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Clustering of tropical species through multivariate analysis of the bonding properties of edge-glued panels (EGP)

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Abstract. Tropical woods have high added value, and the use of waste for panel production is an initiative to add more value to this material, typically consisting of various species. The use of raw materials from tropical solid wood waste in the Amazon region contributes to the reduction of carbon emissions associated with the burning of this material. In this context, this study aimed to cluster species based on the bonding properties of Amazonian woods by applying multivariate analysis. The apparent density 12% and strength of finger joint and edge-glued joints of *Cedrela odorata*, *Enterolobium schomburgkii*, *Erisma uncinatum* and *Qualea paraensis* was evaluated which were joined in homogeneous and hybrid configurations with the adhesives PVA and EPI, as spreading rate of 180 g/m^2. The treatments were compared by multivariate analysis of variance and discriminant analysis. The discrimination of species and combinations based on wood density (low, medium, and high) revealed that this is the most important characteristic for grouping different species that make up tropical hardwood waste for the production of EGP panels. In practice, the separation of species into groups according to wood densities can contribute to a better definition of the indications for use of edge glued panels of each density class, and assertive targeting for applications according to the strength ranges required. In the static bending, parallel tensile and shear tests all species and their combinations met the minimum requirements normative, indicating the approval of species and combinations studied for the production of EGP panels.

Keywords: Mixed EGP species, wood waste, Amazonian woods, edge-glued panels, higher value-added products.

Introduction

Wood from tropical forests is highly valued primarily for its characteristics and properties (Traoré & Martínez Cortizas, 2023). However, the conversion rate of logs to sawn timber in the Amazon is 30-40%, resulting in a significant volume of waste (Clement & Higuchi, 2006; Melo et al., 2012; Valdiones et al., 2022). Residue from primary and secondary wood processing is classified as bark, slabs, shavings, trimmings, cut-offs, wood chips, sawdust, among others (C.T. Donovan Associates Inc., 1990; Numazawa et al., 2003). In this context, solid wood waste such as slabs, trimmings, and leftovers (Brasil, 2016) from tropical species have historically been underutilized.

In the Brazilian Southwest Amazon, the residue generated during the sawing of logs in sawmills is primarily used for heat generation. Initiatives focused on utilizing tropical solid wood residue for the production of higher-value products, such as wood panels, for example, are scarce in this region. (Valdiones et al., 2022). Utilizing solid wood residue for generating new products has limitations such as varying dimensions and species, anisotropy, and natural defects, which can impact the quality of the final product. On the other hand, wood bonding enables the production of reconstituted wood products with larger dimensions, greater dimensional stability, uniform mechanical strength, improving product quality and cost-benefit ratio (Iwakiri, 2005).

Edge-glued panels (EGP) can be an alternative for better utilization of solid wood waste in the Amazon region (Bila et al., 2016). They are characterized by using residue from sawmill processing (edgings and non-conforming pieces) in their production process (Tienne et al., 2011; Trianoski & Iwakiri, 2020). EGP panels are made up of wooden battens edge-glued, and finger joint, and they do not use any type of coating, as one of their characteristics is to emphasize the natural aesthetic appearance of the wood (Tienne et al., 2011; Danawade et al., 2014). According to Trianoski and Iwakiri (2020), the main advantages of this type of panel are improved of saw wood yield, low machinery costs, a simpler production process compared to other reconstituted wood panel industries (such as MDF, MDP, and OSB), and the decorative aspect provided by the use of short and narrow wood pieces. The most commonly used species for the industrial production of EGP panels are *Eucalyptus* spp., *Pinus taeda*, and *Tectona grandis* (ABIMCI, 2019; Trianoski & Iwakiri, 2020). This is facilitated by the availability of the necessary wood volume from numerous plantations of these species. The main challenge of using tropical solid wood waste in serial manufacturing processes is the heterogeneity of species that make up this material. Since sawmills in the Amazon region typically operate on-demand, the seasonality and unpredictability of the availability of waste from the same species pose a challenge for the production of EGP panels with a single species, which is the common practice on an industrial scale. Therefore, there is a need to find solutions that can effectively utilize tropical solid wood waste with their inherent diversity of species.

In this regard, the findings of Musah et al. (2021) have expanded the discussion about the use of mixed species in solid wood panel production. The authors observed that mixing species with distinct anatomical characteristics reduced the negative effects of certain characteristics that would be more influential in single-species gluing. Since adjusting the adhesive formulation to be used in the gluing operations should be done based on factors including wood density (Tsoumis, 1991; Marra, 1992). This study raised the hypothesis that this property could be a determining characteristic in grouping the different species that make up the solid wood residue, allowing for systematization in the process of gluing mixed species. This could expand the availability and possibilities of using lignocellulosic raw materials from timber residue in the Amazon region, contributing to better utilization of this resource as well as income generation. In this context, the objective of this research was to evaluate the feasibility of using the properties of strength and density of EGP panels, produced from solid wood waste, in the clustering of Amazonian species through multivariate analysis.

Material and Methods

Material

The material used in this study consisted of waste wood (slabs, chips, and leftovers) from the sawing of logs from the species *Cedrela odorata* L., *Enterolobium schomburgkii* (Benth.) Benth., *Erisma uncinatum* Warm., and *Qualea paraensis* Ducke, sourced from a Sustainable Forest Management Plan and donated by the company Rovermader (coordinates 11°55’52” S and 61°59’52” W, Alta Floresta D’Oeste-RO, Brazil). Waste from five trees of each species was collected, which had an average diameter at breast height of 55 cm. This material was transformed into battens with dimensions of 30 mm x 60 mm x 400 mm for thickness, width, and length, respectively, and air-dried in a covered area for approximately 90 days. Subsequently, it was transported to the Wood Panel Laboratory at the Federal University of Paraná, Curitiba-PR, where the experiments were conducted.

