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Article

Technological Features of Medium Density Particleboards Produced with *Acrocarpus Fraxinifolius* in Association with *Pinus Oocarpa*

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Abstract: This study aimed to evaluate the effect of mixing *Acrocarpus fraxinifolius* particles with *Pinus oocarpa* particles for the production of medium-density particleboard (MDP). The three-layer MDPs (20/60/20) were produced at five different levels of *Acrocarpus fraxinifolius* particle content (0, 25, 50, 75, and 100%) in association with *Pinus* wood. The adhesive urea-formaldehyde was applied in amount 11% in the faces and 7% in the core, based on the dry mass of particles. The mixture of particles and adhesive was placed in molds (50 x 50 x 1.5 cm) and hot-pressed under a pressure of 3.92 MPa and 160 °C of temperature for 8 minutes. Properties of panels such as density, modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), water absorption (2 and 24h), and thickness swelling (2 and 24h) were evaluated. There were no statistical differences between the densities of the particleboards. The contents 25 to 100% of *Acrocarpus fraxinifolius* obtained improvement in mechanical properties. The MDP 100% *Acrocarpus* showed potential for some higher value uses, such as in dump environments. However, until more testing is done, these panels are only recommended for dry-use applications. Using *Acrocarpus fraxinifolius* in combination with *Pinus* wood, or even using only *Acrocarpus fraxinifolius* wood is suitable for the production of MDP.

Keywords: Hardwood; Particleboard; Alternative species; Physical properties; Mechanical properties.

1. Introduction

In recent years, there was an increase in competition among different industries with the growing demand for wood [1]. As a raw material, the industries of particulate panels use planted forests wood, especially the genre *Pinus* and *Eucalyptus*. However, with advances in forest science, some species regarded as unconventional have been studied in order to also meet this demand in the forest products market [2], once the technology and territory available allow the use of large fast-growing species plantations.

Evaluation of possible potential non-conventional species could offer high-quality raw material to the final product and also mean an incentive to introduce these species in large areas of planted forests, increasing the diversification of raw materials in industrial processes. In the literature, it can be found some species with characteristics similar to species already used for the production of

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wood panels, especially mentioned by the rapid growth and specific density [3,4]. Among these, the *Acrocarpus fraxinifolius* species is gaining notoriety in the academic world, mainly due to its recognized advantages in agroforestry systems, land reclamation, regeneration capacity with high productive activity, and wood quality [5-7]. High-quality *Acrocarpus fraxinifolius* wood should be allocated preferentially for the production of decorative veneers and other value-added uses. However, mechanical wood processing generates considerable quantities of waste, which can be used for the production of reconstituted particle-based wood panels [8]. To enable the use of wood species with higher density in literature, some authors suggest the mixture of species with higher and lower density to improve the bonding process and panel formation. Also, mixing different species, clones, or even agricultural wastes is common in panel industries, aiming to improve the quality of the panels and expand the supply of raw material [9 – 22].

Some early studies with the *Acrocarpus fraxinifolius* species for the production of conventional particleboard have great potential [23]. However, more studies are needed, evaluating medium density particleboard (MDP) panels, in order to obtain more consistent results with current products of industries. In this context, this study aimed to evaluate the effect of *Acrocarpus fraxinifolius* particles in association with *Pinus* particles for the production of MDP panels.

2. Materials and Methods

Six trees of *Acrocarpus fraxinifolius* (20 years old) and six *Pinus oocarpa* (25 years old) were selected and harvested from an experimental area in the campus of the Federal University of Lavras (UFLA), the southern region of the State of Minas Gerais, Brazil, with the geographic coordinates 21°13'21" S and 44°58'26" W and approximate altitude 907 m. The basic density of pinus wood and *Acrocarpus fraxinifolius* wood were determined according to the methodology described in NBR 11941 [24] standard.

