PRODUCTION OF BOLAINA (*Guazuma crinita* Mart) PLYWOOD GLUED WITH UREA-FORMALDEHYDE AND PHENOL-FORMALDEHYDE RESINS

Milciades Leónidas Miguel Castror[1*], Setsuo Iwakiri[2*], Rosilani Trianoski[2], Héctor Enrique Gonzales Mora[1]

[1] Faculty of Forestry Sciences of the National Agrarian University – La Molina (UNALM), Lima, Peru – lmiguel@lamolina.edu.pe; egonzales@lamolina.edu.pe
[2] Faculty of Forestry Engineering and Technology of the Federal University of Paraná, Curitiba, Paraná, Brazil – setsuo@ufpr.br[*]; rosilani@ufpr.br

Received for publication: 04/04/2021 – Accepted for publication:08/12/2021

Resumo

Produção de painéis compensados com madeira de bolaina (Guazuma crinita Mart*) colados com resinas de urea-formaldeído e fenol-frmaldeído para uso interno e externo.* Esta pesquisa teve como objetivo avaliar a qualidade de painéis compensados produzidos com bolaina (*Guazuma crinita* Mart.) e lupuna (*Ceiba pentandra* [L] Gaertn) como espécies de referência. Os painéis foram produzidos com dimensões de 600 mm x 600 mm x 10 mm (cinco camadas), segundo arranjo fatorial (3x2), três composições de lâminas (bolaina, lupuna e bolaina/lupuna) e duas formulações para cada adesivo (A: 45,9% e B: 35,8% dos sólidos totais) para ureia-formaldeído; (B: 40% e C: 34,3%) para fenol-formaldeído, gramatura de 380 g/m^2 em linha de cola dupla, pressão específica de 0,6 MPa, temperatura de 115 ºC e tempo de prensagem de 8 minutos para ureia-formaldeído; e 1,0 MPa, 130 °C e 6 minutos de tempo de prensagem para fenol-formaldeído. O efeito da formulação não influencia significativamente nas propriedades físicas e mecânicas dos painéis, o que representa um aspecto importante do ponto de vista econômico. No entanto, a interação da formulação com as espécies usadas na composição do painel influenciou significativamente nessas propriedades. A resistência ao cisalhamento e o percentual de ruptura da madeira dos painéis atendem aos requisitos mínimos da norma EN 314-2 (1993) para painéis de uso interno e externo, razão pela qual se conclui que a espécie *Guazuma crinita* Mart. atende à viabilidade técnica requerida para produzir painéis compensados para uso interno e externo.

*Palabras-chave***:** compensados, lâminas de madeira, formulação de cola, resistência da linha da cola, pressão específica.

Abstract

Production of bolaina (Guazuma crinita Mart*) plywood, glued with urea-formaldehyde and fenol-formaldehyde resins.* The objective of this research is to evaluate the quality of plywood produced with wood veneers of bolaina (*Guazuma crinita* Mart.) and lupuna (*Ceiba pentandra* [L] Gaertn) as reference species. Panels were produced with the following dimensions: 600 mm x 600 mm x 10 mm (five layers), according to a factorial arrangement of (3x2), with three veneer compositions (bolaina, lupuna, and bolaina/lupuna) and two formulations for each adhesive (A: 45.9% and B: 35.8% of total solids) for urea-formaldehyde; (B: 40% and C: 34.3%) for phenol-formaldehyde, a gramage of 380 g/m^2 in double glue line, a specific pressure of 0.6 MPa, a temperature of 115 ºC, and 8 minutes of pressing time for urea-formaldehyde; and 1.0 MPa, 130 ºC and 6 minutes of pressing time for phenol-formaldehyde. The formulation effect does not have a significant influence on the physical and mechanical properties of the panels, which is an important aspect from an economic viewpoint. However, the interaction with the species used in the composition of the plywood did have a significant influence on said properties. The shear strength and the percentage of failure of the wood used for the panels meet the minimum requirements established in Standard EN 314-2 (1993) for panels for internal and external use, and it is therefore concluded that *Guazuma crinita* Mart. meets the technical feasibility criteria for producing plywood for internal as well as external use.

Keywords: plywood, wood veneer, glue formulation, glue-line strength, specific pressure.

INTRODUCTION

In Peru, 70% of the total volume of raw material extracted from the Amazonian natural forests is used for the production of sawn wood, while 22% is used for the production of plywood, using species such as lupuna (*Ceiba pentandra*) and Capinuri (*Maquira coriaceae* [Karsten] C.C. Berg), which represent 85% of the species used, whereas 15% corresponds to pashaco (*Schizololobium amazonicum* Huber ex. Ducke), copaiba (*Copaifera paupera*), and cumala (*Virola spp*). Unfortunately, the environmental impact, due to this selective extraction of species, has generated restrictions in its demand by the international market, as many countries have started to require certificates of sustainable forest management. In the absence of a policy to promote forest plantations in Peru, businesspeople in the forest sector have begun to invest in forest plantations with native and exotic species, in order to have an additional source of wood supply for manufacturing their products, which would help mitigate the impact produced by overexploitation of the Amazonian natural forests.

The *Guazuma crinita* Mart species has proven to be an excellent alternative for installing forest plantations with native species, due to its good silvicultural behavior, its rapid growth with a harvest period of approximately 7 years, its capacity to manage regrowth up to three times, a wood yield of up to 224 m^3/ha in the eighth year with a growth rate of 28 m^3/ha/year, in addition to the fact that it produces wood with favorable technological characteristics for the production of different timber products (FLORES, 2019; FLORES, 2018). On the other hand, for 2016, the production of bolaina roundwood was 36,465 m^3, which represents 2.52% of the national production, a volume that increased by 3.42% in 2017 (SERFOR, 2018; SERFOR, 2019).