The preparation of the battens

The battens were dried to an average moisture content of 12% in an oven with forced air circulation at 40 °C and then processed to the final dimensions of 22 mm x 55 mm x 310 mm in thickness, width and length, respectively, for edge gluing; and 25 mm x 55 mm x 200 mm in thickness, width and length, respectively, for length gluing. The latter were also machined at the top to make the teeth using finger joint milling.

The apparent density at 12% humidity was determined in accordance with NBR 7190 (ABNT, 1997) based on measurements of all battens used in both types of gluing.

Manufacture of edge-glued joints and finger joints

For edge gluing, Emulsion Polymer Isocyanate (EPI) adhesive with spreading rate of 180 g/m^2, specific pressure of 0.8 MPa, and pressing time of 60 minutes were used. For finger joint, Polyvinyl Acetate (PVA D3) adhesive with spreading rate of 180 g/m^2 and pressure of 0.3 MPa for 30 seconds were used. Each species was glued individually and mixtures between them, resulting in ten treatments. After pressing, edge-glued joints and finger joint were conditioned for seven days at 20 °C and 65% relative humidity before testing.

Gluing quality evaluation

After adhesive curing and stabilization, the edge-glued joints and finger joint specimens were sectioned to create test specimens following the specifications of the EN 13354 (EN, 2008) and ASTM D 5572 (ASTM, 2019) standards, respectively. For the edge gluing, 20 test specimens were tested in the glue line shear test for each of the two pre-treatments (Table 1) for each specie/combination. For the length gluing, 20 test specimens were tested in the static bending test, and 12 were tested in the tensile parallel test for each of the three pre-treatments for each specie/combination.

Table 1. Pre-treatments applied to the test specimens before mechanical tests

Edge gluing	
Pre-treatments	Procedures
Dry	12% humidity
Cold water (wet)	Immersion for 24 hours in cold water at a temperature of 20 ± 3 °C
Lengthgluing	
Pre-treatments	Procedures
Dry	12% humidity
High temperature	6 hours of exposure at 104 ± 3 °C
Triple cycle	4 hours of immersion in water at room temperature, followed by drying for 19 hours in an oven at 41 ± 3 °C; the procedure is repeated for three cycles.

As all species and their combinations (treatments) met the minimum requirements of EN 13353 (EN, 2008) and ASTM D 5572 (ASTM, 2019) standards for all pre-treatments, only the average values of strength for static bending, parallel tensile, and shear were presented.

Statistical analysis

The data related to the evaluated variables were analyzed using multivariate analysis of variance (MANOVA) and discriminant analysis in order to compare the treatments (species and combinations) in each pre-treatment of each test.

In the MANOVA, the measured variables, apparent density at 12% (g/cm³) and strength (MPa), were considered together, and the aim was to test the null hypothesis, which states that there is no difference in the mean vector among species for the static bending, parallel tensile, and shear tests. The statistics used to assess the significance of differences between factors included Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root, which were applied after confirming multivariate normality and homogeneous variance-covariance matrix.

Once the rejection of the multivariate null hypothesis was detected, a discriminant analysis was performed for the set of described variables with the aim of separating the tested treatments and identifying the most important variables in the separation, using the first two discriminant functions. The most important variables were indicated through the highest canonical correlation between the original variable and the discriminant function.

The MANOVA and discriminant analyses were conducted separately for the static bending, parallel tensile, and shear tests.

Results and discussion

Multivariate Analysis of Variance

The results of the MANOVA, considering all the variables evaluated in all pre-treatments for static bending, parallel tensile, and shear, are presented in Tables 2 and 3.

The results obtained from MANOVAs indicated that there were differences, with a significance level of Lambda de Wilks of 0.0001, among the species and their combinations evaluated in all pre-treatments of each test for both length (Table 2) and edge (Table 3) gluing.

Table 2. Multivariate analysis of variance for the set composed of all the variables evaluated by pre-treatment for length gluing

Staticbending								
		Dry		High Temperature		Triple Cycle		Sig.
		Value	F	Value	F	Value	F	
Species	Pillai's trace	1.082	24.896	0.936	18.569	1.074	24.478	0.0001
	Wilks' Lambda	0.095	46.960	0.114	41.230	0.097	46.275	0.0001
	Hotelling's trace	7.611	79.496	7.344	76.702	7.505	78.387	0.0001
	Roy'sLargest Root	7.358	155.344	7.284	153.767	7.263	153.332	0.0001
Paralleltensile								
		Dry		High Temperature		Triple Cycle		Sig.
		Value	F	Value	F	Value	F	
Species	Pillai's trace	1.136	16.084	1.061	13.679	1.079	14.187	0.0001
	Wilks' Lambda	0.071	33.348	0.079	30.713	0.077	31.275	0.0001
	Hotelling's trace	10.167	60.999	9.899	58.845	9.979	59.318	0.0001
	Roy'sLargest Root	9.870	120.639	9.717	117.683	9.771	118.342	0.0001

