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PRODUCTION OF MDP PANELS WITH YERBA MATE HARVEST RESIDUES

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Resumo

Produção de painéis MDP com resíduos da colheita de erva-mate. Avaliou-se a qualidade de painéis MDP produzidos com partículas de madeira de *Pinus taeda* em mistura com resíduos de colheita de erva-mate. Foram produzidos painéis monocamada com adição de 0. 20. 40. 60. 80 e 100% de proporção de resíduos de erva-mate, com massa específica nominal de 0.65 g.cm^{-3}, utilizando 12% de resina uréia-formaldeído, 0.5% de parafina e 2% de catalisador sulfato de amônia. Os painéis foram prensados por 10 minutos, a uma temperatura de 140° C e pressão de 40 kgf/cm². Foram avaliadas as propriedades físicas de densidade aparente, teor de umidade, absorção de água e inchamento em espessura (2 e 24 hours), como também avaliadas as propriedades mecânicas de flexão estática (MOR e MOE), ligação interna, arrancamento de parafuso à face e dureza Janka. Houve tendência de aumento da ligação interna com aumento da proporção de resíduo de erva-mate nos painéis, porém ocorreu o inverso para as demais propriedades mecânicas estudadas. Algumas propriedades físicas como absorção de água e inchamento em espessura resultaram em um melhor desempenho quando adicionadas partículas de erva-mate. Diante disso pode-se concluir que é possível produzir painéis com adição de erva-mate em até 40% na composição com partículas de erva-mate, sem afetar a qualidade das propriedades.
Palavras-chave: *Ilex paraguariensis, Pinus taeda*, subprodutos, composição.

Abstract

The quality of MDP panels produced with *Pinus taeda* wood particles mixed with yerba mate harvest residues was evaluated. Monolayer panels were produced with the addition of 0. 20. 40. 60. 80 and 100% proportion of yerba mate waste, with a nominal specific gravity of 0.65 g.cm^{-3}, using 12% urea-formaldehyde resin, 0.5% paraffin and 2% ammonium sulfate catalyst. The panels were pressed for 10 minutes at a temperature of 140°C and pressure of 40 kgf/cm². The physical properties of apparent density, moisture content, water absorption and thickness swelling (2 and 24 hours) were evaluated, as well as the mechanical properties of static bending (MOR and MOE), internal bonding, screw withdrawal on the face and Janka hardness. There was a trend towards an increase in internal bonding with an increase in the proportion of yerba mate residue in the panels, but the opposite occurred for the other mechanical properties studied. Some physical properties such as water absorption and thickness swelling resulted in better performance when yerba mate particles were added. In view of this, it can be concluded that it is possible to produce panels with the addition of yerba mate up to 40% in the composition with yerba mate particles, without affecting the quality of the properties.
Keywords: Ilex paraguariensis, Pinus taeda, by-products, composition.

INTRODUCTION

Medium Density Particleboard (MDP), an advancement in both production processes and product quality over traditional particleboard, is defined according to Brazilian Standard 14810-2 (ABNT, 2013) as a medium-density particleboard made from wood particles bonded with thermosetting synthetic resin. These particles are consolidated under the combined action of heat and pressure, resulting in a density between 551 kg/m³ and 750 kg/m³ (BUZO *et al*., 2020).

Lignocellulosic residues from Brazilian agro-industries are considered promising alternative sources of raw material to produce particleboards, helping to reduce the use of wood from forest plantations and contributing to the creation of more affordable products (SILVA *et al*., 2017).

According to Sanches et al. (2016), it is noteworthy that there are no restrictions regarding the species of wood used for the particles, allowing for the use of industrial or forestry residues, low-quality woods, non-industrialize or otherwise unused materials, provided their geometry ensures good panel density and the adhesive is compatible with the permeability of the species used in the particles.

