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Evaluation of the Oriented Strand Board Properties Produced Using Tropical Wood Mixtures

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Abstract: The objective of this study was to evaluate the composition of OSB panels created using the Amazonian species *Caryocar villosum* Aubl., *Erisma uncinatum* Warm., and *Hymenolobium excelsum* Ducke. The OSB was produced using a phenol–formaldehyde adhesive at a ratio of 30:40:30 for each layer. Different mixtures of Amazonian wood and *Pinus caribaea* var. *caribaea*. were tested. Physical (water absorption and thickness swelling after 2 and 24 h of immersion in water and non-return rate in thickness) and mechanical (internal bond and parallel and perpendicular static bending) tests were performed. The OSB panels composed of wood mixtures absorbed less water after 2 and 24 h of immersion when compared to the OSB produced using pine wood. After 24 h of immersion in water, the T3 panel (40% *Pinus caribaea* + 40% *Hymenolobium excelsum* + 20% *Caryocar villosum*) presented the lowest absorption value. In terms of swelling in thickness at 2 h and 24 h, the panel composed of 100% pine strands showed the highest swelling value, while the T3 treatment exhibited the lowest swelling value at 2 and 24 h, as well as for the rate of non-return in thickness. Regarding mechanical properties, we observed that all panels exhibited similar resistance for both parallel and perpendicular Modulus of Rupture, as well as parallel and perpendicular Modulus of Elasticity, except for the internal bond, where T3 demonstrated the highest resistance. Additionally, some OSB panels met the requirements of the EN 300 standard for OSB panels.

Keywords: particleboards; oriented strand board; strands; Amazonian trees

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1. Introduction

Oriented Strand Board (OSB) is a wood composite made of wood strands that are arranged in cross-pattern layers, compressed, and joined with synthetic adhesives. OSB is widely used in construction, decks, floors, wall coverings, and as load-bearing support [1]. OSB manufacturers predominantly use conifer species [2]. Softwoods, particularly pine and spruce, are the predominant raw materials employed in nearly all OSB production lines across Europe, and currently no OSB panels are made from 100% hardwood species [3]. However, manufacturers can also use hardwood species or a mixture of hardwood and softwood in OSB production [4]. A study evaluated the influence of fine content and panel density on the properties of mixed hardwood oriented strand board [5]. The authors' findings revealed that as fine levels increased, the parallel Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) decreased, while the perpendicular values increased. In Indonesia, a study aimed to investigate the physical and mechanical properties of strand boards made from the residual veneer material of rubber wood (*Hevea brasiliensis* Mull. Arg.) and falcata wood (*Falcataria moluccana*), and the authors concluded that, based on the results, strand boards obtained from rubber and falcata have the potential to be commercialized [6]. In the United States of America, a work investigated the feasibility of using western juniper (*Juniperus occidentalis*) as a material to manufacture oriented strand board (OSB) panels, and according to the authors, the properties of the juniper panels were found to be equivalent or slightly superior to those of the southern yellow pine panels at the same density level, except for the modulus of elasticity [7]. These studies around the world demonstrate that researchers are interested in exploring new alternative species that can be used in the manufacturing of OSB panels.

In 2020, the world production of OSB was 35.9 million m^3, with the United States being the largest world producer and Brazil occupying the 18th position with a total of 233 thousand m^3 [8]. In Brazil, OSB is produced exclusively using *Pinus* sp. [9], and the factory responsible for its manufacturing in the country produces 13 types of OSB panels that differ in quality and purpose [10]. Studies on the quality of OSB panels made of alternative materials to pine have been intensified in the country, seeking to diversify the sources of supply for the industry [11,12].

The use of alternative species to pine in OSB manufacturing, such as *Erisma uncinatum* and *Schizolobium amazonicum,* showed that the resulting panels exhibited satisfactory results for physical and mechanical properties [13]. On one hand, higher-density woods presented a better performance in terms of physical properties, while lower-density woods outperformed them in mechanical properties, due to the higher resin penetration [13]. A study demonstrated that the use of two low-density tropical woods (*Anacardium* sp. and *Trattinikia* sp.) has potential for OSB manufacturing, with the consequent possibility of classifying them as OSB4, based on the corresponding requirements of EN 300 [14]. A study was carried out using five species of Eucalyptus and a mixture of Eucalyptus and *Pinus taeda* for the manufacture of OSB panels, and the authors observed that both the species used and the mixture showed technical feasibility for the production of OSB panels [15]. OSB panels produced using Balsa wood residues were classified as OSB1, intended for internal and non-structural applications [16].