Sig.: significance

Table 3. Multivariate analysis of variance for the set composed of all variables evaluated by pre-treatment for edge gluing

		Shear				
		Dry		24h Cold water		Sig.
		Value	F	Value	F	
Species	Pillai's trace	1.440	8.562	1.672	17.022	0.0001
	Wilks' Lambda	0.031	15.011	0.021	19.240	0.0001
	Hotelling's trace	15.945	24.803	13.916	21.647	0.0001
	Roy'sLargest Root	14.935	49.784	10.797	35.988	0.0001

Sig.: significance

Discriminant Analysis

Two discriminant functions were determined for each pre-treatment of each test, explaining 100.0% of the total variability in all cases (Table 4). The first discriminant function exhibited the highest percentage of total explained variance for all pre-treatments in all tests. This indicates that this function contributed the most to demonstrating the differences between species combinations (groups).

For static bending, the correlation between the variables and the discriminant functions was 0.938 and 0.449 (dry), respectively; 0.938 and 0.238 (high temperature), and 0.938 and 0.441 (triple cycle). For parallel tensile, it was 0.953 and 0.478 (dry), 0.952 and 0.393 (high temperature), and 0.952 and 0.414 (triple cycle). And for shear, it was 0.968 and 0.709 (dry) and 0.957 and 0.870 (wet). The high coefficients of canonical correlation for the first function indicate a high degree of association between it and the groups.

The canonical correlation revealed the contribution that each variable provided to each discriminant function, through correlations between the explanatory variables and the standardized discriminant functions. The first discriminant function presented the variable apparent density 12% as the one with the greatest weight (canonical correlation) associated with it in all pre-treatments for static bending, parallel tensile, and shear, while for the second discriminant function, the variable with the greatest weight was strength (Table 5).

The discriminant functions obtained showed that the species *Q. paraensis,E. schomburgkii*, and their combination (*Q. paraensis* x *E. schomburgkii*) had higher densities at 12% moisture content and also higher strengths in the dry pre-treatment in the static bending and shear tests (Tables 6 and 7 and Figures 1 and 2). The highest average strength values in the high-temperature pre-treatment for static bending were observed for *E. schomburgkii*, *C. odorata*, and their combination (*C. odorata* x *E. schomburgkii*). While for the triple cycle pre-treatment, *Q. paraensis*, *E. uncinatum*, and their combination (*E. uncinatum* x *E. schomburgkii*) showed the highest average strengths in this test.

For parallel tensile tests, *Q. paraensis* x *E. schomburgkii*, *C. odorata* x *E. schomburgkii*, and *Q. paraensis* x *C. odorata* (dry); *E. schomburgkii*, *Q. paraensis* x *C. odorata*, and *C. odorata* (high temperature); and *E. schomburgkii*, *Q. paraensis*, and *C. odorata* x *E. schomburgkii* (triple cycle) showed the highest average strength values. In the wet pre-treatment for shear tests, the highest average strength values were observed for *E. schomburgkii*, *C. odorata* x *E. schomburgkii*, and *Q. paraensis* x *C. odorata.*

Table 4. Percentage of total variance explained by the discriminant functions obtained, relative to eigenvalues and canonical correlation coefficients for each of the discriminant functions

Test	Pre-treatment	Function	Self-value	% variance	% cumulative	Canonical correlation
Staticbending	Dry	1	7.358	96.7	96.7	0.938
		2	0.253	3.3	100.0	0.449
	High Temperature	1	7.284	99.2	99.2	0.938
		2	0.060	0.8	100.0	0.238
	Triple Cycle	1	7.263	96.8	96.8	0.938
		2	0.242	3.2	100.0	0.441
Paralleltensile	Dry	1	9.870	97.1	97.1	0.953
		2	0.296	2.9	100.0	0.478
	High Temperature	1	9.717	98.2	98.2	0.952
		2	0.182	1.8	100.0	0.393
	Triple Cycle	1	9.771	97.9	97.9	0.952
		2	0.207	2.1	100.0	0.414
Shear	Dry	1	14.935	93.7	93.7	0.968
		2	1.009	6.3	100.0	0.709
	24h Cold water	1	10.797	77.6	77.6	0.957
		2	3.120	22.4	100.0	0.870

Table 5. Canonical correlations between the original variables evaluated and the discriminant functions obtained by pre-treatment for each test

Variable	Dry		High Temperature		Triple Cycle	
	StaticBending					
	FD1	FD2	FD1	FD2	FD1	FD2
ρ 12% (g/cm^3)	**0.993**	0.116	**0.999**	0.053	**1.000**	0.003
Strength (MPa)	0.241	**0.971**	-0.002	**1.000**	0.179	**0.984**
	ParallelTensile					
ρ 12% (g/cm^3)	**0.992**	0.123	**1.000**	-0.031	**1.000**	-0.017
Strength (MPa)	0.073	**0.997**	0.053	**0.999**	0.138	**0.990**

	Shear			
	Dry		24h Cold water	
	FD1	FD2	FD1	FD2
ρ 12% (g/cm^3)	**0.855**	-0.519	**0.981**	0.192
Strength (MPa)	0.691	**0.723**	0.045	**0.999**

ρ 12%: density at 12% humidity. Bold: variables with greatest weight (greater canonical correlation). FD1: discriminant function 1 and FD2: discriminant function 2.