In the production of plywood, factors related to the technology used must be carefully evaluated, and in particular, the physicochemical process of adhesion in the gluing of wood veneers (MARRA, 1992). The type of resin used for gluing needs to be suitable for the use of panels, allowing for urea-formaldehyde for internal and phenol-formaldehyde for external use. Both the formulation of a glue batter and the gramage are parameters that will directly influence the quality of the gluing, as well as the cost of producing the panels (BALDWIN, 1981).

The basic density of the wood is a very important physical property for the production of wood panels, fundamentally in the gluing stage, considering that there is an inverse relationship between the density of the wood and the porosity and penetration action of adhesives on the woody structure, so much so that low-density wood types present greater penetration of the adhesive and could cause a weak glue line (IWAKIRI, 2020). For this reason, it is recommended that the basic density of the species to be laminated should be between 0.38 and 0.70 g/cm^3, and preferably with values close to 0.50 g/cm^3 (ALMEIDA, *et al.*, 2004).

With regard to the chemical properties of the wood, extractives and pH are considered to be the most important values, as they can interfere with the cure of the adhesive during the process of pressing the panel in the hot press, considering that some extractives present in the veneers can hinder the vaporization process and its migration from one glue line to another, and from that line to the edges of the panel, as well as its subsequent release towards the external environment. This process, as it is very slow, will lead to an increase in the internal vapor pressure, which will result in the "explosion" at the moment of opening the press, causing the panel to delaminate (MARRA, 1992). The percentage of extractives present in the wood varies from 1 to 10%, which influences the formation as well as the performance of the adhesive bond, mainly related to the greater or lesser exposure of areas where extractives are concentrated on the surface of the wood to be glued. Due to the migration of the extractives from the internal layers to the surface layers during the drying process of the veneers, the pH of the wood varies from 3 to 6, thus being important because it can inhibit the chemical reactions of polymerization of the adhesive depending on whether an acidic or alkaline medium is needed for the polymerization of the adhesive, impairing the adhesion resistance of the glue lines (IWAKIRI, 2020). The research on the use of bolaina wood (*Guazuma crinita* Mart.) for plywood production, when establishing the chemical characterization of the wood, established an average of total extractives of 1.80% and a pH of 6.76 (MIGUEL, *et al.*, 2019).

The objective of this research is to assess the potential use of the wood obtained from *Guazuma crinita* Mart. trees for the production of plywood and veneers for internal and external use, with two formulations and different compositions of veneers in the panel structure, using *Ceiba pentandra* (L) Gaertn as a reference species.

MATERIALS AND METHODS

To conduct the research, 4 *Guazuma crinita* Mart trees obtained from an experimental 15-year old plantation located in the district of Manantay, in the province of Coronel Portillo, and in the department of Ucayali were used, as well as lupuna veneers (*Ceiba pentandra* (L) Gaertn), donated by Industrial Ucayali SAC, a company based in the city of Pucallpa, which is the capital of the department of Ucayali, Peru, with the following coordinates: Latitude 08 ° 25'25 "SW and Longitude 74 ° 32'40" WO.

The basic density of the wood was determined as established in Standard NTP 251.011 (2014), while the chemical properties of the wood were based on Standard TAPPI T 204 (2017) for total extractives, and on Standard TAPPI 252 (2016) for the pH of the wood.

The 2.2 mm thick veneers were obtained by unwinding. They were then dried at a moisture content of 6 to 8%, and guillotined to final dimensions of 600 mm x 600 mm or submultiples of these dimensions. Following production control, they were sent to the Forest Products Laboratory of the National Agrarian University – La Molina (UNALM, for its Spanish acronyms).

In the laboratory, the veneers were classified and dried to an average moisture content of 10% for gluing with urea-formaldehyde (UF), and 6% for gluing with phenol-formaldehyde (FF). Urea-formaldehyde resins with 65% solids content, Brookfield viscosity of 450 cP and a pH value of 8, as well as phenol-formaldehyde resins with 46% solids content, Brookfield viscosity of 350 cP and pH of 12, were used.

The panels were produced at laboratory scale, with a nominal thickness of 11 mm, and three repetitions per treatment. The results were subjected to statistical analysis using Shapiro Wilk, Bartlett, and ANOVA tests, in a 3x2 factorial arrangement, with three panel compositions: 100% bolaina, 100% lupuna, and 60% bolaina and 40% lupuna; and two formulations: A: 45.8% and B: 35.8% of total solids content for urea-formaldehyde, and B: 40% and C: 34% of total solids for phenol-formaldehyde. After rejecting the null hypothesis, the Tukey test was applied for the comparison of means, and with a confidence level of 95%. The following variables were analyzed: panel thickness, apparent density, moisture content, water absorption, swelling, and swelling plus thickness recovery, glue-line shear strength, as well as MOE and MOR in static bending.

Three panels were prepared for each treatment, using urea-formaldehyde and phenol-formaldehyde resins with two formulations per resin, as shown in Table 1.

Table 1. Formulations used for urea-formaldehyde and phenol-formaldehyde resins
Tabela 1. Formulações usadas para as resinas de uréia-formaldeído e fenol-formaldeído

Formulation	**UF**		**FF**	
(parts/weight)	**A**	**B**	**B**	**C**
Resin	100	100	100	100
Wheat flour	20	40	10	20
Water	20	40	10	20
Catalist	1,5	1,7	-	-
TS (%)	45,9	35,8	40,0	34,28

UF: urea-formaldehyde; FF: phenol-formaldehyde; TS: total solids content.

Five veneers per panel were glued using a gramage of 380 g/m^2 in double glue line. Pressing was carried out with a specific pressure of 0.6 MPa, a temperature of 115 ºC, and a pressing time of 8 minutes for urea-formaldehyde, and 1.0 MPa, 130 °C and 6 minutes of pressing time for phenol-formaldehyde.