Therefore, the use of alternative wood species, such as tropical species, can be an alternative in the production of OSB panels, as long as they are mixed with other species of lower density [17,18].

In some timber sectors, between 30% and 70% of the volume of roundwood harvested is converted into waste [19,20]. Therefore, the use of residues from the primary and secondary processing of tropical wood and the study of these species in panel production can provide subsidies for the installation of OSB factories in the Amazon region [18]. As an example, a study carried out using tropical wood residues demonstrated the potential use of residues for non-structural purposes, furniture, tools, and panels composed of short pieces [21]. Developing materials made of forest biomass by-products can be a viable alternative for replacing conventional materials, in addition to showing the potential for waste reuse [22,23].

In 2020, according to data from the Timberflor platform [24], 27,180 m^3 of *Caryocar villosum*, 50,629 m^3 of *Erisma uncinatum* wood, and 12,422 m^3 *Hymenolobium excelsum* were harvested in log form. Considering the large volume of waste generated in wood processing, these species show potential as raw materials for the production of OSB panels. Given the need for further studies regarding the performance of Amazonian woods in OSB manufacturing, this study aims to evaluate the potential of using a mixture of three Amazonian wood species that have been underutilized by the Brazilian wood industry—*Caryocar villosum* Aubl., *Erisma uncinatum* Warm., and *Hymenolobium excelsum* Ducke—in the composition of OSB panels.

2. Material and Methods

2.1. Raw Material

We evaluated the species *Erisma uncinatum*, *Hymenolobium excelsum*, and *Caryocar villosum*, with bulk density of 530, 630, and 730 kg/m^3, respectively. They were sourced from an area of sustainable forest management in Vale do Jari, Almeirim, Pará, Brazil (01°31′24″ S, 52°34′54″ W). The wood of *Pinus caribaea* var. *caribaea*., which has a basic density of 484.9 kg/m^3, was obtained at Fazenda Areão, Piracicaba, Sao Paulo, Brazil (22°42′30″ S, 47°38′51″ W).

2.2. Wood Strand Production and Drying

The Amazonian woods, originally in the form of boards, were converted into blocks with dimensions of 90 mm wide and 25 mm thick. The blocks were then subjected to an autoclave process, which involved the application of vacuum and pressure until they reached complete saturation in water. This process facilitated the generation of strand particles, as the wooden boards were initially dried in the open air, with a moisture content of approximately 12%. The vacuum and pressure cycles were alternated every two hours, and the time spent (in days) in the autoclave differed for the three species due to their different basic densities. Thus, *Caryocar villosum*, *Hymenolobium excelsum*, and *Erisma uncinatum* took three, two, and one day, respectively, to achieve complete saturation.

Before generating the wood strands, the blocks were soaked in hot water at 90 °C for 8 h using a heating tank. Subsequently, strands with dimensions of 0.65 × 25 × 90 mm (t × w × l) were produced (Figure 1). The *Pinus caribaea* wood did not require autoclaving or preheating since it was naturally saturated and easy to cut.

Figure 1. Wood strands before (**A**) and after (**B**) the blocks were soaked in hot water. (**A**) before heating in hot water, it was not possible to obtain entire strands, as they were brittle. (**B**) the quality of the strands obtained is superior to those made before the hot bath, as they are solid and have the appropriate geometry for the production of OSB panels. Note: The numbers in the strands in (**B**) represent the thickness.

Afterward, the strands were dried in an oven with forced air circulation at 80 °C until the strands reached a final moisture content between 3% and 4%.

2.3. Wood Strands Extractive Contents

As we immersed the wood in hot water, we compared the extractive contents in the samples before and after the hot bath. Our objective was to identify and determine if any changes occurred and what effect they might have had on the properties of the OSB panels. The analysis was performed following the NBR 14853 (2010) [25] standard to determine the total extractive content. Random samples of *Caryocar villosum*, *Hymenolobium excelsum*, and *Erisma uncinatum* were ground and classified, and the fraction retained on a 40-mesh sieve was used for analysis. Three extractions were conducted in a Soxhlet flask using different solvents.

For the first extraction, we used alcohol:toluene (1:2) with a total extraction time of 8 h. The second extraction used ethyl alcohol for 8 h duration. The third extraction involved hot water in Erlenmeyer flasks placed in a water bath at 95 °C for one hour, homogenizing them every 15 min. Subsequently, the samples underwent a filtering process and were dried in an oven at 103 ± 2 °C. We then determined the total extractive content.