Table 6. Apparent density at 12% humidity and average strengths for length and edge gluing

Species	ρ 12% (g/cm^3)	Dry	High Temperature	Triple Cycle
StaticBending				
		Strength (MPa)		
C. odorata	0.53	48.43	29.84	**52.63**
E. schomburgkii	**0.78**	**53.17**	29.32	**55.29**
E. uncinatum	0.55	36.53	**31.10**	37.70
Q. paraensis	**0.79**	**53.61**	**33.39**	56.23
C. odorata x *E. schomburgkii*	0.67	50.35	28.64	**52.23**
E. uncinatum x *C. odorata*	0.54	39.41	30.83	40.00
E. uncinatum x *E. schomburgkii*	0.67	48.54	**32.02**	48.10
E. uncinatum x *Q. paraensis*	0.66	45.08	28.50	45.92
Q. paraensis x *C. odorata*	0.67	49.19	23.83	50.57
Q. paraensis x *E. schomburgkii*	**0.77**	**52.96**	28.38	51.76
ParallelTensile				
C. odorata	0.52	22.90	**29.62**	29.63
E. schomburgkii	**0.77**	26.58	**33.93**	**34.53**
E. uncinatum	0.55	20.34	20.99	22.29
Q. paraensis	**0.80**	22.42	26.91	**33.47**
C. odorata x *E. schomburgkii*	0.66	**29.14**	29.12	**32.16**
E. uncinatum x *C. odorata*	0.53	24.63	26.70	22.46
E. uncinatum x *E. schomburgkii*	0.65	24.43	25.99	28.61
E. uncinatum x *Q. paraensis*	0.66	22.96	23.77	23.56
Q. paraensis x *C. odorata*	0.64	**28.76**	**29.66**	29.45
Q. paraensis x *E. schomburgkii*	**0.77**	**31.35**	27.90	29.77

Shear	ρ 12% (g/cm^3)	Dry	24h Cold water
		Strength (MPa)	
C. odorata	0.49	9.15	6.88
E. schomburgkii	**0.79**	**14.83**	**9.03**
E. uncinatum	0.58	8.57	5.11
Q. paraensis	**0.78**	**14.08**	4.30
C. odorata x *E. schomburgkii*	0.65	11.21	**7.85**
E. uncinatum x *C. odorata*	0.54	8.31	6.33
E. uncinatum x *E. schomburgkii*	0.68	11.06	7.51
E. uncinatum x *Q. paraensis*	0.67	9.79	6.57
Q. paraensis x *C. odorata*	0.67	10.33	**7.71**
Q. paraensis x *E. schomburgkii*	**0.77**	**14.64**	7.44

Bold: highest average values observed. ρ 12%: apparent density at 12% humidity in g/cm³.

The centroids of species combinations for the two discriminant functions in each pre-treatment of each test are presented in Table 7. When the two functions are combined, the centroids showed the distribution and distinction of the groups in a two-dimensional space.

The results of discriminant functions 1 and 2, by species combination for each pre-treatment of each test, with the respective centroid groups, are presented in Figures 1 and 2. The discriminant graph distinguished the groups of species combinations based on discriminant functions 1 and 2.

The distribution of centroids, along with other statistics, showed that function 1 differentiated all species combinations, allowing for the observation of a separation into three groups based on apparent density at 12% in all pre-treatments of all tests, which are: I) *C. odorata*, *E. uncinatum* and their combination (*C. odorata* x *E. uncinatum*), with an average apparent density at 12% of 0.51, 0.56, and 0.54 g/cm^3, respectively; II) *E. uncinatum* x *Q. paraensis*, *E. uncinatum* x *E. schomburgkii*, *Q. paraensis* x *C. odorata* and *C. odorata* x *E. schomburgkii* with an average apparent density at 12% of 0.66, 0.67, 0.66, and 0.66 g/cm^3, respectively; and III) *Q. paraensis*, *E. schomburgkii* and *Q. paraensis* x *E. schomburgkii*with an average apparent density at 12% of 0.79, 0.78, and 0.77 g/cm^3, respectively.

Table 7. Centroids of each species combination in each pre-treatment for length and edge gluing

Static Bending						
Species	Discriminant Function					
	Dry		High Temperature		Triple Cycle	
	FD1	FD2	FD1	FD2	FD1	FD2
C. odorata	-3.873	1.066	-3.730	0.018	-3.727	1.089
E. schomburgkii	3.214	0.011	3.199	-0.020	3.193	0.140
E. uncinatum	-3.135	-0.888	-3.228	0.140	-3.214	-0.724
Q. paraensis	3.586	-0.016	3.545	0.375	3.560	0.182
C. odorata x *E. schomburgkii*	0.051	0.378	0.099	-0.091	0.093	0.351
E. uncinatum x *C. odorata*	-3.405	-0.392	-3.439	0.114	-3.426	-0.420
E. uncinatum x *E. schomburgkii*	0.332	0.039	0.322	0.236	0.334	-0.169
E. uncinatum x *Q. paraensis*	-0.059	-0.378	-0.097	-0.105	-0.102	-0.341
Q. paraensis x *C. odorata*	0.101	0.193	0.153	-0.556	0.122	0.154
Q. paraensis x *E. schomburgkii*	3.189	-0.013	3.176	-0.110	3.166	-0.262
Parallel Tensile						
C. odorata	-4.165	-0.112	-4.102	0.510	-4.122	0.721
E. schomburgkii	3.690	-0.061	3.763	0.661	3.655	0.337
E. uncinatum	-3.188	-0.620	-3.232	-0.675	-3.237	-0.447
Q. paraensis	4.649	-0.841	4.519	-0.306	4.504	0.068
C. odorata x *E. schomburgkii*	-0.054	0.650	0.057	0.224	0.038	0.503
E. uncinatum x *C. odorata*	-3.859	0.161	-3.778	0.108	-3.804	-0.344
E. uncinatum x *E. schomburgkii*	-0.218	-0.141	-0.214	-0.175	-0.287	0.043
E. uncinatum x *Q. paraensis*	0.130	-0.417	0.087	-0.484	0.069	-0.727
Q. paraensis x *C. odorata*	-0.521	0.619	-0.406	0.319	-0.433	0.183
Q. paraensis x *E. schomburgkii*	3.536	0.763	3.619	-0.127	3.592	-0.333