In Brazil, yerba mate naturally occurs in an area of approximately 540.000 km², encompassing the states of Paraná, Santa Catarina, Rio Grande do Sul, the southernmost part of São Paulo, and Mato Grosso do Sul. In neighboring countries, the plant is native to the Province of Misiones, parts of the Provinces of Corrientes and Tucumán in Argentina, and the area between the Paraná and Paraguay rivers in Paraguay (EMBRAPA, 2019).

Considering the application of yerba mate processing residues, some studies have explored their use in the production of reconstituted panels. For instance, Cunha et al. (2019) concluded that residues from the processing of *Ilex paraguariensis* (yerba mate) showed potential for use in medium-density particleboard panels when mixed in a 50:50 ratio with *Pinus taeda* particles. However, to increase the proportion of yerba mate particles, more rigorous control of particle geometry is necessary.

According to Kuram (2021), yerba mate sticks are a waste product generated in large quantities by the industry, and their utilization could add value to this product. Guiotoku *et al*. (2008) found that yerba mate stick residues have potential for use in the production of reconstituted panels, with the yerba mate stick panels exhibiting greater dimensional stability and lower water absorption compared to commercial *Pinus taeda* panels.

Carvalho *et al*. (2015) concluded that panels produced with yerba mate harvest residues, as well as mixtures of these with *Pinus spp.* particles, exhibited static bending strength (modulus of rupture) values that were below the standards stipulated by Brazilian Standard 14810-2 (ABNT, 2002). Since these panels did not meet one of the minimum requirements, panels produced with yerba mate residues should not be used as a substitute for MDP panels. The authors also concluded that the removal of bark did not affect the properties of the panels compared to those with bark, making debarking unnecessary.

The pressure from stakeholders, market changes, corporate strategies, and the pursuit of environmental innovation, in addition to regulatory pressure, have increasingly driven companies to measure and evaluate their social and environmental impacts. Most of these approaches focus on mitigating negative environmental and social impacts, such as reducing material and energy use or preventing pollution and waste (DIJKSTRA-SILVA et al., 2022).

Given the growing market demand for particleboard and the search for cellulosic residues to reduce the use of wood from forest plantations in panel production, this study aims to investigate the technical feasibility of producing MDP panels with different proportions of *Pinus taeda* particles and *Ilex paraguariensis* harvest residues.

MATERIAL AND METHODS

The *Ilex paraguariensis* harvest residues (branches) were donated by Dallegrave Florestal S/A, a company located in the municipality of Irati, PR, and subsequently stored in a covered area to keep the material dry. The branches were chipped using a branch chipping machine to reduce them to smaller particles (chips), which were then ground in a forage grinder to obtain particles of the ideal size for panel production (sliver-type). The *Pinus taeda* sliver-type particles were obtained by grinding strand-type particles sourced from an OSB factory, following the same methodology used for the yerba mate particles (Figure 1).