2.4. OSB Production

To bond the OSB panel, we used a phenol–formaldehyde (PF) resin containing 53.09% solids, applied at 6% solids, based on the dry mass of the strand particles. Additionally, a 1% paraffin emulsion was incorporated into the strands. All applications were performed with a compressed air gun in a rotary mixer.

The orientation of the inner layer of the panels was placed perpendicular to the outer faces in a 30:40:30 ratio. The mats were pre-pressed using a target pressure of 1.6 kgf/cm^2 for a duration of 10 min, using a manual hydraulic press. Subsequently, they were subjected to a secondary press process using a motorized hydraulic press, applying 35 kgf/cm^2 of pressure at a temperature of 180 °C for 10 min. The panels (Figure 2), which were produced to have a nominal density of 650 kg/m^3 and dimensions of 15.7 × 560 × 560 x mm (t × w × l), were kept in a room with controlled temperature and humidity (22 ± 2 °C and 65 ± 5%) until reaching the equilibrium humidity for the physical and mechanical tests.

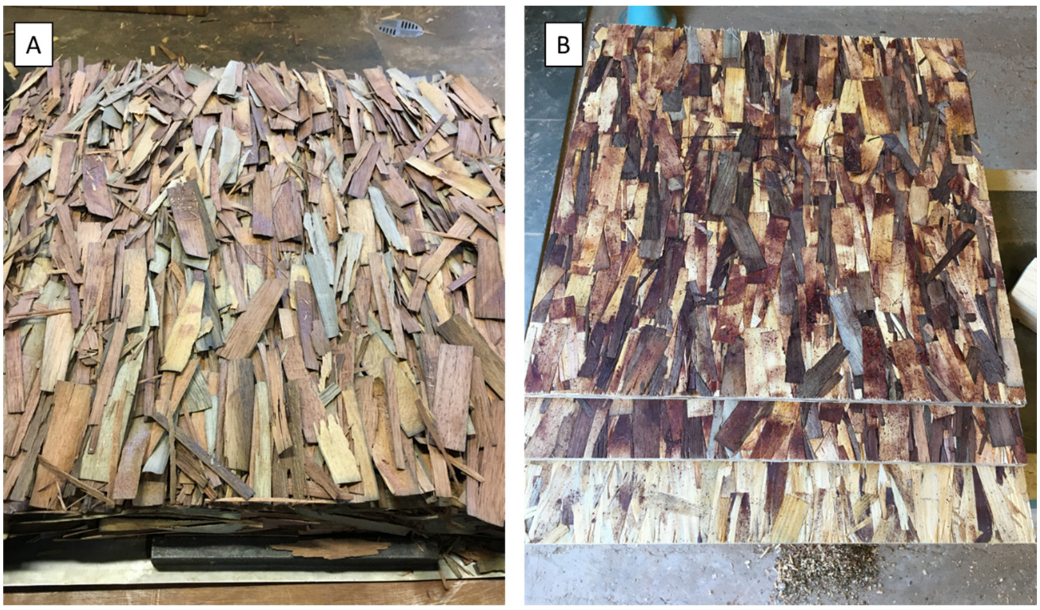

Figure 2. OSB panels from wood mixture. (**A**) Strands before pressing; (**B**) panel after hot pressing.

2.5. Physical and Mechanical Properties

Physical tests, including water absorption (WA) and thickness swelling (TS) after 2 and 24 h of immersion in water, as well as the non-return rate in thickness (NRRT), were conducted following the EN 317 standard [26]. The internal bond test (IB) was carried out following the EN 319 standard [27]. The modulus of rupture (MOR) and modulus of elasticity (MOE) for parallel (//) and perpendicular (⊥) static bending were determined following the EN 310 standard [28].

2.6. Experimental Design and Statistical Analysis

The experimental design was completely randomized and consisted of five types of OSB with three replications, totaling 15 panels with different proportions of strands per species (Table 1). In all panels, pine strands had some percentages in the composition of the OSB panels. To compare the different mixtures, an analysis of variance was performed, and Tukey's mean test, at a 5% error probability level. The statistical software used for data analysis was R software version 4.2.2. The average values of each evaluated property, per panel category, were obtained and then compared with the minimum values specified by the EN 300 standard [29].

Table 1. Composition of the OSB panels produced. Each column indicates the proportion of wood used from each species and the proportional distribution of the mass of the mixture in the external and internal layers.