Shear				
	Discriminant Function			
	Dry		24h Cold water	
	FD1	FD2	FD1	FD2
C. odorata	-4.859	1.765	-4.799	0.222
E. schomburgkii	4.799	0.522	3.419	2.376
E. uncinatum	-3.276	-0.571	-2.154	-1.966
Q. paraensis	4.225	0.012	4.283	-3.209
C. odorata x *E. schomburgkii*	-0.229	0.233	-0.551	1.174
E. uncinatum x *C. odorata*	-4.306	0.058	-3.593	-0.473
E. uncinatum x *E. schomburgkii*	0.363	-0.536	0.454	0.725
E. uncinatum x *Q. paraensis*	-0.602	-1.400	0.287	-0.371
Q. paraensis x *C. odorata*	-0.312	-0.921	-0.440	0.999
Q. paraensis x *E. schomburgkii*	4.197	0.838	3.094	0.522

FD1: discriminant function 1 and FD2: discriminant function 2.

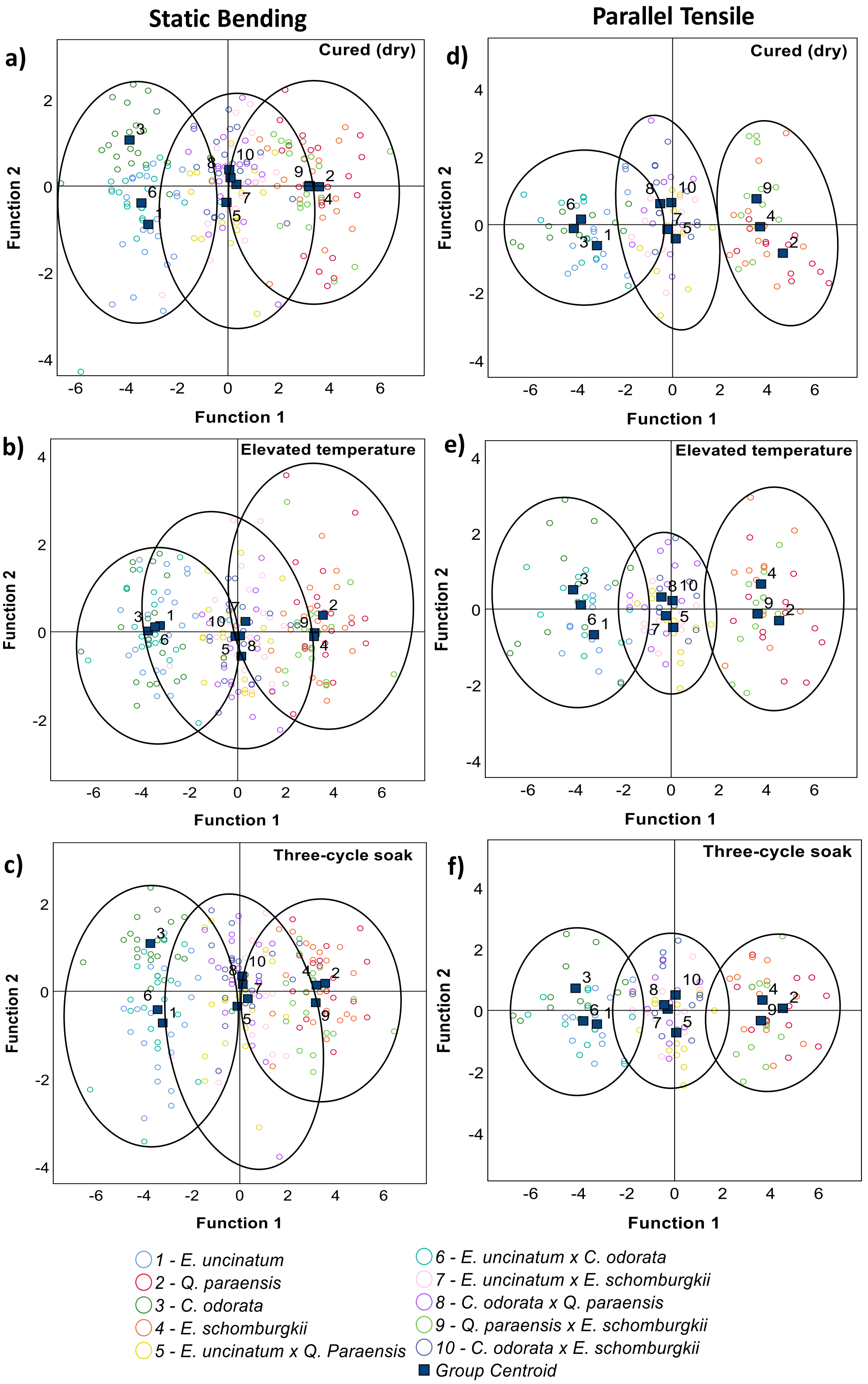

Figure 1. Discriminant graph of species combinations for length gluing. a-c) Dry, high temperature and triple cycle pre-treatments of the static bending test; d-f) Dry, high temperature and triple cycle pre-treatments of the parallel tensile test.