Following a period of acclimatization of the panels with a temperature of 20± 2°C and relative humidity of 65±%, test pieces were obtained in order to evaluate the following properties: water absorption, swelling, swelling plus recovery of thickness, according to Technical Standards NBR 9486 (2011c) and NBR 9535 (2011d), glue-line shear strength according to the procedures described in European Standards EN 314-1 (2004) and EN 314-2 (1993), and static bending (modulus of rupture and modulus of elasticity), according to the procedure described in European Standard EN 310 (1993).

The results were subjected to statistical analysis using Shapiro Wilk, Bartlett, and ANOVA tests, in a 3x2 factorial arrangement. After rejecting the null hypothesis, the Tukey test was applied for the comparison of means, with a confidence level of 95%.

RESULTS

Basic Density and Chemical Properties of the Wood

Table 2 shows the average values and coefficient of variation of the basic specific mass, the percentage of total extractives, and the pH value of *Guazuma crinita* and *Ceiba pentandra* wood.

Table 2. Average basic density, extractives, and pH values of bolaina and lupuna wood
Tabela 2. Valores médios de densidade básica, extrativos e pH da madeira de bolaina e lupuna

Characteristic	**Bolaina**	**Lupuna**
Specific mass (g/cm^3)	0,42 (6,88)	0,35 (7,10)
Total extractives (%)	4,20 (1,47)	3,25 (0,54)
pH	5,88 (1,45)	5,99 (4,02)

The values between brackets refer to the variation coefficient.

Thickness, Apparent Density, Moisture Content and Compaction

The mean thickness, apparent density, moisture content, and compaction values of the panels are shown in Table 3.

Table 3. Mean thickness, apparent density, moisture content, and compaction values of the panels
Tabela 3. Valores médios de espessura, densidade aparente, teor de umidade e compactação dos painéis

Treatment	E (mm)	CV (%)	Dap (g/m^{-3})	CV (%)	CH (%)	CV (%)	CP (%)	CV (%)
A	9,99a^{ns}	5,30	0,56a^{ns}	4,51	13,95^{a}	4,77	15,62a^{ns}	27,98
B	10,22a^{ns}	5,42	0,55a^{ns}	6,17	13,01^{b}	8,68	10,99a^{ns}	55,73
T1.UF/A/Bo	10,18^{abc}	2,82	0,58^{a}	3,22	13,88^{a}	3,25	16,15^{ab}	22,95
T2.UF/A/Lu	9,40^{c}	2,87	0,53^{bc}	3,42	14,23^{a}	5,52	18,95^{a}	6,26
T3.UF/A/Bo-Lu	10,40^{a}	3,63	0,56^{ab}	0,15	13,75^{a}	6,36	11,77^{abc}	39,93
T4.UF/B/Bo	10,76^{a}	3,28	0,58^{a}	0,93	13,63^{a}	6,62	5,21^{c}	61,16
T5.UF/B/Lu	9,59^{bc}	1,33	0,51^{c}	0,35	11,71^{b}	4,81	18,43^{c}	5,71
T6.UF/B/Bo/Lu	10,30^{ab}	2,28	0,56^{ab}	2,69	13,71^{a}	2,63	9,33b^{c}	12,62
B	8,81a^{ns}	8,58	0,58a^{ns}	4,54	13,54^{a}	6,90	23,78a^{ns}	34,83
C	9,17a^{ns}	8,22	0,56a^{ns}	549,	11,29^{b}	6,74	22,22a^{ns}	37,23
T7.FF/B/Bo	9,77^{a}	1,40	0,59^{a}	6,66	13,13^{ab}	12,6	13,90^{b}	23,81
T8.FF/B/Lu	8,20^{b}	3,64	0,56^{a}	3,19	13,94^{a}	2,42	31,15^{a}	15,50
T9.FF/B/Bo-Lu	8,44^{b}	2,02	0,59^{a}	4,70	13,54^{a}	2,77	26,27^{a}	6,50
T10.FF/C/Bo	9,90^{a}	5,65	0,58^{a}	3,93	11,29^{bc}	3,38	13,02^{b}	43,35
T11.FF/C/Lu	8,44^{b}	4,84	0,55^{a}	5,25	12,00^{abc}	4,81	29,63^{a}	5,46
T12.FF/C/Bo-Lu	9,17^{ab}	4,90	0,54^{a}	6,17	10,58^{c}	5,46	24,00^{ab}	20,83

A & B: formulations with urea-formaldehyde; B & C: formulations with phenol-formaldehyde; E: thickness; Dap: apparent density; CH: moisture content; CP: compaction; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

Absorption, Swelling and Swelling plus Thickness Recovery

Table 4 shows the mean absorption, swelling, and swelling plus thickness recovery values of the panels.

Table 4. Results for absorption, swelling, and swelling plus thickness recovery of the panels
Tabela 4. Resultados da absorção, inchamento e inchamento além da recuperação da espessura dos painéis

Treatment	A (mm)	CV (%)	H (%)	CV (%)	IR (%)	CV (%)
A	35,68 a^{ns}	21,86	8,74 a^{ns}	36,48	2,49 a^{ns}	108,40
B	37,40 a^{ns}	28,63	8,55 a^{ns}	23,53	2,20 a^{ns}	91,98
T1.UF/A/Bo	31,18 a	8,70	7,18 a	24,14	2,59 a	76,34
T2.UF/A/Lu	45,11 b	13,30	9,80 b	19,81	2,05 a	83,14
T3.UF/A/Bo-Lu	31,19 a	11,35	9,24 c	52,12	2,84 a	147,76
T4.UF/B/Bo	27,42 c	11,62	7,38 a	20,49	2,40 a	90,79
T5.UF/B/Lu	49,60 d	15,25	10,28 b	23,16	2,57 a	112,09
T6.UF/B/Bo/Lu	35,17 e	13,30	7,99 c	5,44	1,64 a	35,62
B	43,95 a	29,23	13,48 a^{ns}	72,28	5,65 a^{ns}	78,17
C	50,15 b	26,25	10,92 a^{ns}	30,25	4,48 a^{ns}	62,09
T7.FF/B/Bo	34,53 a	13,94	6,59 a	15,83	2,24 a	33,48
T8.FF/B/Lu	60,53 b	21,79	22,37 b	55,03	10,24 b	40,40
T9.FF/B/Bo-Lu	45,72 c	22,63	11,48 c	31,83	4,46 c	62,16
T10.FF/C/Bo	34,00 a	14,37	7,10 a	14,21	1,51 d	69,86
T11.FF/C/Lu	60,94 d	13,24	14,0 d	13,58	6,46 e	33,35
T12.FF/C/Bo-Lu	49,43 e	15,45	11,65 c	14,69	5,46 f	36,97