2.1. Obtaining and processing of lignocellulosic particles.

Pinus oocarpa and *Acrocarpus fraxinifolius* logs were sectioned in small logs with length 55 cm, being posteriorly steamed at 60°C for 24 hours, and 2.0 mm thick rotary cut veneers were obtained from the steamed logs. The veneers were transformed into particles by a hammer-mill containing a sieve (opening 2 mm).

For each species, the particulates materials were separately sieved through a combination of three superposed sieves with the following opening: 1 mm (top), 0.5 mm (middle), and 0.25 mm (bottom), in order to remove the fine content (lower than 0.25 mm). Particles retained between the sieves with opening 1 mm and 0.5 mm were used in the core of the MDPs, while the particles retained between the sieves of 0.50 mm and 0.25 mm were used in the faces. All the particles were dried at 70° C until they reach 3% moisture (dry basis) and packed in polyethylene bags until the production of the MDPs.

2.2. Production of the MDPs.

Fifteen panels were produced, corresponding to the five treatments which evaluated the different percentages of *Acrocarpus fraxinifolius* particles (0, 25, 50, 75, and 100%) in the MDPs in combination with *Pinus* particles. The panels were produced with a nominal density of 700 kg.m^{-3} and distribution of the layers 20/60/20 (face/core/face). The adhesive urea-formaldehyde (solid content 57%, viscosity 261.4 cP and pH 9.5) was separately applied in the particles of the core and the faces of each panel, being used 11% of adhesive in the faces and 7% in the core. The adhesive was applied to the particles by spraying in the rotary drum. After gluing, the particles were deposited in a mold box (480 x 480 mm), layer by layer, for manual pre-pressing with press 0.4 MPa. Subsequently, the mixture of adhesive and particles was forwarded to a hot press for 8 min at 160° C and pressure 3.94 MPa. The panels were conditioned at a temperature of 20±2° C and relative humidity of 65±5% in a climatized room for 15 days.

2.3. Characterization of the MDPs and statistical analysis.

The samples for physical and mechanical tests were obtained using a circular saw. Apparent Density (AP), water absorption after 2 and 24 h of immersion (WA2h and WA24h), thickness swelling after 2 and 24 h immersion (TS2h and TS24h) and internal bond (IB) were determined according to the described in ASTM D1037 [25] standard. Modules of rupture (MOR) and elasticity (MOE) were determined following the DIN 52362 [26] standard. The compaction ratio was obtained through the relation between the panel density and the density of the composition material. The results were analyzed by analysis of variance and regression analysis, both at 5% significance level, in order to investigate the effect of *Acrocarpus fraxinifolius* particle addition on the properties of the MDPs.

3. Results and Discussion

3.1. Physical properties of MDPs.

The apparent density of the panels ranged from 632 to 683 kg.m^{-3} (Table 1). Therefore all panels produced showed medium density from 551 to 750 kg.m^{-3}, according to NBR 148109 [27] standard. There was no statistical difference between the average apparent densities of the panels of different treatments. The values found for the basic density of *Acrocarpus fraxinifolius* wood and *Pinus* wood were 520 and 410 kg.m^{-3}, respectively. These basic density values may interfere significantly with particleboard properties. The compaction ratio ranged from 1.26 to 1.62 among the different treatments. Only the treatments with 25, 50, and 75% *Acrocarpus fraxinifolius* particles were within the acceptable range (1.3 to 1.6) by Maloney [9]. However, the values were close. According to the author, the minimal compaction ratio should be close to 1.3 to ensure adequate contact area between the particles, resulting in suitable minimum densification for the panel consolidation.

Table 1. Average apparent density and compaction ratio of the particleboards.

Acrocarpus fraxinifolius (%)	Apparent density (kg.m^{-3})^{ns}	Compaction ratio
0	666 $^{(\pm 10)*}$	1.62$^{(\pm 0.03)}$
25	632$^{(\pm 16)}$	1.44$^{(\pm 0.04)}$
50	683$^{(\pm 10)}$	1.47 $^{(\pm 0.02)}$
75	651$^{(\pm 16)}$	1.32$^{(\pm 0.03)}$
100	656$^{(\pm 12)}$	1.26$^{(\pm 0.02)}$

^{ns}Apparent density of MDP panels does not differ statistically by the analysis of variance at 5% significance.
*Standard deviation.