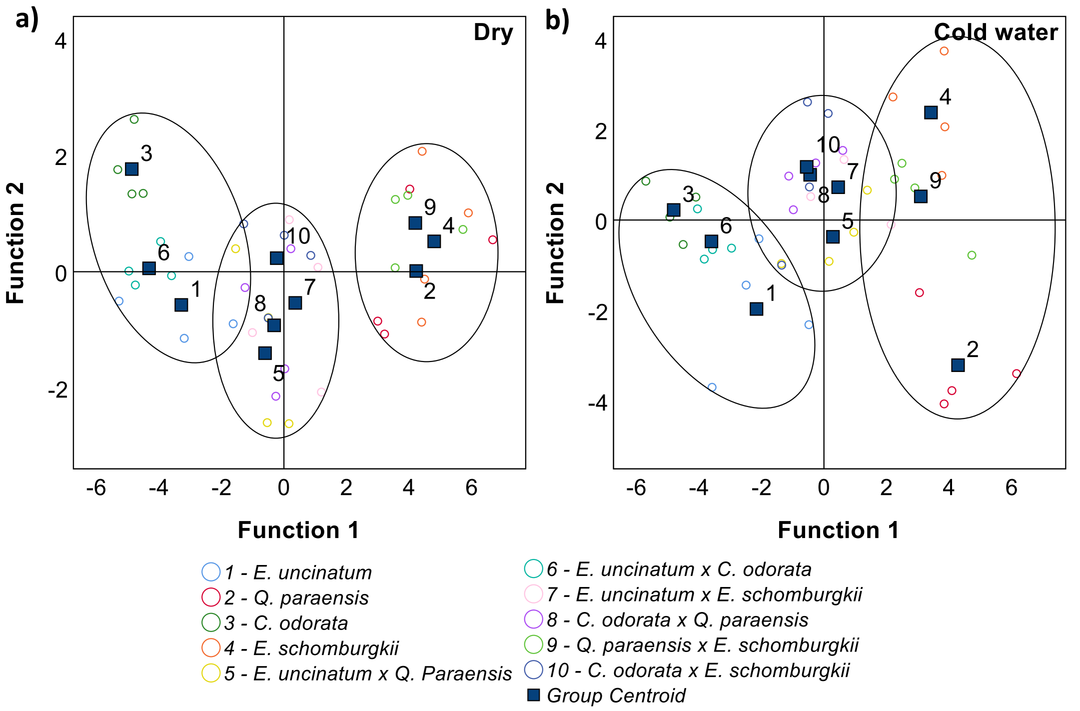

Figure. 2 Discriminant graph of species combinations for edge gluing. a) Dry pre-treatment; b) 24h cold water pre-treatment (wet).

In the present study, *C. odorata*, *E. uncinatum*, and their combination can be considered as low-density woods; the hybrid joints of *C. odorata* x *E. schomburgkii*, *E. uncinatum* x *E. schomburgkii*, *E. uncinatum* x *Q. paraensis*, and *Q. paraensis* x *C. odorata* as medium-density; and *E. schomburgkii, Q. paraensis*, and their combination as high-density, following Coradin et al. (2010). In Brazil, the species most commonly used in the production of EGP panels are those with low to medium wood density, such as *E. grandis* (0.39 g/cm^3 to 0.50 g/cm^3), *P. taeda* (0.32 g/cm^3 to 0.34 g/cm^3), and *T. grandis* (0.48 g/cm^3 to 0.64 g/cm^3) (Lobãoet al., 2011). Despite the recommendation against using higher-density woods for EGP panel production (Trianoski & Iwakiri, 2020; Trianoski et al., 2020), it is important to note that the high-density species (*E. schomburgkii* and *Q. paraensis*) evaluated in this study exhibited satisfactory strengths and met the normative requirements, indicating that they can also be used for this purpose.

The discrimination of species and combinations based on wood density (low, medium, and high) indicated that this is the most important characteristic for grouping different species that make up tropical solid wood waste for EGP panel production. The gluing of wood depends, among other factors, on anatomy, porosity, and density (Iwakiri et al., 2021), as these properties are related to adhesive mobility, void spaces to be filled, anchorage, and adhesion (Iwakiri, 2005). Therefore, the formulation of the adhesive to be used in gluing should be based on wood density (Tsoumis, 1991; Marra, 1992), a practice that can minimize reductions in glue line strength, as observed for *C. odorata* x *E. schomburgkii* and *Q. paraensis* x *C. odorata* in high-temperature and triple-cycle pre-treatments, *Q. paraensis* x *E. schomburgkii* (dry, high temperature, and triple cycle) and *E. uncinatum* x *Q. paraensis* (high temperature) in the static bending test, and *E. uncinatum* x *C. odorata* (dry - shear).