ID	Strand Proportion (%)				F:C:F *
	Pinus	*Erisma uncinatum*	*Hymenolobium excelsum*	*Caryocar villosum*	
T1	100%	-	-	-	30:40:30
T2	40%	50%	-	10%	30:40:30
T3	40%	-	40%	20%	30:40:30
T4	40%	25%	35%	-	30:40:30
T5	40%	20%	20%	20%	30:40:30

Note: Face (F), Core (C). * F:C:F—indicates the percentage mass distribution of wood strands in the external layers (F) and in the internal layer (C).

3. Results

3.1. Wood Strand Extractive Contents

Table 2 presents the results of the total extractive analysis. *Caryocar villosum* showed the highest amount of extractives (10.0%) both before and after immersion in hot water, followed by *Hymenolobium excelsum* (6.78%) and *Erisma uncinatum* (4.80%).

Table 2. Average extractive content of tropical wood species before and after immersion in a hot water bath. The extractive content with a p-value < 0.05, the difference before and after immersion in hot water, was considered statistically significant.

Wood Species	Extractives (%)		p-Value
	Before	After	
Erisma uncinatum	4.80 ± 0.10	3.52 ± 0.35	38.46
Caryocar villosum	10.0 ± 0.16	7.25 ± 0.54	71.03
Hymenolobium excelsum	6.78 ± 0.08	6.88 ± 0.36	0.24

Warming the *Hymenolobium excelsum* blocks did not influence the average extractive content (p-value = 0.24). However, warming the other species caused significant changes in the extractive content in the strands, which should be considered when analyzing the performance of the OSB panels that used these species in the mixture.

3.2. Physical Properties of the OSB Panels

The average values of apparent density (AD), compaction ratio (CR), moisture content, and non-return rate in thickness (NRRT) are presented in Table 3. The panels' effective density was higher than the nominal density of 650 kg/m^3. The compaction ratio values of all the panels produced were greater than 1.3, and the panels' moisture content did not show a statistically significant difference. The non-return rate in thickness (NRRT) of T1 (100% pine) was the highest and statistically different from that of T3 (40% pine, 40% *Hymenolobium excelsum*, and 20% *Caryocar villosum*), which had the lowest NRRT.

Table 3. Average values of the physical properties of the OSB panels.

ID	AD (kg/m^3)	CR	MC (%)	NRRT (%)
T1	725.9 ± 0.025 a	1.49 ± 0.03 d	7.70 ± 1.19 a	18.49 ± 6.06 ab
T2	735.3 ± 0.042 a	1.60 ± 0.04 c	8.17 ± 0.43 a	16.21 ± 4.41 bc
T3	730.6 ± 0.055 a	1.63 ± 0.05 b	8.13 ± 0.30 a	10.82 ± 2.86 d
T4	725.3 ± 0.042 a	1.75 ± 0.05 a	8.23 ± 0.36 a	14.67 ± 3.19 bcd
T5	734.4 ± 0.044 a	1.58 ± 0.05 c	8.11 ± 0.39 a	13.22 ± 3.61 cd

Notes: apparent density (AD), compaction ratio (CR), moisture content (MC), and non-return rate in thickness (NRRT). Means followed by the same letter in the column do not statistically differ according to Tukey's test ($\alpha = 0.05$).

Pine panels (T1) showed higher water absorption (WA) after 2 and 24 h (Figure 3A). OSB panels made of tropical wood demonstrated similar behavior after two hours of immersion in water, showing no statistically significant difference. The tropical OSB panels displayed water absorption ranging between 18% and 23%. After 24 h of immersion, the T3 panel recorded the lowest absorption at 39%. For thickness swelling, based on Figure 3B, it was found that the T1 exhibited the highest thickness swelling after 2 h. Similarly, even after 24 h, the T1 continued to show the greatest thickness swelling, which was statistically similar to T2, while T3 exhibited the lowest thickness swelling.