The analysis of variance and polynomial regression showed a significant difference between the properties of water absorption and thickness swelling both after 2 and 24 hours of immersion in water for different panels (Figures 1 and 2).

In general, with the addition of *Acrocarpus fraxinifolius* particles in the composition of MDP panels, there was a decrease in WA; however, the has TS increased. With the decrease of the compaction ratio, typically occurs an improvement in physical properties due to the lower specific area of wood available for binding with water, as seen for WA of this study. However, in the woods with higher densities, the cell wall is thicker, resulting in lower-dimensional stability [28], due to the higher wall fraction to absorb water, as observed in this study for the TS.

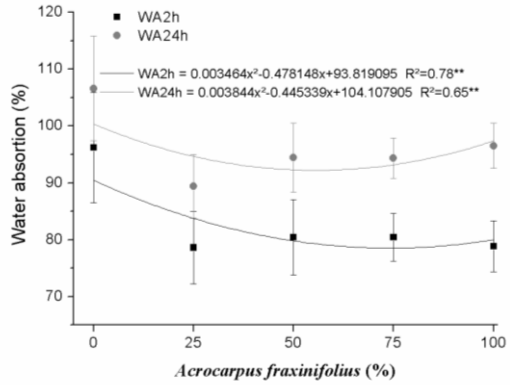

Figure. 1. Water absorption after 2h and 24h of immersion at different levels of *Acrocarpus fraxinifolius* particle content.

**Significant P-value at 1% significance level.

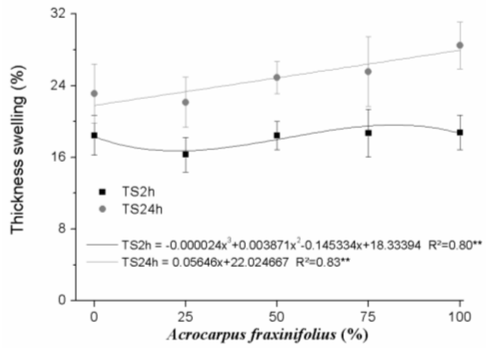

Figure 2. Thickness swelling after 2h and 24h of immersion at different levels of *Acrocarpus fraxinifolius* particle content.

**Significant P-value at 1% significance level.

Bufalino et al. [3], studying particleboard composed by different percentages of *Toona ciliata* in the panels (50 and 100%) in association with pinus wood and eucalyptus wood, observed the same trend for TS obtained in this research. According to Gatchell et al. [29], the trend may be due to a smaller surface area of wood in the same unit volume which results in reduced contact points between particles, increasing the thickness swelling.

Another aspect that may have negatively impacted the TS is the chemical composition (10.6% extractive, 20.1% lignin and 69.3% holocellulose) of *Acrocarpus fraxinifolius* [30], compared to chemical composition (5.2% extractive, 28.3% lignin, and 66.2% holocellulose) of *Pinus oocarpa* (SCATOLINO et al., 2013). Thus, beyond the higher basic density of the wood of *Acrocarpus fraxinifolius*, the amount of lignin is significantly lower than the *Pinus*. Lignin serves as a binder, increasing the rigidity of the particles, assisting in the particle-adhesive interface, and increasing the dimensional stability of wood panels [31]. The increasing of *Acrocarpus fraxinifolius* amount in the composition of MDP panels worsened the thickness swelling; however, none of the treatments in the study obtained the thickness swelling lower than 14% after 24 hours of immersion in water, so the utilization of these materials is restricted to indoor environments (including securities) according to EN 312 [32].