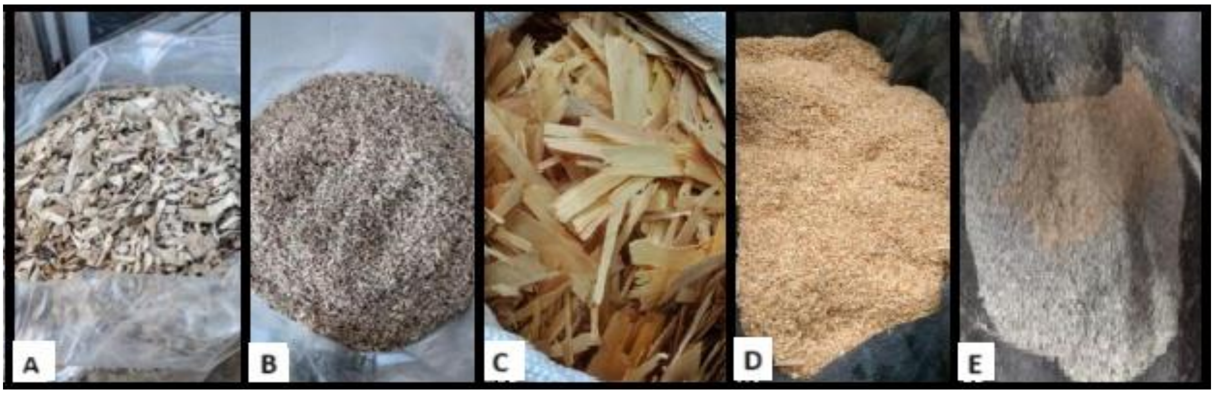

Figure 1. Production of particles to produce MDP panels. (A) Wood chip of *Ilex paraguariensis*; (B) Sliver-type particles of *Ilex paraguariensis* wood; (C) Strand-type particle of *Pinus taeda* wood; (D) Sliver-type particle of *Pinus taeda* wood; (E) Sliver-type particles before being mixed in the proportion 60% *Ilex paraguariensis*/40% *Pinus taeda*.

Figura 1. Produção de partículas para produção dos painéis MDP. (A) Partículas tipo cavacos de madeira de *Ilex paraguariensis*; (B) Partículas de madeira de *Ilex paraguariensis*; (C) Partículas tipo *strand* de madeira de *Pinus taeda*; (D) Partículas de madeira de *Pinus taeda*; (E) Partículas antes de serem misturadas na proporção 60% de *Ilex paraguariensis*/40% de *Pinus taeda*.

The basic density of yerba mate wood was determined in the laboratory, where non-standardized samples of yerba mate branches were weighed to obtain the saturated volume using the hydrostatic balance method. The samples were then placed in an oven at 103±2°C and weighed consecutively until the mass stabilized, allowing for the determination of the density value. The *Pinus taeda* strand particles were obtained from the same company used in the study by Gorski et al. (2015), which allowed for the use of the existing data, corresponding to 0.41 g/cm³.

To standardize the material size, the yerba mate harvest residue particles were classified using a sequence of sieves with mesh sizes of 3.35 mm, 2.36 mm, and 600 µm. The material retained on the 3.35 mm sieve was chosen due to its greater quantity and size similarity to the *Pinus taeda* wood particles, and these particles were used to produce mono-layer panels.

For the bonding, a low formaldehyde-emission urea-formaldehyde adhesive, type E-1. with 65% solids was used in a proportion of 12%, along with paraffin emulsion with 30% solids in a proportion of 1% based on the weight of the particles, as well as a catalyst to accelerate the adhesive curing time.

The experiment was designed to evaluate the influence of yerba mate wood particles on the composition of panels made with *Pinus taeda* wood particles. Panels were produced with 100% *Pinus taeda* (control) and four types of panels with different compositions of *Pinus taeda* and yerba mate, along with one panel made with 100% yerba mate (Table 1). The panel dimensions were 50 x 50 x 1 cm with a nominal density of 0.70 g/cm³. Two panels of each type were produced, and at least three test specimens were taken from each panel, totaling 12 panels and/or 36 repetitions.

Table 1. Composition of particles used in the treatments of the panels produced.
Tabela 1. Composição de partículas utilizadas nos tratamentos dos painéis produzidos.

Panel	**Composition of Particles**		**Repetitions**
	Pinus taeda (%)	Yerba mate (%)	
P1	100	-	6
P2	80	20	6
P3	60	40	6
P4	40	60	6
P5	20	80	6
P6	-	100	6
Total			**36**

Note: P.: Panel.

The panels were produced in the Wood Technology Laboratory at the Midwestern Parana State University - Unicentro. Initially, the *Pinus taeda* and yerba mate particles were placed in an oven with forced ventilation for 24 hours at 65°C to reduce moisture content. The particles were then weighed according to the proportions required for each type of panel, as well as the amounts of adhesive, paraffin, and catalyst to be used. The solutions were sprayed onto the particles using a spray gun operated by an air compressor in a rotating drum for 10 minutes.

The mattress assembly, with dimensions of 50 cm x 50 cm, was done manually, and pre-pressing was performed for two minutes to allow the initial settling of the particles. Two metal spacers, each 1 cm thick, were placed on the sides of the panel to ensure consistent thickness during pressing. The material was then placed in a hot press for 10 minutes at a temperature of 140°C and a pressure of 40 kgf/cm² (Figure 4). After, the panels were conditioned in a climate-controlled room with a temperature of 20±2°C and humidity of 65±5%.