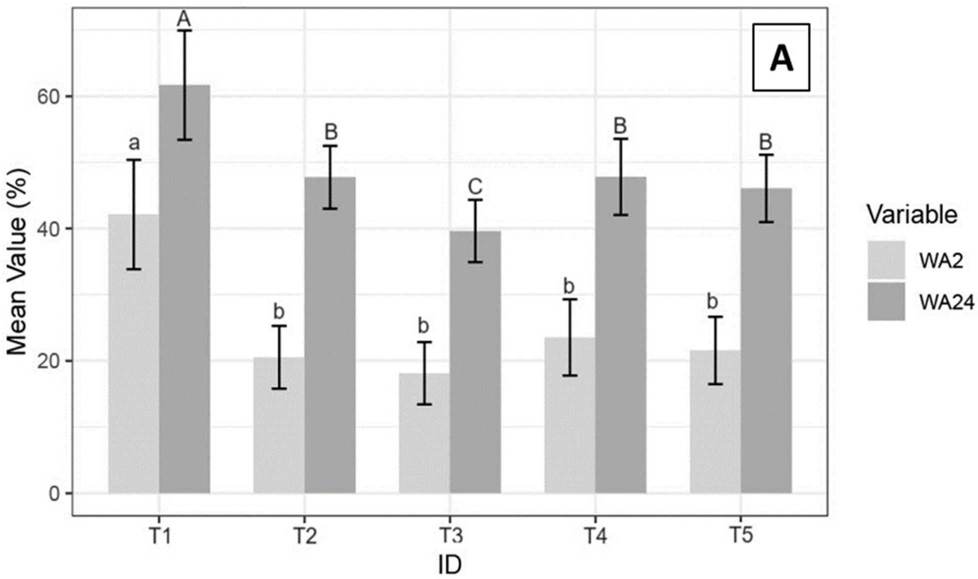

Figure 3. *Cont.*

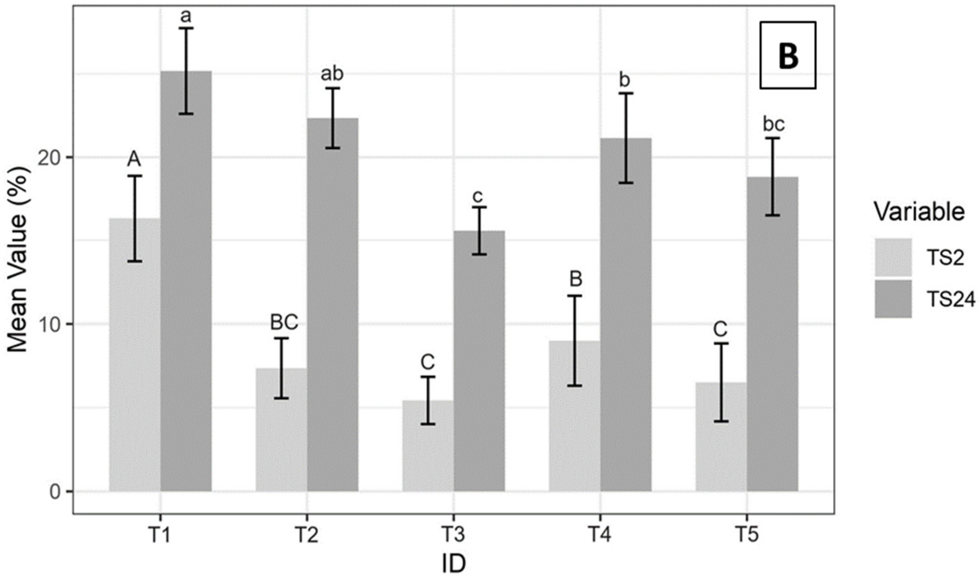

Figure 3. Average values for water absorption (WA) and thickness swelling (TS) percentages after 2 and 24 h of immersion. (**A**,**B**) Means followed by the same letter are not statistically different according to Tukey's test (α = 0.05) for water absorption and thickness swelling, respectively.

3.3. OSB Panels' Mechanical Properties

The OSB panels did not exhibit a significant difference in MOE and MOR in both parallel and perpendicular directions (Figure 4A–D). For MOE (//), the values ranged from 7290 MPa to 8283 MPa (p-value = 0.235), and on the perpendicular, MOE (⊥) values varied from 1022 MPa to 1333 MPa (p-value = 0.359). Figure 4C,D shows that the parallel (//) and perpendicular (⊥) MOR values demonstrated a behavior similar to MOE. MOR (//) values ranged from 39 MPa to 50 MPa (p-value = 0.842), whereas MOR (⊥) values ranged from 13 MPa to 19 MPa (p-value = 0.383).