These reductions in strength can, in part, be attributed to differences in permeability between species since most configurations were composed of one low-density species (*C. odorata* or *E. uncinatum*) in combination with a high-density species (*E. schomburgkii* or *Q. paraensis*). Considering the complexity of anatomical characteristics, the results found here suggest that gluing species with similar densities can balance the dimensional changes resulting from the absorption and loss of moisture in hybrid EGP panels. Since the stress generated in the glue lines due to wood swelling and shrinkage is proportional to its density (Morin-Bernard et al., 2020), wood density significantly influences the strength and durability of bonds (Frihart, 2005). Consequently, it is considered the determining property of the physical and mechanical properties of EGP panels (Rojas et al., 2020).

These findings demonstrate that it is possible to maximize the use of raw materials from tropical solid wood waste in the Amazon region, and additionally, minimize carbon emissions associated with the burning of this material. Furthermore, in practice, the separation of species into groups according to wood densities can also contribute to a better definition of the recommended uses of EGP panels for each density class, allowing for precise targeting for applications according to the required strength ranges.

Conclusion

In the length gluing, the strength results for static bending and parallel tensile of all species and combinations met the minimum requirements of ASTM D 5572 standard (ASTM, 2019) for all pre-treatments.

In edge gluing, the shear results for all species and combinations also met the minimum requirements of the EN 13354 standard (EN, 2008) for all pre-treatments.

The species *C. odorata*, *E. schomburgkii,E. uncinatum*, and *Q. paraensis* showed potential for the production of EGP panels, both in homogeneous and hybrid configurations.

The discriminant analysis separated the tested treatments into three groups of species/combinations, with the most important variable in this separation being the apparent density at 12%.

Therefore, it is recommended that for the production of EGP panels with solid wood waste, species should be grouped and adhesive formulation should be based on wood density.

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References

ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DE MADEIRA PROCESSADA MECANICAMENTE (ABIMCI). Estudo Setorial 2019: ano base 2018. Curitiba, 2019. 161p. https://abimci.com.br/wp-content/uploads/2022/09/Estudo-Setorial-2019.pdf. Accessed 04 september 2023

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). Projetos de estruturas de madeira – NBR 7190. Rio de Janeiro, 1997. 107p.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM). Standard specification for adhesives used for finger joints in nonstructural lumber products - D 5572. West Conshohocken: United States, 2019. 17p.

BILA, N. F.; IWAKIRI, S.; TRIANOSKI, R.; PRATA, J. G. Avaliação da qualidade de juntas coladas de seis espécies de madeiras tropicais da Amazônia. Floresta, v. 46, n. 4, p. 455-464, 2016. https://doi.org/10.5380/rf.v46i3.36311

BRASIL. Ministério do Meio Ambiente. Resolução CONAMA N° 474, de 6 de abril de 2016. Altera a Resolução nº 411, de 6 de maio de 2009, que dispõe sobre procedimentos para inspeção de indústrias consumidoras ou transformadoras de produtos e subprodutos florestais madeireiros de origem nativa, bem como os respectivos padrões de nomenclatura e coeficientes de rendimento volumétricos, inclusive carvão vegetal e resíduos de serraria, e dá outras providências. 2016. http://www.ibama.gov.br/component/legislacao/?view=legislacao&legislacao=138205#:~:text=Altera%20a%20Resolu%C3%A7%C3%A3o%20n%C2%BA%20411,de%20rendimento%20volum%C3%A9tricos%2C%20inclusive%20carv%C3%A3o. Accessed 14 August 2022

C.T. DONOVAN ASSOCIATES INC. Opportunities and constraints associated with using wood waste for fueling Connecticut. Office of Policy and Management, Energy Division. Connecticut, 1990.

CLEMENT, C. R.; HIGUCHI, N. A florestaamazônica e o futuro do Brasil. Ciencia e Cultura,v. 58, n. 3,p. 44-49, 2006.

CORADIN, V. T. R.; CAMARGOS, J. A. A.; PASTORE, T. C. M.; CHRISTO, A. G. Madeiras comerciais do Brasil: chave interativa de identificação baseada em caracteres gerais e macroscópicos. Serviço Florestal Brasileiro, Laboratório de Produtos Florestais: Brasília, 2010.https://lpf.florestal.gov.br/en-us/chave-interativa-de-identificacao. Accessed 15 september 2023

DANAWADE, B. A.; MALARI, R. R.; PATIL, B. S.; HANAMAPURE, R. S. Effect of finger joint on flexural strength of teak wood. International Journal of Engineering and Technology,v. 5, n. 6,p. 4929-4937, 2014.

EUROPEAN STANDARD (EN). Solid wood panels (SWP) – Requirements – EN 13353. Bruxelas, p. 10, 2008.

EUROPEAN STANDARD (EN). Solid wood panels – Bonding quality – Test Method – EN 13354. Bruxelas, p.11, 2008.

FRIHART, C. Adhesive bonding and performance testing of bonded wood products. Journal of ASTM International,v. 2, n. 7, 2005. https://doi.org/10.1520/jai12952 article 12952

IWAKIRI, S. Painéis de Madeira Reconstituída. FUPEF: Curitiba, 2005.