After stabilization, the physical-mechanical properties were analyzed, including apparent density, moisture content, water absorption for 2 and 24 hours, thickness swelling for 2 and 24 hours, MOR (modulus of rupture) and MOE (modulus of elasticity) in static bending, internal bonding, screw withdrawal resistance, and Janka hardness, according to the American Society for Testing and Materials (ASTM D 1037. 2006) standard.

The compaction ratio was also determined by the relationship between the panel density and the density of the particles. Considering the average density of *Pinus taeda* obtained by Gorski et al. (2015) as 0.41 g/cm³ and the average density of yerba mate wood obtained in this study as 0.38 g/cm³, the compaction ratio can be calculated.

The average values verified for each type of panel were compared with the requirements of the American National Standards Institute - ANSI A 208.1 (2010), as well as other standards and research. For comparison between the different types of panels, ANOVA was applied with a 5% probability of error, provided the assumptions of homogeneity of variances and normal distribution were met. If a significant difference was found, Tukey's test was performed to compare the means.

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RESULTS

Physical Properties of Panels

Table 2 presents the physical properties of the panels, including apparent density, moisture content, and compaction ratio, along with the respective averages for each type of panel.

Table 2. Average values of density, moisture content and compaction ratio of panels according to particle composition.
Tabela 2. Valores médios de densidade, teor de umidade e razão de compactação dos painéis de acordo com a composição de partículas.

Panel	Particles (%)		Density (g/cm³)	Moisture Content (%)	Compaction Ratio
	Pinus taeda	Yerbamate			
P1	100	-	0.71 A	10.77 A	1.74 A
P2	80	20	0.71 A	10.18 AB	1.75 A
P3	60	40	0.75 A	10.09 AB	1.88 A
P4	40	60	0.71 A	9.96 B	1.81 A
P5	20	80	0.71 A	9.99 B	1.83 A
P6	-	100	0.75 A	10.06 AB	1.98 A
F calculado			0.771 ns	3.18 *	0.26 ns

Note: P.: panel; Tukey's Test was applied; *: significant at 5% probability of error; ns: not significant.

For density, there were no significant differences between the average values, which ranged from 0.71 to 0.75 g/cm³. There were significant differences in the average moisture content values, which ranged from 9.96% to 10.77%. The average compaction ratio values, which ranged from 1.74 to 1.98, showed no statistically significant differences.

Dimensional Stability of Panels

The average results of the water absorption and thickness swelling tests obtained from the produced panels are presented in Table 3.

Table 3. Average values of water absorption and swelling of the panels according to the composition of particles in the panels.
Tabela 3. Valores médios de absorção de água e inchamento dos painéis de acordo com a composição de partículas nos painéis.

Panel	Particles (%)		Water absorption		Thickness Swelling	
	Pinus taeda	Yerba mate	2 hours (%)	24 hours (%)	2 hours (%)	24 hours (%)
P1	100	-	15.25 AB	49.39 A	4.64 ABC	15.90 A
P2	80	20	18.30 A	50.06 A	5.45 A	16.34 A
P3	60	40	16.26 A	42.02 AB	4.94 AB	13.32 AB
P4	40	60	15.84 A	45.84 AB	3.04 BCD	11.28 BC
P5	20	80	9.50 C	37.35 AB	2.51 CD	11.29 BC
P6	-	100	9.89 BC	32.56 B	2.09 D	7.74 C
Calculated F			7.72 *	3.59*	7.30*	9.50*

Note: P.: panel; Tukey's Test was applied; *: significant at 5% probability of error; ns: not significant.