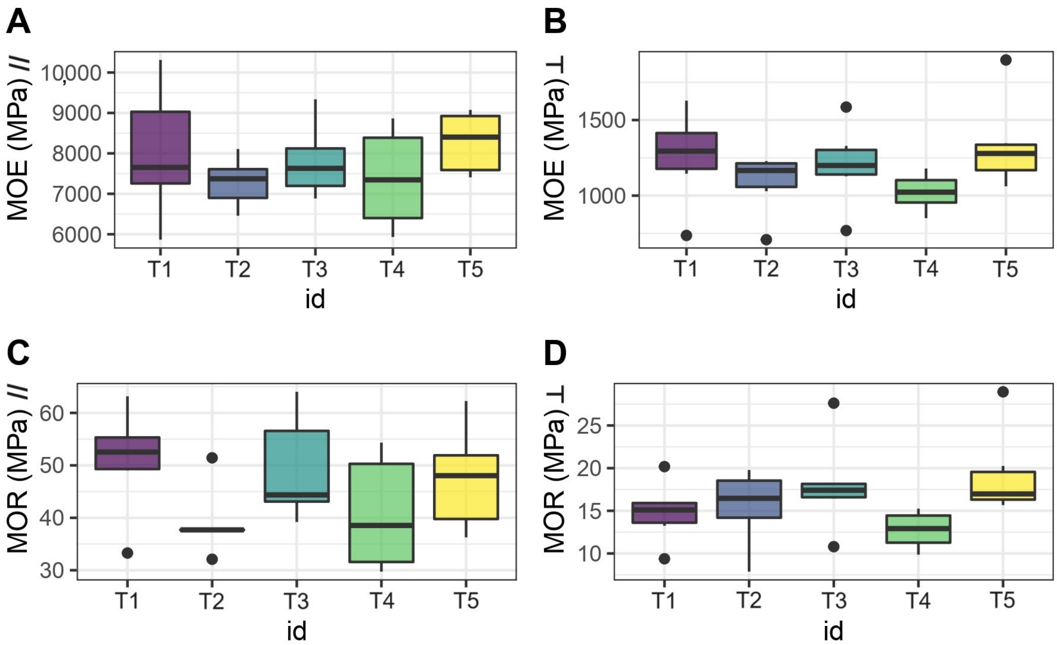

Figure 4. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). (**A**) MOE parallel. (**B**) MOE perpendicular. (**C**) MOR parallel. (**D**) MOR perpendicular. The black points represent possible outliers.

According to Figure 5, T3 (40% *Hymenolobium excelsum* + 20% *Caryocar villosum* + 40% *Pinus*) exhibited the highest resistance for internal bonding (0.48 MPa) and was found to be statistically different from T1 (100% *pinus* strands). T2 presented the lowest internal bond (IB) resistance among all OSB panels, at 0.29 MPa.

