood density however, is lower than that of other pine species. This study aimed to evaluate the properties of veneer on panels produced with twelve-year old *P. patula* wood compared with panels produced with *P. taeda* wood of the same age, which is commonly used for panel production. Panels were bonded with urea-formaldehyde and phenol-formaldehyde adhesives using veneers applied on two types of plywood panel. The *P. patula* panels showed lower strength, stiffness and density when bonded with urea-formaldehyde, and higher strength, density and stiffness when bonded with phenol-formaldehyde in comparison with *P. taeda*. *P. patula* panels can be used for multilayer panel production.

**Keywords:** phenol-formaldehyde, urea-formaldehyde, *Pinus taeda*, plywood, veneers.

## 1. INTRODUCTION

In Brazil, the plywood sector has an established production capacity of over 4 million cubic meters, with 74% of the total being exported (Vieira et al., 2012). Approximately 70% of the plywood panels are produced with pine wood, such as *Pinus taeda* L. and *Pinus elliottii* Engelm. The wood of these trees is in high demand, making the consideration of other species for panel production necessary (Iwakiri et al., 2012).

*Sapajus nigritus* damages *P. taeda* plants in Paraná and Santa Catarina state, leading to reduced wood production (Liebsch et al., 2018). There is no efficient control method for *S. nigritus*, such that alternative plant species may be able to mitigate this problem.

*Pinus patula* Schltdl & Cham is native to the Mexican mountains, in Sierra Madre Oriental and is one of the most exploited species in the country (Sánchez-González, 2008; Van Zonneveld et al., 2009). Its species grow up to 12.6 $m^3$/ha/year by twelve years of age (Santiago-García et al., 2015). In Brazil, *P. patula* is planted in southeast Minas Gerais, northeast São Paulo, west Santa Catarina and in the mountains of Rio Grande do Sul with wood productivity higher than *P. taeda* (Aguiar et al., 2014). There is no record of *S. nigritus* damage to *Pinus patula* trees.

In Brazil, pine plantations have suffered a reduction in their forest rotation, undergoing two thinnings, the first at eight years and the second between 12 and 13 years, and clear cutting between 19 and 20 years (Folmann et al., 2014). Thus, it is important to evaluate the possibilities of using wood from younger trees, such as the 12 year-old trees used in this study.

It was found that *P. elliottii* showed a variation of wood density in the radial direction that allowed the categorization of its wood by means of this characteristic, as either juvenile or adult. This variation was similar to that found by other researchers for *P. patula* and *P. taeda*, showing that for these species juvenile wood occurred until the 5th growth ring and the adult wood after the 14th ring in relation to the pith (Palermo et al., 2013). Thus, the wood used in this study was considered juvenile and transition.

According to Vieira et al. (2012), the consolidation of the plywood industry occurred in 1965, with one of the driving factors being the development of urea-formaldehyde and phenol-formaldehyde resins, which gave plywood panels a more efficient bonding, providing humidity resistance between the veneers. This development allowed for their use in external environments, or in internal environments with the presence of high humidity.

The construction principles used in plywood panel manufacture aim to balance the physical-mechanical variation of the veneers' adjacent layers, arranged in the longitudinal and perpendicular direction to the panel plane. Balancing of plywood panels can be achieved with an even or odd number of veneers, but for that, the layers of their structural composition should always be in odd numbers (Ross, 2010). Different structural compositions consist in the addition or arrangement of the veneers in alternation or in the same direction, in relation to the surface veneer, reinforcing the area that suffers greater structural demands under bending.

Thus, other principle construction compositions such as laminated veneer lumber (LVL) could be used for plywood panels. LVL are parallel veneer panels used as a structural component in buildings, especially in countries where there is a tradition of using wood in construction systems (Müller et al., 2015). According to Wilson & Dancer (2005), in southeastern regions of the U.S., LVL panels are produced with *Pinus elliottii* or *Pinus taeda* wood, hot-pressed with phenol-formaldehyde adhesive. The veneers generally have 2.54 or 3.18 mm and LVL can vary in thickness and width but is most commonly produced with the dimensions 4.45 cm thick and 121.9 cm wide, with lengths of 18.29 m. After being cut into narrower dimensions, they are currently used as an alternative to structural timber for headers and beams and as flanges in "I" composite beams.