There was a statistically significant difference in all tests conducted to verify the dimensional stability of the panels. In the water absorption test for two hours of immersion, the variation ranged from 9.50% to 18.30%, and for 24 hours, the variation ranged from 32.56% to 50.06%. For thickness swelling, the average variation for two hours of immersion ranged from 2.09% to 5.45%, while for 24 hours, it ranged from 7.74% to 16.34%

Mechanical Properties of Panels

Table 4 presents the average results of the mechanical properties obtained from the tests.

Table 4. Influence of panel composition on static bending, internal bonding, screw withdrawal and Janka hardness tests.
Tabela 4. Influência da composição dos painéis nos ensaios de flexão estática, ligação interna, arrancamento de parafuso e dureza Janka.

Panel	Particles (%)		MOR (MPa)	MOE (MPa)	IB (MPa)	SW (N)	JH (MPa)
	Pinus taeda	Yerbamate					
P1	100	-	15.72 A	1.951.04 A	0.81 B	2.249.76 AB	71.96 AB
P2	80	20	15.85 A	1.845.41 AB	1.10 AB	2.725.16 A	66.31 AB
P3	60	40	16.34 A	1.890.7 AB	1.26 AB	2.240.19 AB	77.56 A
P4	40	60	13.66 A	1.568.72 B	1.26 AB	2.437.03 A	67.25 AB
P5	20	80	14.46 A	1.626.33 AB	1.19 AB	1.943.30 AB	55.56 AB
P6	-	100	15.04 A	1.670.08 AB	1.51 A	1.238.07 B	41.18 B
Calculated F			2.05 ns	3.74*	3.24*	4.86*	3.41*

Note: P.: panel; MOR: Modulus of Rupture; MOE: Modulus of Elasticity; IB: Internal Bonding; SW: Screw Withdrawal; JH: Janka Hardness; Tukey's Test was applied; *: significant at 5% probability of error; ns: not significant.

A statistically significant difference was observed in the average MOE values, where panel P4 showed lower values compared to the control, a situation similar to those reported by other authors. The average values for modulus of rupture (MOR) and modulus of elasticity (MOE) ranged from 13.66 to 15.72 MPa and 1,568.72 MPa to 1,951.04 MPa, respectively.

There was a statistically significant difference in the average internal bonding values, which tended to increase with the addition of yerba mate particles, reaching 1.51 MPa in panel P6.

A statistically significant difference was also observed in the average screw withdrawal values, which ranged from 1,238.07 N to 2.725.16 N.

Additionally, a statistically significant difference was noted in the average Janka hardness values, with the highest average obtained for panel P3 at 77.56 MPa. This value did not differ statistically from the other panels produced, except for panel P6, which had an average of 41.18 MPa.

DISCUSSION

Physical Properties of Panels

According to ANSI A 208.1 (2010), panels with a density of 0.64 to 0.80 g/cm³ are considered medium-density, and the final density of the panels must not differ by more than 10% from the nominal density determined during manufacturing. In this case, all panel's-type met the requirements.

The parameters established for moisture content in particleboard panels range between 5% and 13%, according to Brazilian Standard 14810-2 (ABNT 2013). The panel with the highest moisture content was P1, composed of 100% *Pinus taeda*, with 10.77%, compared to panels P4 and P5, which had 9.96% and 9.99%, respectively. According to Iwaki et al. (2018), this projection of moisture content in particleboard can be directly related to the anisotropic accumulation of water within the fibers or particles, making it difficult to completely remove the water even with the application of heat.

The compaction ratios in the panels of this study are considered high. According to Narciso *et al*. (2021), the compaction ratio of a panel is very important and should be around 1.3 to 1.6. Trianoski *et al*. (2011) describe that higher compaction values are typically seen in species with lower specific gravity. Iwakiri *et al*. (2018) state that wood with a lower specific gravity tends to increase the compaction ratio in panels.

Dimensional Stability of Panels

The panels met the regulatory requirements for thickness swelling, as ANSI 208.1 (2010) considers a percentage of up to 35% acceptable after 24 hours of water immersion. Cunha et al. (2019), who produced panels with Ilex paraguariensis (yerba mate) and Pinus taeda particles at a density of 0.70 to 0.76 g/cm³, reported water absorption values ranging from 16.10% to 32.33% after two hours and from 40.44% to 52.95% after 24 hours. For thickness swelling, the averages observed were from 10.85% to 14.51% after two hours and from 18.45% to 24.88% after 24 hours.