A & B: formulations with urea-formaldehyde; B & C: formulations with phenol-formaldehyde; AA: absorption; H: swelling; IR: swelling plus thickness recovery; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

Results for Panels glued with Urea-formaldehyde (UF)

Glue-Line Shear Strength

Table 5 shows the mean glue-line shear strength values, as well as the percentage of failure of the wood, obtained in both dry and wet (obtained after 24h immersion in water) conditions.

Table 5. Glue-line shear strength for UF panels
Tabela 5. Resistência ao cisalhamento da linha de cola em painéis com UF

Treatment	dry				24h immersion in water			
	RLC (MPa)	CV (%)	FM (%)	CV (%)	RLC (MPa)	CV (%)	FM (%)	CV (%)
A	2,16a[ns]	46,27	84,80a[ns]	30,04	1,99a[ns]	46,43	83,37a[ns]	31,79
B	2,39a[ns]	48,70	86,16a[ns]	25,24	1,89a[ns]	52,84	78,82a[ns]	37,76
T1.UF/A/bo	2,58[a]	45,23	68,82[a]	51,58	2,61[a]	30,88	64,17[a]	51,94
T2.UF/A/lu	1,89[b]	40,01	96,25[b]	7,35	1,82[b]	48,18	99,06[b]	2,99
T3.UF/A/bo-lu	2,00[b]	45,41	89,72[c]	17,37	1,54[cd]	49,00	88,61[c]	20,03
T4.UF/B/bo	2,98[c]	45,34	76,29[ab]	39,72	2,54[e]	44,86	67,50[ab]	52,09
T5.UF/B/lu	1,88[b]	41,62	92,50[d]	12,00	1,45[cd]	28,11	95,67[d]	8,97
T6.UF/B/bo-lu	2,22[d]	44,40	90,83[cd]	14,97	1,61[d]	54,47	76,11[e]	38,88

A & B: formulations with urea-formaldehyde; RLC: glue-line shear strength; FM: percentage of failure of the wood; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

Parallel and Perpendicular Static Bending

The mean values of the modulus of elasticity (MOE) and the modulus of rupture (MOR) are shown in Table 6.

Table 6. Parallel and perpendicular static bending results – UF
Tabela 6. Resultados de flexão estática paralela e perpendicular – UF

Treatment	Parallel Direction				Perpendicular Direction			
	MOE (MPa)	CV (%)	MOR (MPa)	CV (%)	MOE (MPa)	CV (%)	MOR (MPa)	CV (%)
A	5118a[ns]	27,83	53,31a[ns]	22,59	1717,9a[ns]	22,37	26,51a[ns]	37,88
B	5355a[ns]	29,35	54,84a[ns]	26,01	1729,5a[ns]	33,01	24,15a[ns]	24,27
T1.UF/A/bo	5989[a]	16,76	56,61[a]	20,69	1989,0[a]	18,20	30,98[a]	20,70
T2.UF/A/lu	3813[b]	12,37	40,50[b]	12,37	1309,9[b]	9,14	25,12[b]	61,39
T3.UF/A/bo-lu	5444[c]	28,54	61,75[c]	8,22	1854,9[c]	11,09	23,43[c]	11,86
T4.UF/B/bo	5926[a]	27,21	63,34[d]	15,74	2224,0[d]	17,27	28,77[d]	21,49
T5.UF/B/lu	3806[b]	22,49	37,79[e]	18,08	1097,8[e]	25,38	18,82[e]	10,26
T6.UF/B/bo-lu	6333[d]	11,28	63,38[cd]	11,28	1866,8[c]	16,04	24,86[f]	14,18

A & B: formulations with urea-formaldehyde; MOR: modulus of rupture; MOE: modulus of elasticity; Pa: parallel; Pe: perpendicular; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

Panels glued with Phenol-formaldehyde Resin

Glue-Line Shear Strength

The mean glue-line shear strength values, as well as the percentage of failure of the wood, in both wet conditions (obtained after 24h immersion in water) and after boiling for 6 hours, are shown in Table 7.

Table 7. Glue-line shear strength for FF panels

Tabela 7. Resistência ao cisalhamento da linha de cola em painéis com FF

Treatment	24h immersion in water				6h boiling			
	RLC (MPa)	CV (%)	FM (%)	CV (%)	RLC (MPa)	CV (%)	FM (%)	CV (%)
B	1,83^{a}	60,26	70,90a^{ns}	44,59	1,62a^{ns}	70,68	59,05^{a}	56,31
C	1,44^{b}	68,83	76,84a^{ns}	37,68	1,22a^{ns}	81,40	80,10^{b}	34,18
T7.FF/B/bo	2,34^{a}	54,01	51,18^{a}	63,23	2,13^{a}	60,98	42,06^{a}	72,11
T8.FF/B/lu	1,47^{b}	42,48	86,92^{bc}	19,01				
T9.FF/B/bo-lu	1,26^{c}	48,48	94,00^{d}	7,24	1,03^{b}	47,99	78,97^{b}	31,08
T10.FF/C/bo	2,14^{d}	60,61	50,83^{a,b}	63,68	2,11^{c}	53,79	57,78^{c}	55,99
T11.FF/C/lu	0,99^{e}	23,04	90,34^{c}	11,64	0,84^{d}	39,27	90,34^{d}	16,06
T12.FF/C/bo-lu	1,08^{f}	45,46	93,33^{d}	10,26	0,64^{e}	65,72	95,45^{e}	6,67

B & C: formulations with phenol-formaldehyde; RLC: glue-line shear strength; FM: percentage of failure of the wood; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

Parallel and Perpendicular Static Bending

Table 8 shows the mean values of modulus of elasticity (MOE) and modulus of rupture (MOR) values.