Although LVL panels have specific production conditions for structural applications, the type of arrangement used in these parallel veneer panels could also be used in the plywood panel industry for specific purposes. An example would be small pieces that are supported only on the longest sides, thus requiring greater bending effort in this direction. Further, for indoor use, they can be glued with other types of non-waterproof adhesives. Aydin et al. (2004) used urea-formaldehyde and PVA to bond LVL panels made from *Eucalyptus camaldulensis* and *Fagus orientalis* woods, while Melo & Del Menezzi (2014) produced and evaluated the properties of LVL panels made from *Schizolobium amazonicum* and PVAc adhesive.

Purba et al. (2019) also produced and evaluated the properties of LVL panels made from secondary quality hardwood and PVAc adhesive.

Multi-laminated panel production, using perpendicular or parallel veneer arrangements, could be a viable alternative to *P. patula* wood use, due to good results from *P. taeda* plywood (Iwakiri et al., 2012; Müller et al., 2015). This study aimed to evaluate the *P. patula* multilayered wood panel quality produced with urea-formaldehyde and phenol-formaldehyde adhesives with veneers arranged in perpendicular and parallel on timber panels.

## 2. MATERIAL AND METHODS

### 2.1. Biological material

Eighteen trees each were harvested for *P patula* and *P. taeda* (reference species), with diameters (DHB) ranging from 17 to 33 cm. Nine trees were used for panel production and nine for wood basic density evaluation.

Twelve-year-old trees from both species were harvested in General Carneiro, Paraná state, Brazil (26º25'39" S; 51º18'56" W) 1300 meters above sea level. Data from a weather station located 5 km from the study area indicated average annual precipitation of 1776 mm, the occurrence of frost between May and September and temperate climate according to Köppen classification.

### 2.2. Wood basic density

The wood basic density was determined by the ratio between dry mass and saturated volume, according to NBR-11941. Discs were removed from the base (0.10 m), DHB (1.3 meter high), at 25, 50 and 70% of the total tree height.

### 2.3. Lamination, drying and sorting

The trees used for lamination were cut into 2.75 m long logs, and those with a diameter at the thin point equal to or greater than 17 cm were laminated. The number of rolled logs from each tree was recorded and the relative height at which each tree could be laminated was calculated.

Veneers with 600 x 600 mm and 2.2 mm thickness were produced from *P. patula* and *P. taeda* trees and their quality was evaluated according to NBR ISO 2426-1 and 2426-3 and ABIMCI technical parameters (ABIMCI, 2002). The A and B class surface covers and the C +, C and D Classes were used for the core in multilayered panels, according to ABIMCI classifications.

### 2.4. Panel production

The panels of each species were produced with two adhesive types and the seven veneers arranged according Figure 1. The adapted parallel arrangement (referred to in this study as Parallel Veneer Panel – PVP) was realized to facilitate the glue line shear strength test between this veneer and the adjacent one, allowing the evaluation of this mechanical property using the standard plywood test.

Since the plywood glue line shear strength test is performed on veneers that are arranged perpendicular to each other, this adaptation has allowed the same test to be used on the innermost glue line for both panel arrangements, making it possible to compare this property between the panels produced with the two types of arrangements.

On the other hand, the panel central veneer in perpendicular arrangement caused minimal influence on the panel bending strength, or elasticity modulus, (perpendicular x parallel direction) because its inertia moment is minimal and, therefore, caused minimal influence on bending properties.

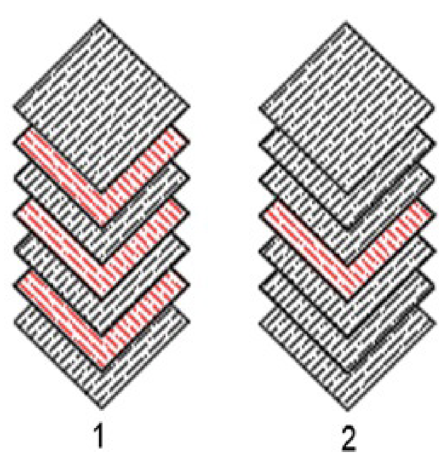


**Figure 1.** Veneer composition in panels. 1. Typical plywood; 2 adapted PVP.

Three panels per treatment were produced with *P. patula* and *P. taeda*, applying two types of adhesives (Urea-formaldehyde - UF and Phenol-formaldehyde - PF), and two veneer arrangements, totaling eight panel types (Table 1).

Seven-layer plywood panels of 600 × 600 mm were pressed in the heated hydraulic laboratory press. For UF and PF adhesives, the glue spread was 160 g/m$^2$ based on wet mass with the adhesive properties and glue compositions complying with the technical parameters (Table 2). Ammonium sulfate was also used as a catalyst at a 2% ratio in the urea-formaldehyde glue composition.