IWAKIRI. S.; TRIANOSKI, R.; ZUNTA, R. R.; PEREIRA, G. F.; ROSA, T. S. Avaliação dos efeitos do adesivo, gramatura e pressão na qualidade de painéis EGP de *Eucalyptus badjensis*. ScientiaForestalis, 49: e3437, 2021. https://doi.org/10.18671/scifor.v49n129.20

KEFFER, J. F.; TRIANOSKI, R.; SANTOS, R. A.; IWAKIRI, S.; ZAMARIAN, E. H. C. Potential for using tropical solid wood waste from the Amazon for the production of edge gluedpanels. Scientific Electronic Archives, v. 17, n. 1, 2024.http://dx.doi.org/10.36560/17120241855

LOBÃO, M. S.; CASTRO, VR, RANGEL A, SARTO C, TOMAZELLO FILHO, M.; SILVA JUNIOR, F. G.; CAMARGO NETO, L.; BERMUDEZ, M. A. R. C. Agrupamento de espécies florestais por análises univariadas e multivariadas das características anatômica, física e química das suas madeiras. Scientia Forestalis,v. 18,n. 1, p. 16-29, 2011.

MARRA, A. A. Technology of wood bonding: principles in practice. Van Nostrand Reinhold: New York, 1992.

MELO, L. E. L.; SILVA, C. J.; LOPES, K. V.; BRITO, P. G. M. B.; SANTOS, I. S. Resíduos de serraria no estado do Pará: caracterização, quantificação e utilização adequada. Floresta e Ambiente,v. 19, n. 1,p. 113-116,2012. https://doi.org/10.4322/floram.2012.012

MORIN-BERNARD, A.; BLANCHET, P.; DAGENAIS, C.; ACHIM, A. Use of northern hardwoods in glued-laminated timber: a study of bondline shear strength and resistance to moisture. European Journal of Wood and Wood Products,v. 78,p. 891-903,2020. https://doi.org/10.1007/s00107-020-01572-3

MUSAH, M.; WANG, X.; DICKINSON, Y.; ROSS, R. J.; RUDNICKI, M.; XIE, X. Durability of the adhesive bond in cross-laminated northern hardwoods and softwood. Construction and Building Materials,v. 307, n. 2, 124267, 2021. https://doi.org/10.1016/j.conbuildmat.2021.124267

NUMAZAWA, S.; CARVALHO, M. S. P.; BRANDÃO, A. T. O.; ALVES, R. L.; RODRIGUES, A. F. Determinação do índice de conversão da tora em madeira serrada de oito espécies florestais processadas na empresa Comércio Madeira Dunorte Ltda. In: Anais do IX Congresso Internacional de Compensado e madeira Tropical, 2003, Belém, p. 22.2003.

ROJAS, J. C. C.; IWAKIRI, S.; TRIANOSKI, R.; MORA, H. E. G. Uso de residuos de processos de transformación secundaria de tres especies tropicales en la fabricación de paneles encolados lateralemente. ScientiaForestalis,v. 48, n. 125, e3168, 2020. https://doi.org/10.18671/scifor.v48n125.20

SIKORA, K.; MCPOLIN, D.; HARTE, A. Shear strength and durability testing of adhesive bonds in cross-laminated timber. The Journal of Adhesion,v. 92, n. 7-9,p. 758-777, 2016. https://doi.org/10.1080/00218464.2015.1094391

TIENNE, D. L. C.; NASCIMENTO, A.M.; GARCIA, R. A.; SILVA, D. B. Qualidade de adesão de juntas de madeira de *Pinus* coladas em condições simuladas de serviço interna e externa. Floresta e Ambiente,v. 18, n. 1,p. 16-29, 2011. https://doi.org/10.4322/floram.2011.0191

TRAORÉ, M.; MARTÍNEZ CORTIZAS, A. Comparative study of four timber wood species in southern Mali (West Africa) by combining FTIR spectroscopy and multivariate analysis. European Journal of Wood and Wood Products, v. 81, p. 1513-1524, 2023. https://doi.org/10.1007/s00107-023-01979-8

Trianoski R, Iwakiri S (2020) Painéis colados lateralmente - EGP. In: Iwakiri S, Trianoski R (eds) Painéis de madeira reconstituída, 2 ed. FUPEF, Curitiba, pp 118-135.

TRIANOSKI, R.; IWAKIRI, S.; BONDUELLE, G. M. Qualidade das juntas coladas de madeira de cinco espécies de *Eucalyptus* com adesivos acetato de polivinila e resorcina-formaldeído. Madera y Bosques,v. 26, n. 3, e2632064,2020.https://doi.org/10.21829/myb.2020.2632064

TSOUMIS, G. (Science and technology of wood: stucture, properties and utilization. Van Nostrand Reinhold: New York. 1991.

VALDIONES, A. P.; CARDOSO, B.; DAMASCENO, C.; KOURY, C. G.; SOUZA JR., C.; CARDOSO, D.; MEIRELLES, F.; COSTA, J. N.; RIBEIRO, J.; SOBRAL, L. M.; LENTINI, M. W.; ANDRADE, M. BT.; PACHECO, P.; MORGADO, R. P.; CARVALHO, T.; SILGUEIRO, V. A Evolução do setor madeireiro na Amazônia entre 1980 e 2020 e as oportunidades para o seu desenvolvimento inclusivo e sustentável na próxima década. Imazon: Imaflora: ICV: IDESAM, Belém, 2022. https://imazon.org.br/wp-content/uploads/2022/06/Evolucao-do-Setor-Madeireiro-na-Amazonia-de-1980-a-2020.pdf. Accessed 04 August 2022

YELLE, D. J.; STIRGUS, A. M. Influence of anatomical, physical, and mechanical properties of diffuse-porous hardwoods on moisture durability of bonded assemblies. General Technical Report FPL-GTR-244. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 2016. https://doi.org/10.2737/FPL-GTR-244