Table 8. Parallel and perpendicular static bending results – FF
Tabela 8. Resultados de flexão estática paralela e perpendicular – FF

Treatment	Parallel Direction				Perpendicular Direction			
	MOE (MPa)	CV (%)	MOR (MPa)	CV (%)	MOE (MPa)	CV (%)	MOR (MPa)	CV (%)
B	5101a^{ns}	31,75	45,83a^{ns}	35,39	1341a^{ns}	59,46	22,87a^{ns}	46,53
C	5613a^{ns}	31,10	51,94a^{ns}	31,19	1569a^{ns}	43,73	24,85a^{ns}	40,70
T7.FF/B/bo	5462^{ab}	29,83	56,98^{a}	33,12	2266,0^{a}	28,49	35,22^{a}	23,70
T8.FF/B/lu	4933^{abc}	20,47	40,80^{b}	20,47	919,0^{b}	60,40	16,30^{b}	27,73
T9.FF/B/bo-lu	4883^{bc}	36,70	39,04^{bc}	29,06	850,4^{b}	32,70	16,39^{c}	26,56
T10.FF/C/bo	77037^{a}	14,52	68,81^{d}	9,93	2263,0^{a}	16,16	34,77^{a}	17,19
T11.FF/C/lu	3735^{c}	33,64	36,73^{c}	25,59	1424,0^{c}	47,13	21,21^{d}	50,65
T12.FF/C/bo-lu	5910^{ab}	23,52	49,00^{e}	23,52	1031,9^{d}	21,71	18,86^{e}	17,51

B & C: formulations with phenol-formaldehyde; MOR: modulus of rupture; MOE: modulus of elasticity; Pa: parallel; Pe: perpendicular; CV: coefficient of variation. The means followed by the same letter in the same column are statistically equal, based on the Tukey test at 95% probability.

DISCUSSION

Basic Density and Chemical Properties of the Wood

The average basic density for *Guazuma crinita* was 0.42 g/cm^3, which is similar to the value obtained by Acevedo and Kikata (1994) of 0.41 g/cm^3 and by Miguel *et al*. (2019), of 0.42 g/cm^3. The average basic density for *Ceiba pentandra* was 0.35 g/cm^3, which was higher than the value determined by Flores (2019) of 0.28 g/cm^3, classifying them as low-density woods. However, the values are within the range of 0.38 to 0.70 g/cm^3 recommended by Almeida *et al*. (2004), for the woods used in the production of plywood.

With regard to the results of the chemical characteristics of bolaina wood, the mean total extractives value of 4.20%, is within the range of 1 to 10% recommended by Iwakiri (2020), and higher than the value determined by Miguel *et al*. (2019), which is of 1.80% for four-year-old bolaina wood. The mean pH value was of 5.88, which is within the range of 3 to 6 recommended by Iwakiri (2020). In lupuna, the percentage of extractives obtained of 3.25% and the pH value of 5.99 are within the ranges recommended by Iwakiri (2020).

Thickness, Apparent Density, Moisture Content and Compaction

The results obtained from the variance analysis in factorial arrangement show that the effect of the formulation, as well as the interaction of both the formulation and species variables used in the panel composition, do not have a significant statistical influence on the mean thickness and apparent density values.

The average thickness for panels glued with urea-formaldehyde varies from 9.40 to 10.76 mm and from 8.20 to 9.77 mm for panels glued with phenol-formaldehyde, noting that the highest values correspond to the bolaina and bolaina/lupuna panels, and the lowest values to the lupuna panels, which is attributed to the use of the same specific pressure for species of different basic densities, i.e. 0.42 g/cm^3 for bolaina and 0.35 g/cm^3 for lupuna.

The apparent density results for the panels glued with urea-formaldehyde vary from 0.51 to 0.58 g/cm^3 with a compaction percentage of 18.43% and 16.15%, and from 0.54 to 0.59 g/cm^3 with a compaction of 24.00% and 26.27%, for panels glued with phenol-formaldehyde. The Brazilian Association of the Mechanically Processed Wood Industry (ABIMCI, for its Portuguese acronym) (2007), establishes a minimum density value of 0.476 g/cm^3 for pine panels with a thickness of 12 mm and five layers. All of the panels exceeded this value. The average increase in the density of the panels glued with urea-formaldehyde, compared to the density of the wood was 23.6% for bolaina and 36.4% for lupuna, while in the panels glued with phenol-formaldehyde, the increase in density was 26.3% for bolaina and 38.6% for lupuna. This can be explained by the use of the same specific pressure during pressing of the panels at 0.6 MPa and 1.0 MPa for panels glued with urea-formaldehyde and phenol-formaldehyde, respectively, for different basic densities.

The moisture content results ranged from 11.71 to 14.23% for the panels glued with urea-formaldehyde and from 10.58 to 13.94% for the panels glued with phenol-formaldehyde. Except for T5 (UF) and T10, T11, and T12 (FF), the results for all panels glued with urea-formaldehyde and phenol-formaldehyde exceeded the minimum value of 12% suggested by ABIMCI (2007).

Absorption, Swelling and Swelling plus Thickness Recovery

The results obtained from the variance analysis in factorial arrangement show that the formulation effect does not have a significant statistical influence on the mean absorption, swelling, and swelling plus thickness recovery values.