The pressing process occurred with 12 kgf/cm$^2$ for 15 minutes at 110°C for urea-formaldehyde and 140°C for phenol-formaldehyde. The resulting panels had a 13.5 mm nominal thickness and were conditioned in a climatic chamber according to NBR-9489 recommendations.

The properties of multilaminated panels were evaluated based on plywood ABNT standards for both types of panels produced. This option of standards for both the panel veneer compositions, made their comparison possible and fulfilled study objectives. Additionally, it was found that prior studies involving LVL panels were carried out and evaluated by means of physical and mechanical properties traditionally used for plywood panels. (Tenorio et al., 2011; Guimarães et al., 2015; Mendoza et al., 2017).

The apparent density (NBR-9485), moisture content (NBR-9484), water absorption (NBR-9486), thickness swelling (NBR-9535), static bending in parallel and perpendicular directions (NBR-9533) and bond quality (NBR-ISO-12466/1 and NBR-ISO-12466/2) after wet treatment were evaluated for both adhesives and after boiling for phenol-formaldehyde.

### *2.5. Statistical analysis*

The variance homogeneity (Bartlett's test at 95% significance) and normality test (Shapiro Wilk test at 95% significance) were performed. The means per panel type were analyzed by variance analysis and Tukey test at 95% significance.

## 3. RESULTS

### *3.1. Wood basic density*

The wood basic density varied from 320 to 400 kg/m$^3$ and 300 to 350 kg/m$^3$ for *P. taeda* and *P. patula*, respectively, depending on trunk height (Figure 2).

**Table 1.** Panels produced according to the experimental design.

| Panel | Adhesive | Composition | Species |
|---|---|---|---|
| 1 | urea-formaldehyde | Plywood | *Pinus taeda* |
| 2 | urea-formaldehyde | Plywood | *Pinus patula* |
| 3 | urea-formaldehyde | PVP | *Pinus taeda* |
| 4 | urea-formaldehyde | PVP | *Pinus patula* |
| 5 | phenol-formaldehyde | Plywood | *Pinus taeda* |
| 6 | phenol-formaldehyde | Plywood | *Pinus patula* |
| 7 | phenol-formaldehyde | PVP | *Pinus taeda* |
| 8 | phenol-formaldehyde | PVP | *Pinus patula* |

PVP=parallel veneer panel.

**Table 2.** Physical-chemical adhesive characteristics and glue composition.

| Parameters | Urea-formaldehyde | | | | Phenol-formaldehyde | | | |
|---|---|---|---|---|---|---|---|---|
| Solid content (1g/3h/105°C) | 64-66% | | | | 48-51% | | | |
| Viscosity (25°C) | 300-1000 cP | | | | 400-800 cP | | | |
| pH | 7.4-9.0 | | | | 11.5-13.0 | | | |
| Density (25°C) | 1250-1300 kg/m$^3$ | | | | 1190-1250 kg/m$^3$ | | | |
| Glue composition | **AP (%)** | **WF (%)** | **$H_2O$ (%)** | **SC (%)** | **AP (%)** | **WF (%)** | **$H_2O$ (%)** | **SC (%)** |
| | 40 | 30 | 30 | 25 | 69 | 13 | 18 | 35 |

Notes: pH: hydrogen potential; cP: centipoise; AP: adhesive; WF: wheat flour; $H_2O$: water; SC: solid content.

### 3.2. Panel physical properties

The panel density ranged from 426 to 542 kg/m$^3$; equilibrium moisture from 10.38 to 11.05%; thickness from 12.90 to 13.88 mm; water absorption from 95 to 101%, thickness swelling from 6.37 to 9.53% and swelling plus recovery from 2.30 to 3.94% (Table 3).

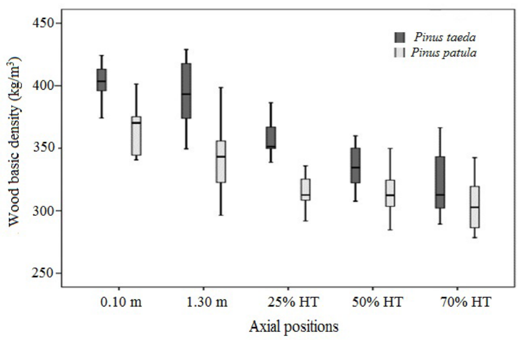


**Figure 2.** *Pinus patula* and *Pinus taeda* wood basic density (kg/m$^3$) in different axial positions.

### 3.3. Panel mechanical properties

The mechanical property values in the different types of panels produced varied as a function of species, adhesive and composition (Table 4).