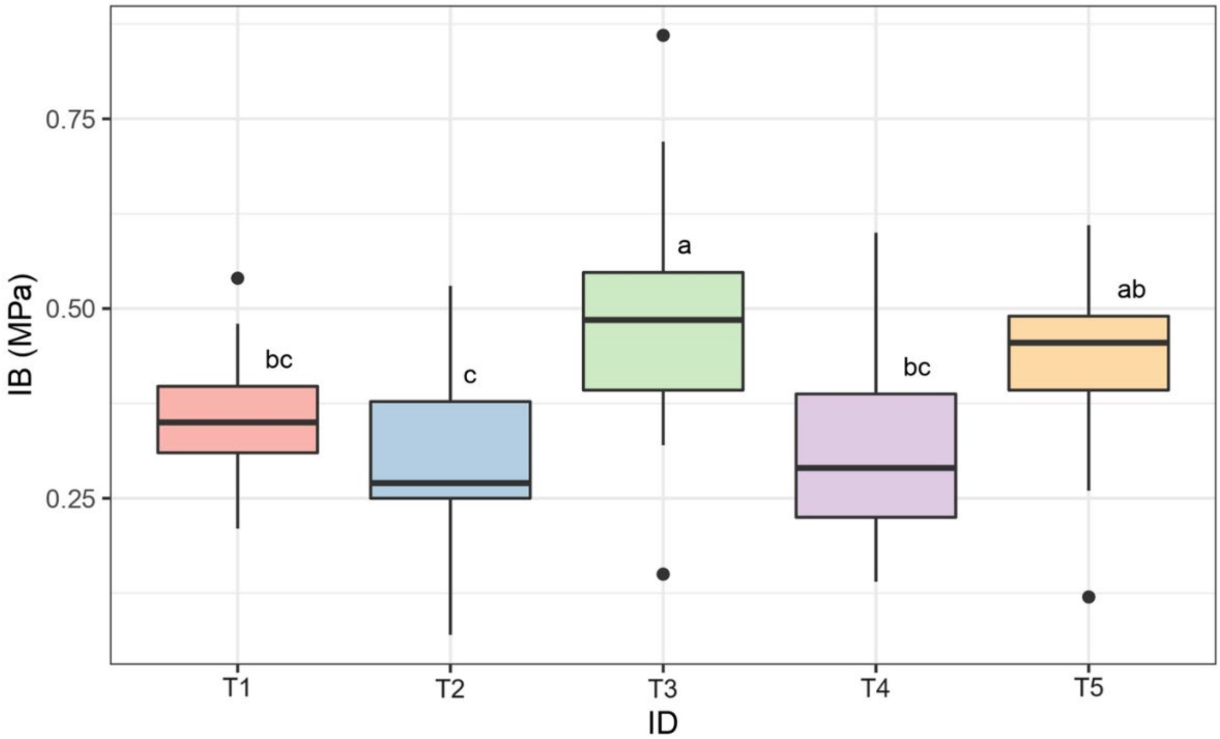

Figure 5. Internal Bond (IB). Means followed by the same letter in the column do not differ statistically according to Tukey's test (α = 0.05). The black points represent possible outliers.

4. Discussion

4.1. Extractive Content

Regarding the percentage of total extractives, it appears that the species that presented the highest extractive content was *Caryocar villosum*, followed by *Hymenolobium excelsum* and *Erisma uncinatum*. According to Frihart and Hunt [30], higher-density woods have a higher concentration of extractives, which can interfere with the curing of adhesives. As reported by Iwakiri [31], the concentration of extractives in the surface layers of wood can block the passage of water and delay its evaporation rate, increasing pressing time.

Wood species with a low extractive content are preferable, as wood with a high extractive content is more susceptible to generating problems, such as, for example, negatively interfering with the curing of the resin during the pressing cycle, which can result in a lower bonding efficiency between wood particles [32]. The pH of wood varies depending on the species and is in the range of three to six. The pH of the extractives present in the wood can inhibit the chemical reactions that harden the adhesive, thus harming the development of resistance, as well as the adequate cohesion of the glue line [31].

4.2. Physical Properties

It is known that during the production process of OSB panels, there are occasional material losses in the operational phase of mat formation, causing the effective density of the panels to be lower than the nominal density [33]. In order to avoid the material losses problem during the production process, in the calculation for the manufacture of the panels assessed in this study, 10% extra material was added, which is why the effective density of the panels produced in this study was higher than the planned nominal density of 650 kg/m^3. Panels with an apparent density of 590 to 800 kg/m^3 are classified as medium-density panels [34]. Thus, all the panels obtained in this study fit the classification mentioned by the referred authors.

As shown in Table 3, the panel compression rate was greater than 1.3. A wooden panel compaction ratio must be at least 1.3 for the necessary mat densification to occur, providing adequate contact between strands, so that there is good bonding and proper consolidation of the panel during the hot-pressing phase [34].

The 100% pine (T1) showed the highest water absorption at 2 and 24 h (Figure 1). In addition to the species factor, another component that may have influenced this result is the difference between the basic density of pine wood and the densities of wood mixtures. Lower-density woods, due to their greater porosity, absorb a greater amount of water compared to high-density woods [13]. Particleboards with wood residue mixtures from five tropical species (*Hymenolobium* sp./*Andira* sp., *Qualea* sp., *Nectandra* sp./*Ocotea* sp., *Cedrelinga cateniformis,* and *Mezilaurus itaúba*), showed lower water absorption values when compared to panels only composed by the low-density *Cedrelinga cateniformis* species [35]. As observed by Lunguleasa et al. [36], the water absorption of OSB panels manufactured in the laboratory using softwood mixtures (fir, spruce and pine) was superior to panels made of fast-growing hardwood mixtures (poplar, willow and birch).

Regarding swelling in thickness after 24 h, the OSB composed only of pine strands showed the highest mean swelling value, and the panels that contained some percentage of wood mixtures showed the lowest value of swelling in thickness. Zhuang et al. [37], when studying the physical and mechanical properties of OSB panels with mixtures made from eastern Canadian softwood species, observed that panels with wood mixtures showed less swelling in thickness than panels composed 100% of balsam fir particles. When comparing the swelling in thickness to the compaction ratio (Figure 1), it is noted that T4 presented the highest compaction ratio, however, it was not the highest swelling value after 24 h of immersion. Iwakiri et al. [38] also found a lower thickness swelling in the OSB panel that presented the highest compression ratio among the others adopted by them. These results differ from what is mentioned by Kelly [39], who states that the greater the compression rate of the panel, the greater its thickness swelling due to the greater release of compression tension that is retained in these panels before immersion in water. Considering the longer immersion time, the thickness swelling is partially inherent to the wood and also due to the adsorption of water by the hydroxyl groups, which are present in the chemical components of the cellulosic wall [40].