The interaction between formulation and species used in producing the panels, does influence the absorption and swelling results, but not the swelling plus thickness recovery. The mean absorption values for panels glued with urea-formaldehyde ranged from 27.42 to 49.60%, and from 34.00 to 60.94% for panels glued with phenol-formaldehyde, noting that the highest value was obtained by the lupuna panels and the lowest value by the bolaina panels, which is attributed to the higher porosity of lupuna compared to bolaina, due to its lower basic density. The swelling results varied from 7.18 to 10.28% in the panels glued with urea-formaldehyde and from 6.59 to 14.0% in the panels glued with phenol-formaldehyde; the highest value is obtained by the lupuna panels and the lowest value by the bolaina panels, which is related to the absorption results. The results of swelling plus thickness recovery varied from 1.54 to 2.84% in the panels glued with urea-formaldehyde and from 6.59 to 14.0% in the panels glued with phenol-formaldehyde, noting that the highest value corresponds to the bolaina/lupuna panels, and the lowest value to the lupuna panels, for the panels glued with urea-formaldehyde; and from 1.51 to 10.24% for the panels glued with phenol-formaldehyde. The highest value is obtained by the lupuna panels and the lowest by the bolaina panels, which is related not only to the greater absorption and swelling, but also to the higher compaction values.

Results for Panels glued with Urea-formaldehyde (UF)

Glue-Line Shear Strength

The results obtained show that the formulation effect does not exert a significant statistical influence on the glue-line shear strength and the percentage of failure of the wood, which is a result that can be considered very important from an industrial point of view, as, according to Marra (1992), the amount of the adhesive must be conditioned to the cost, use, and minimum strength required. The average dry shear-strength values vary from 1.88 to 2.98 MPa, with an average percentage of failure of the wood of 92.50 and 76.29%, respectively; the highest value corresponds to the bolaina panels and the lowest value to the lupuna panels. These results were higher than the mean values found by Iwakiri *et al*. (2012a), from 1.00 to 1.36 MPa, for panels from *Sequoia sempervirens*, and within the range obtained by Trianoski *et al*. (2015), from 2.06 to 3.73 MPa, in the production of panels from *Melia azederach* L. The average of the wet shear-strength values (24h immersion in water), varied from 1.45 to 2.61 MPa, with a percentage of failure of 95.67 and 64.17%, respectively; the highest values corresponded to the bolaina panels and the lowest values to the lupuna panels. These results are higher than the mean values established by Iwakiri *et al*. (2012a), of 1.17 MPa with a percentage of failure of the wood of 23%, for panels from *Pinus taeda,* and by Iwakiri *et al*. (2012b), which range from 0.62 to 1.25 MPa, with a percentage of failure of 20% and 68.5%, respectively, for panels from *Sequoia sempervirens*. Likewise, it should be noted that the average glue-line shear strength values obtained for the bolaina and lupuna panels comply with the minimum requirements established by European Standard EN 314-2 (1993) for panels for interior use, which range from 0.6 to 1.0 MPa, associated with a percentage of failure of the wood higher than 40%; all treatments resulted in a percentage of failure exceeding 64%.

Parallel and Perpendicular Static Bending

The results obtained show that the formulation effect (A and B) does not have a significant statistical influence on the modulus of elasticity and the modulus of rupture in both parallel and perpendicular directions. This result can be considered very important from an industrial point of view, as it allows for maximizing productivity and minimizing product costs, so the quantity of the adhesive must be conditioned to the cost, use, and minimum strength required, (MARRA, 1992). Considering the interaction of the two variables formulation and species used in the composition of the panel, for parallel MOE, they do not significantly influence the treatments (T1xT4 and T2xT5), with the exception of (T3xT6) where there is a significant influence. The average parallel MOE varies from 3813 to 6333 MPa; the highest value corresponds to the bolaina panels and the lowest value to the lupuna panels, which is attributed to the basic density value of bolaina (0.42 g/cm^3), which is higher than that of lupuna (0.35 g/cm^3). Regarding the parallel MOR, interaction of the variables significantly influences the mean values of these properties (T1xT4 and T2xT5), with no significant differences in the T3xT6 and T4xT6 interactions. The average parallel MOR varies from 37.79 to 63.38 MPa. The highest value corresponds to the bolaina panels, while the lowest value corresponds to the lupuna panels, which is attributed to the basic density of the bolaina, which is higher compared to the values obtained by Iwakiri *et al*. (2011) from 3444 to 4234 MPa for the MOE and 23.4 to 33.2 MPa for the MOR, in the production of panels using *Schizolobium amazoninicum*.

As the European standard does not establish minimum values for the modulus of rupture and the modulus of elasticity, the values obtained from *Guazuma crinita* were compared with the data available for panels from *Pinus taeda* glued with urea-formaldehyde resin. According to the technical catalog of the Brazilian Association of the Mechanically Processed Wood Industry (ABIMCI, 2002), the mean values of MOE and parallel MOR of the commercial panels produced with *Pinus taeda*, with a specific mass of 0.53 g/cm^3, are 6890 MPa and 38.1 MPa, respectively. Therefore, the parallel MOE values obtained for the bolaina and lupuna panels can be considered satisfactory, whereas the MOR values are higher than the reference values.

As for perpendicular MOE values, the formulation and species interaction used in the composition of the panels significantly influence the treatments (T1xT4 and T2xT5) and (T3xT6). The average perpendicular MOE ranges from 1097.8 to 2224.0 MPa. The highest value is obtained by the bolaina panels and the lowest value by the lupuna panels, which is attributed to the higher basic density of bolaina (0.42 g/cm^3), which is higher than the value obtained by lupuna (0.35 g/cm^3). For perpendicular MOR, the formulation and species interaction used in the composition of the panels significantly influence the treatments (T1xT4 and T2xT5) and (T3xT6). The average perpendicular MOR varies from 18.82 to 30.98 MPa, where the highest value corresponds to the bolaina panels and the lowest value to the lupuna panels, which is attributed to the higher basic density of bolaina, with values that are higher than those obtained by Iwakiri *et al*. (2011) from 1304 to 1586 MPa for the MOE and 11.2 to 19.1 MPa for the MOR, in the production of panels from *Schizolobium amazoninicum*. According to the technical catalog of ABIMCI (2002), the mean MOE and perpendicular MOR values of the commercial *Pinus taeda* panels are 2839 MPa and 25.3 MPa, for a specific mass of 0.53 g/cm^3. Therefore, the perpendicular MOE values obtained for the bolaina and lupuna panels can be considered satisfactory, whereas the bolaina MOR values of 30.98 MPa and 28.77 MPa are higher than the reference values.