## 4. DISCUSSION

### 4.1. Wood basic density

The base of *P. patula* and *P. teada* presented higher basic density than the top. Cells with higher lumen and thinner wall are produced during the initial cambium activity (in the top) resulting in low basic density. However, this tendency is reversed with cambium maturation, generating cells with thicker cell walls, which increases the basic density. The wood produced during the cambium mature stage presents better quality for panel production (Vidaurre et al., 2011).

ABIMCI (2002) recommends that pine plywood panels have an apparent density of 517 kg/m$^3$ and a

**Table 3.** Panel physical properties.

| Panel | Adhesive | PC | Species | AD (kg/m$^3$) | EMC (%) | Th (mm) | WA (%) | TS (%) | SPR (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | UF | Plywood | *P. taeda* | 542c | 10.78ab | 13.83a | 95a | 9.53b | 3.94a |
| 2 | UF | Plywood | *P. patula* | 458ab | 10.81ab | 13.45a | 104a | 6.37a | 2.91a |
| 3 | UF | PVP | *P. taeda* | 526c | 10.75ab | 13.88a | 97a | 6.98ab | 2.43a |
| 4 | UF | PVP | *P. patula* | 430ab | 11.05b | 13.67a | 101a | 6.39a | 2.40a |
| 5 | FF | Plywood | *P. taeda* | 453ab | 10.64ab | 13.06a | 99a | 8.93ab | 2.30a |
| 6 | FF | Plywood | *P. patula* | 472b | 10.40a | 13.27a | 100a | 8.20ab | 2.93a |
| 7 | FF | PVP | *P. taeda* | 426a | 10.56a | 13.03a | 99a | 7.50ab | 2.37a |
| 8 | FF | PVP | *P. patula* | 471b | 10.38a | 12.90a | 101a | 7.72ab | 3.11a |

Notes: PC: Panel composition; AD: Apparent density (kg/m$^3$); EMC: Equilibrium moisture content (%); Th: thickness (mm); WA: Water absorption (%); TS: Thickness swelling (%); SPR: Swelling plus recovery (%); UF: Urea-formaldehyde; FF: Phenol-formaldehyde; PVP: parallel veneer panel.

**Table 4.** Panel mechanical properties.

| Panel | Ad | PC | Species | MOR // (MPa) | MOR ⊥ (MPa) | MOE // (MPa) | MOE ⊥ (MPa) | GL (MPa) Wet | WF (%) Wet | GL (MPa) Boil | WF (%) Boil |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UF | Plyw | *P. taeda* | 39.7ab | 26.4b | 5131a | 2300b | 1.00a | 20 | --- | --- |
| 2 | UF | Plyw | *P. patula* | 33.9a | 27.3b | 4689a | 2732b | 0.97a | 20 | --- | --- |
| 3 | UF | PVP | *P. taeda* | 48.9bc | 6.4a | 6867b | 343a | 1.02a | 20 | --- | --- |
| 4 | UF | PVP | *P. patula* | 40.7ab | 4.1a | 4681a | 266a | 0.98a | 20 | --- | --- |
| 5 | PF | Plyw | *P. taeda* | 40.1ab | 25.1b | 5864ab | 2254b | 1.01a | 30 | 0.90a | 25 |
| 6 | PF | Plyw | *P. patula* | 54.7c | 27.8b | 7136b | 2278b | 0.99a | 30 | 0.78a | 20 |
| 7 | PF | PVP | *P. taeda* | 48.1bc | 4.8a | 7139b | 292a | 1.01a | 30 | 0.82a | 20 |
| 8 | PF | PVP | *P. patula* | 54.7c | 5.1a | 7136b | 305a | 0.89a | 30 | 0.84a | 20 |

Notes: Ad: adhesive; PC: Panel composition; MOR: Modulus of rupture (MPa); MOE: Modulus of elasticity (MPa); GL: glue line shear strength (MPa); WF: Wood Failure (%); UF: Urea-formaldehyde; PF: Phenol-formaldehyde; Plyw: plywood; PVP: parallel veneer panel.

maximum humidity of 11%. Considering an average wood shrinkage of 0.53% per moisture content percentile for both pine species used, and a panel compaction of 10%, an ideal basic wood density of approximately 445 kg/m$^3$ is estimated. Therefore, the range of basic density variation for both species was considered low for panel production. The disadvantage of this is greater veneer compaction during pressing. On the other hand, soft woods can facilitate the lamination process (Almeida et al., 2014).