Overall, the addition of yerba mate particles resulted in reduced water absorption and swelling in the panels, regardless of the immersion times. This effect is likely due to the increased compaction ratio in the panels when higher proportions of particles with lower apparent density were used, along with improved bonding quality. Souza *et al*. (2019), in analyzing the effects of increasing the compaction ratio of particleboard panels from 1.2 to

1.6, observed a reduction in water absorption and thickness swelling, attributing it to the higher compaction of wood particles and the consequent reduction in porosity, which made it more difficult for water to penetrate the denser structure of the panels.

According to Iwakiri *et al*. (2018), panels produced with six tropical wood species that had lower specific gravity and higher compaction ratios exhibited lower water absorption. Carvalho *et al*. (2015), who worked with panels made from *Pinus spp*. and yerba mate pruning residues, both with and without bark, found water absorption values after 24 hours ranging from 103% to 129%. They concluded that panels produced solely with yerba mate residue showed lower water absorption compared to panels made with *Pinus taeda* wood alone. This can be explained by the addition of paraffin during the production process of particleboard, which aims to increase moisture resistance and reduce thickness swelling, thereby enhancing dimensional stability (TRIANOSKI *et al*., 2011).

Mechanical Properties of Panels

According to ANSI/A 208.1 (2010), minimum values of 12.5 MPa for MOR (Modulus of Rupture) and 1,800 MPa for MOE (Modulus of Elasticity) are required. Therefore, panels with proportions higher than 40% yerba mate particles do not meet the required quality standards. The reduction in MOE was also observed in the study by Carvalho et al. (2015), who used yerba mate pruning residues with *Pinus taeda* and reported a value of 1,180.10 MPa for panels made with 100% yerba mate particles. Cunha et al. (2019) observed MOE values of 1,442.50 MPa in panels produced with 100% yerba mate wood, noting a gradual reduction in values as yerba mate particles were incorporated, which is consistent with the results obtained in the present study. Rusch *et al*. (2023) found that increasing the proportion of yerba mate particles led to a reduction in the modulus of elasticity, attributed to the slenderness ratio of the particles.

Except for panel P1, all other treatments met the internal bond parameters, with the minimum value stipulated being 0.90 MPa according to ANSI A 208.1 (2010). Souza *et al*. (2019) concluded that the addition of smaller and finer yerba mate residue particles resulted in higher compaction, reducing voids and porosity, and leading to better internal bonding. Rusch *et al*. (2023) observed that panels made from pure yerba mate or with some mixture had internal bond values exceeding the minimum required by the standard, attributing this to the rounded shape of yerba mate particles, which allowed better accommodation during the pressing process.

All panels exhibited Janka hardness values greater than the ANSI A 208.1 (2010) requirement of 22.70 MPa. However, it is noted that panels with added yerba mate tended to have reduced hardness. This is due to the shape of the particles and their slenderness ratio; species that produce longer and finer wood particles benefit from increased rigidity and, consequently, hardness of the panels (SOUZA *et al.,* 2019).

The minimum value for screw withdrawal resistance was achieved according to ANSI A 208.1 (2010), which is 1,020 N. A decrease in values was observed with increasing yerba mate content in the panels. Souza et al. (2019) found screw withdrawal resistance values of 926.48 N in panels made with 100% yerba mate particles and 993.09 N for panels with a composition of 50% yerba mate and 50% *Pinus elliottii*, which was also influenced by the slenderness ratio of the particles.

CONCLUSIONS

- The addition of yerba mate particles progressively improved the dimensional stability properties of the panels.
- It is feasible to use yerba mate harvest residue in the production of MDP panels, but it is recommended to add up to 40% of yerba mate particles mixed with *Pinus taeda* particles to avoid compromising the quality of the panels.

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