Panels glued with Phenol-formaldehyde Resin

Glue-Line Shear Strength

The results obtained show that the formulation effect (B and C) does exert a significant statistical influence on the glue-line shear strength and the percentage of failure of the wood, obtaining an average glue-line shear strength value of 1, 83 MPa for formulation B and 1.44 MPa for formulation C, with an average percentage of failure of 70.90 and 76.84%, for the wet test (24h immersion in water) and 1.22 a 1.62 MPa, with a percentage of failure of 80.10 and 59.05%, respectively, for the test after boiling. Likewise, the interaction of the two variables formulation and species used in the composition of the panel significantly influence the shear strength values of the glue line of the panels. The mean wet shear values (24h immersion in water) vary from 0.99 to 2.34 MPa, with an average percentage of failure of the wood of 90.34 and 51.18%, respectively. The highest value is obtained by the bolaina panels and the lowest value by the lupuna panels, while the average results were higher than the values found by Iwakiri *et al*. (2013), from 1.13 to 1.37 MPa, for phenolic panels produced with *Sequoia sempervirens*. The average of the shear values in the boiling test (6 hours) ranged from 0.64 to 2.13 MPa, with a percentage of failure of 95.45 and 60.98%. The highest value corresponds to the bolaina panels and the lowest value to the lupuna panels, while the average results were higher than the average values found by Iwakiri *et al.* (2013); from 0.66 to 0.94 MPa for phenolic panels from *Sequoia sempervirens.*

and by Iwakiri *et al*. (2011), which range from 0.67 to 0.84 MPa for panels from *Shizolobium amazonicum*. Likewise, it should be noted that the mean glue-line shear strength values obtained for panels produced with bolaina and lupuna, comply with the minimum requirements established by European Standard EN 314-2 (CEN, 1993) for panels for outdoor use, which range from 0.6 to 1.0 MPa, associated with a percentage of failure of the wood higher than 40%; all treatments corresponded to a percentage of failure of the wood exceeding 42%.

Parallel and Perpendicular Static Bending

The results obtained show that the formulation effect (B and C) does not have a significant statistical influence on the modulus of rupture and the modulus of elasticity in both parallel and perpendicular directions. This result can be considered very important from an industrial viewpoint, because it allows for maximizing productivity and minimizing the costs of the product (MARRA, 1992). Considering the interaction of the formulation and species variables used in the composition of the panel, for parallel MOE, it is observed that the species variable does not significantly influence the treatments (T7xT10, T8xT11, and T9XT12). The average parallel MOE value varies from 3735 to 7037 MPa. The highest value is obtained by the bolaina panels and the lowest value by the lupuna panels, which is attributed to the higher basic density of bolaina. For parallel MOR, the interaction of the variables significantly influences the results of the treatments (T7xT10, T8xT11, and T9xT12). The average parallel MOR value varies from 36.73 to 68,81 MPa; the highest value corresponds to the bolaina panels, while the lowest value corresponds to the lupuna panels, which is attributed to the higher basic density of bolaina.

According to the technical catalog of ABIMCI (2002), the mean MOE and parallel MOR values of commercial panels produced with *Pinus taeda* are 6890 MPa and 38.1 MPa. For a specific mass of 0.53 g/cm^3, the MOE values were lower than the values registered for *Pinus taeda*. However, the MOR values were higher, except for the lupuna panels of formulation C.

As for perpendicular MOE values and the formulation and species interaction, a significant influence can be observed of the species variable in the results obtained in the treatments (T8xT11 and T9xT12), while there is no influence of the species in the results obtained from the treatments (T7xT10). The average perpendicular MOE value varies from 850.4 to 2266.0 MPa, where the highest value is obtained by the bolaina panels and the lowest value is obtained by the bolaina/lupuna panels, which is attributed to the higher basic density of bolaina. As for perpendicular MOR values and the formulation and species interaction used in the panel composition, it is observed that there is a significant influence of the species variable in the results obtained in the treatments (T8xT11 and T9xT12), while there is no influence of the species in the results obtained in the treatments (T7xT10). The average perpendicular MOR value ranges from 16.30 to 35.22 MPa. The highest value corresponds to the bolaina panels and the lowest value to the lupuna panels, which is due to the higher basic density of bolaina. According to the technical catalog of ABIMCI (2002), the mean values of MOE and perpendicular MOR of the commercial *Pinus taeda* panels are, respectively, 2839 MPa and 25.3 MPa, for a specific mass of 0.53 g/cm^3. The MOE and MOR values obtained were lower than those obtained for *Pinus taeda*, except for the MOR of the bolaina panels, which registered values higher than those of *Pinus taeda*, and therefore, the values obtained for the bolaina and lupuna panels can be considered satisfactory, taking into account the lower specific mass of bolaina (0.42 g/cm^3) and lupuna (0.35 g/cm^3).

CONCLUSIONS

- Based on the comparisons made with *Pinus taeda*, the most commercially used species, data from the literature and the requirements established in European Standards EN 314-1: 2004 and EN 314-2: 1993 for glue-line shear strength, *Guazuma crinita* Mart. presents high technical feasibility as a species for the production of plywood for both interior and exterior use.
- The formulation effect does not have a statistically significant influence on the physical and mechanical properties of the panels.
- The formulation and species interaction of the panel composition does have an influence on the results of the physical and mechanical properties of the panels.
- Panels produced with *Guazuma crinita* Mart. present the best results in terms of physical properties, glue-line shear strength, and resistance to static bending, due to which it is recommended for the production of plywood and veneers glued with either urea-formaldehyde or phenol-formaldehyde resins.