## 4.2. Panel physical properties

The *P. patula* and *P. taeda* panel apparent density bonded with phenol-formaldehyde was lower than the 517 kg/m$^3$ required by quality standards. However, all panels showed equilibrium moisture content and nominal thickness variation lower than the 11 and +/- 5% maximum limit suggested (ABIMCI, 2002).

Average panel thickness was 13% less than the sum of the veneer thicknesses used, showing that there was veneer compaction. Costa & Del Menezzi (2017) verified that different densification strategies caused an increase in the mechanical properties of plywood produced with paricá wood of density similar to *P. Patula* and *P. taeda*.

There are no normative standards for dimensional stability properties, however, the thickness swelling values for five tropical pinus species bonded with urea-formaldehyde for plywood production ranged from 5.06 to 7.09% and swelling plus recovery from 1.68 to 2.89% (Iwakiri et al., 2001), lower than those in this study.

*Pinus* plywood may present water absorption close to 60% (Almeida et al., 2013; Silva et al., 2012; Campos et al., 2009), lower than those observed in this study. This difference is due to low wood density of both species used and the veneer thickness of 2.2 mm. The adhesive type did not influence water absorption.

Panel swelling occurs due to the release of internal stresses during the pressing process (Iwakiri et al., 2001). The lower wood density of both species results in greater compaction. The panels were formed with seven 2.2 mm veneers, but their final thickness ranged from 12.90 to 13.88 mm, causing internal stresses. These tensions are released during water absorption, following which, the panel does not return to its original state. Therefore, this study is able to explain thickness swelling and swelling plus recovery values.

## 4.3. Panel mechanical properties

The plywood panel presented averages for modulus of rupture (MOR) and modulus of elasticity (MOE), both parallel and perpendicular, above the minimum of 25.79/18.04 MPa and 4735/2220 MPa, respectively, stipulated by ABIMCI (2002). Also, the glue line shear strength values under wet conditions were higher than the 0.88 for shear strength and 20% for wood failure, required by ABIMCI (2002).

Plywood panels produced with five tropical pine species, between 20 and 25 years old, showed parallel MOR and MOE values ranging from 58 to 102 MPa and 6,300 to 13,714 MPa, respectively (Iwakiri et al., 2012), higher than those of this study. This difference occurred due to the juvenile wood use, since the trees in this study were 12 years old.

The *P. elliottii* wood showed juvenile wood up to the 7th growth ring and mature wood up the 20th growth ring. A similar trend occurs for *P. taeda* and *P. patula* (Palermo et al., 2013). Thus, all the 12-year old trees used presented either juvenile or transition wood, of lower density and, consequently, lower mechanical strength.

There are no minimum requirements for the PVP panel properties evaluated in this study. However, MOR of 74.49 MPa, MOE of 5338.95 MPa and glue line shear strength of 2.67 MPa for PVP were found for *Pinus oocarpa* panels with 663 kg/m$^3$ basic density (Lima et al., 2013). Values of 43.6 MPa, 3944 MPa, 1.81 MPa and 460 kg/m$^3$ for parallel MOR, parallel MOE, glue line shear strength and density of panels produced with *P. taeda* veneers on the surface and *Schizolobium amazonicum* (paricá) in the core were also reported (Iwakiri et al., 2010). A relationship between the density and mechanical strength of the panel can be observed by comparing the values obtained in this study.

The parallel and perpendicular MOE and MOR values, confirm the balance effect in plywood panels. On the other hand, adapted PVP panels showed different strength and stiffness values in perpendicular and parallel directions.

*Pinus taeda* showed higher mechanical strength than *P. patula* panels when urea-formaldehyde adhesive was used with this trend changing when phenol-formaldehyde was applied. This was attributed to the density variations of the panels. The *P. patula* panels presented lower density with urea-formaldehyde and higher density with phenol-formaldehyde (Table 3). Therefore, there is a direct relationship between panel density and resistance.

## 5. CONCLUSIONS

All panels have properties compatible with those required by ABIMCI, except for the apparent density. The adapted PVP panels presented differences in the mechanical properties between axial and tangential directions and the comparison of parallel and perpendicular MOE and MOR values confirms the balance effect in plywood panels.

When bonded with urea-formaldehyde, *Pinus patula* panels showed lower strength, stiffness and density than *P. taeda* panels. The reverse trend occurred in panels glued using phenol-formaldehyde.

12-year-old *Pinus patula* panels showed adequate physical and mechanical properties, independent of the adhesive and veneer arrangement, demonstrating the potential of this species for panel production.

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