Regarding NRRT, T1t showed a higher average value than the OSB-composed wood mixture with 40% pine strands. Gorski et al. [41] obtained a non-return rate in thickness of 32.01% in OSB panels made from mixtures of *Pinus* spp. and *Eucalyptus benthamii*. The results obtained in this study were lower than those found by the aforementioned authors.

As for the classification, the panels T2, T3, T4, and T5 can be classified as type OSB/1 (non-structural for general and interior use); T3 and T5 also fall under the OSB/2 classification (load-bearing panels, used in dry conditions) according to EN 300 [29].

4.3. Mechanical Properties

As shown in Figure 3, the panels made using wood mixtures demonstrate mechanical resistance that is comparable to those made entirely of pine strands. This finding proves to be advantageous as it opens up the possibility of using Amazonian wood mixtures as an alternative raw material with similar characteristics to pine wood. This is particularly helpful during times when pine wood is scarce or expensive in the industry, especially in Brazil where the paper and cellulose industry is the largest consumer of pine wood.

As for the Modulus of Rupture (MOR) in the parallel direction, it is noted that the values found for all the panels were higher than the limits established by the EN 300 standard [29]. However, in the perpendicular MOR, all OSB panels reached the minimum values for the classification OSB/1, OSB/2, and OSB/3, except for OSB/4, where T3 and T5 presented compatible values for such classification. Iwakiri et al. [38] obtained results for the parallel and perpendicular modulus of rupture of 38.79 and 23.29 MPa, respectively, for OSB panels produced using a mix of species. Cabral et al. [42], when producing OSB panels using pine and eucalyptus mixtures, obtained values of 30.69 and 22.32 MPa for the parallel and perpendicular MOR, respectively. The results found in this study were slightly superior to the results from the mentioned authors.

When considering the parallel MOE, EN 300 [29] stipulates the minimum values of 2500, 3500, 3500, and 4800 MPa for them to be classified as type OSB/1, OSB/2, OSB/3, and OSB/4, respectively. According to the results presented in Figure 3, all panels obtained values higher than what is established by the norm in all classifications. For the MOE in the perpendicular direction, the standard establishes the minimum values of 1200, 1400, 1400, and 1900 MPa for OSB/1, OSB/2, OSB/3, and OSB/4, respectively. It is observed in Figure 3 that, for the perpendicular MOE, only T1 and T3 presented average values above what is required by the norm for all classifications. Iwakiri et al. [34] obtained an average of 5732 and 2531 MPa, for the parallel and perpendicular MOE, respectively, in OSB panels of wood mixtures of *Acrocarpus fraxinifolius*, *Grevillea robusta*, *Melia azedarach*, and *Toona ciliata*.

The internal bond of T3 and T5 was equivalent to each other and was superior to the others produced using wood mixtures. The EN 300 [29] standard stipulates the minimum values for the IB property of 0.30, 0.32, 0.32, and 0.45 MPa for OSB/1, OSB/2, OSB/3, and OSB/4, respectively. T3 reached the minimum value to be classified as OSB/4, while T1, T3, T4, and T5 can be classified as OSB/1, OSB/2, and OSB/3.

5. Conclusions

The aim of this study was to determine the physical and mechanical properties of OSB made from a mixture of three Amazonian wood species and Pinus. The results indicate that the addition of tropical wood mixture strands significantly improved the technological properties of OSB panels. Furthermore, the results demonstrated that the studied species have potential for use in the manufacturing of OSB. In terms of physical properties, it was observed that some OSB that contained wood mixtures showed less swelling in thickness than the OSB composed only of pine strands. In terms of mechanical properties, panels with wood mixtures were expected to achieve higher mechanical strength by using tropical species wood rather than pine wood. It was observed that all resistance values were statistically similar to the panel composed of 100% pine strands, except for the internal bond in which T3 (composed of 60% Amazonian wood strands) was superior to T1 (OSB produced 100% with strands of pine). However, even though only the internal bond presents superior resistance, it is observed that the mechanical properties of panels composed of a mixture of wood showed satisfactory results compared to panels composed only of pine strands. Therefore, a mixture of these three species in addition to pinus could be used to introduce a new competitive product on the traditional OSB market. It was observed that the physical and mechanical properties of OSB panels follow the EN 300 Standard. However, more work is needed to understand the behavior of tropical woods in the manufacture of OSB panels. It is recommended that studies of the chemical properties of wood be conducted to identify the influence of chemical composition on the physical and mechanical strength of the panels.

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