REFERENCES

ACEVEDO, M., KIKATA, Y. **Woods Atlas of Peru**. Lima, La Molina National Agrarian University -Perú, Nagoya University, 1994.

ALMEIDA, R., BORTOLETO JR., JANKOWSKY, I. Production of blades from the wood of clones of the hybrid Eucaliyptus grandis x Eucalyptus urophila. **Scientia Forestalis**. n.65, p. 49-58. 2004.

BRAZILIAN ASSOCIATION OF MECHANICALLY PROCESSED WOOD INDUSTRY (ABIMCI). **Pine plywood panels**. Technical catalogue. Curitiba, Brazil. 2002.

BRAZILIAN ASSOCIATION OF TECHNICAL STANDARDS (ABNT). **NBR 9486**: Offset: determination of water absorption. Rio de Janeiro, Brazil.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 9535**: Compensado: determinação da em espessura e inchamento mais recuperação em espessura. Rio de Janeiro, Brasil. 2011.

BALDWIN, R. **Plywood manufacturing practices**. San Francisco, Estados Unidos. Miller Freeman, 1981.

EUROPEAN COMMITTEE FOR STANDARDIZATION. **EN 310:1993**: Wood based panels - Determination of modulus of elasticity and modulus of rupture in static bending and of bending strength. Brussels. 1993.

EUROPEAN COMMITTEE FOR STANDARDIZATION. **EN 314-1:2004** – Plywood bonding quality. Part 1: Test methods. Brussels. 2004.

EUROPEAN COMMITTEE FOR STANDARDIZATION. **EN 314-2:1993**: Plywood – Determination of shear bonding strength. Parte 2: Test. Brussels. 1993.

FLORES, Y. **Fichas técnicas para plantaciones con especies nativas en zona de selva baja**. Instituto Nacional de Innovación Agraria, Lima, Perú. 2019.

FLORES, Y. **Árboles nativos de la Región Ucayali**. Estación Experimental Agraria Pucallpa, Perú. 2018.

INSTITUTO NACIONAL DE LA CALIDAD (INACAL). **NTP 251.011**. Madera. Método para determinar la densidad. Lima, Perú. 2014.

INSTITUTO NACIONAL DE LA CALIDAD (INACAL). **NTP 251.040**. Madera. Tableros de madera contrachapados. Clasificación por sus caras. Lima, Perú. 2019.

IWAKIRI, S., TRIANOSKY. R, **Painéis de Madeira Reconstituída**. Curitiba, Brasil. 2020.

IWAKIRI, S., CUNHA, A. B., PRATA, J. G., BRAZ, R. L., CASTRO, V.G., KAZMIERCZAK S., PINHEIRO, E., RANCATTI, H., SANCHES, F. L., Produção de painéis compensados com lâminas de madeira de *sequoia sempervirens* e resina ureia formaldeído. **Revista Floresta**, Curitiba, PR, v. 42, n. 4, p. 809 – 816. 2012a.

IWAKIRI, S., CUNHA, A. B., TRIANOSKI, R., BRAZ, R. L., CASTRO V. G., KAZMIERCZAK S., PINHEIRO, E., RANCATTI, H., SANCHES F. Produção de Painéis Compensados Fenólicos com Lâminas de Madeira de *Sequoia sempervirens*. **Floresta e Ambiente**. 20(2):264-270. 2013

IWAKIRI, S., VARGAS, C. A., PARCHEN C. F. A., WEBER, C., BATISTA, C. C., GARBE, E. A., CIT, E. J., PRATA, JG. Avaliação da qualidade de painéis compensados produzidos com lâminas de madeira de *schizolobium amazonicum*. **Revista Floresta**, Curitiba, PR. v.41, n.3, p. 451-458. 2011.

IWAKIRI, S., SANCHES, F., POTULSKI, D., DA SILVA, J., DE ANDRADE, M., MARCHESAN, R. Avaliação do potencial de uso de espécies de pinus tropicais e eucalipto na produção de painéis compensados uréicos. **Revista Floresta**, Curitiba, PR. v. 42, n. 2, 277 - 284. 2012b.

MARRA, A. **Technology of wood bonding: principles in practice**. New York, Estados Unidos. 1992.

MIGUEL, M., IWAKIRI, S., TRIANOSKI, R., GONZALES, H., MIGUEL, C. Producción de tableros de partículas con Bolaina (*Guazuma crinita* Mart) procedente de una plantación de cuatro años. **Revista Ciência da Madeira**, 10(2): 197-204, 2019. DOI: 10.12953/2177-6830/rcm. v10n3p197-204

SERVICIO NACIONAL FORESTAL Y DE FAUNA SILVESTRE (SERFOR). **Anuario Forestal y de fauna silvestre 2016.** Ministerio de Agricultura y Riego. Perú. 2018.

SERVICIO NACIONAL FORESTAL Y DE FAUNA SILVESTRE (SERFOR). **Anuario Forestal y de fauna silvestre 2017.** Ministerio de Agricultura y Riego. Perú. 2019.

TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRIA. **TAPPI T 252 om-16**: pH an electrical conductivity of water extracts of pulp, paper, and paperboard. Atlanta, Estados Unidos. 2016.

TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRIA. **TAPPI T 204 om-17**: Solvent extractives of Wood and Pulp. Atlanta, Estados Unidos. 2017.

TRIANOSKI, R., IWAKIRI, S., MATOS, J., HIGA, A., BRAZ, R. L. Avaliação das propriedades de painéis compensados de *Melia azedarach* produzidos com diferentes gramaturas e tempos de prensagem. **Revista Árvore**, Viçosa-MG, v.39, n.4, p.759-768, 2015.