3.2. Mechanical properties of MDP panels.

The polynomial regression obtained for MOR, MOE, and IB properties was significant and showed an increase in the values of mechanical properties with the increase of *Acrocarpus fraxinifolius* particles in the MDP panels (Figures 3-5).

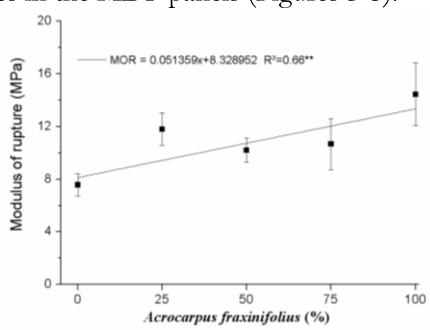

Figure 3. Modulus of rupture at different levels of *Acrocarpus fraxinifolius* particle content.
**Significant P-value at 1% significance level.

There was significant variation for the properties MOR, MOE and IB. The MOR and MOE properties showed a positive linear trend as that increased the percentage of particles *Acrocarpus fraxinifolius*. Panels produced with up to 50% hardwood did not vary with the *Pinus* particles. From 75% of the composition with particles of *Acrocarpus fraxinifolius,* a significant increase in IB property was observed.

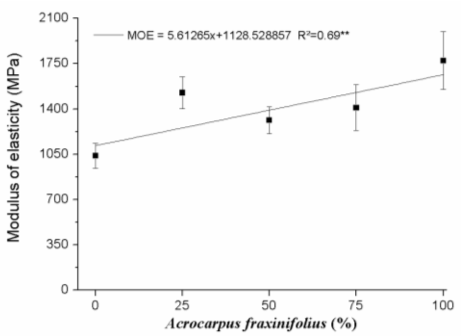

Figure 4. Modulus of elasticity at different levels of *Acrocarpus fraxinifolius* particles content
**Significant P-value at 1% significance level.

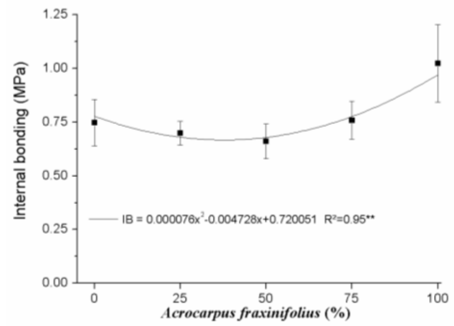

Figure 5. Internal bonding at different levels of *Acrocarpus fraxinifolius* particles content
**Significant P-value at 1% significance level.

The significant increase for MOR and MOE in MDP panels with the increase in hardwood particles can be explained by the wood *Acrocarpus fraxinifolius* have higher density than the *Pinus*, thus higher mechanical strength. Evaluating the compaction ratio (see table 1), the panels with greater amounts of *Acrocarpus fraxinifolius* particles have a smaller surface area (particle number), receiving a greater amount of adhesive per unit area, improving adhesion and, therefore the mechanical resistance of the panels [31].

The trend observed for IB property also can be explained by the amount of adhesive per particle, where the panels with lower compaction ratios are favored with more adhesive per unit area. Another important aspect is that the wood of *Acrocarpus fraxinifolius* has a pH close to 5.14, while the *Pinus* wood has a pH close to 4.56 [2]. It is also known that formaldehyde urea is polymerized in an acid medium pH (3 - 3.5), then the panels with higher concentrations of *Pinus* particles may have been premature curing, damaging the mechanical properties [23].

Similar results to those found in this study were observed by Trianoski et al. [2], which evaluated the effect of different bark percentages in particleboard produced with particles of *Acrocarpus* sp. The authors found MOR values, MOE and IB 13.09, 1861.25, and 1.12 MPa, respectively, for panels produced with 100% of particles of *Acrocarpus* sp.

Only panels composed of 100% of particles *Acrocarpus* did not reach the minimum required by standard EN 312 [32] for the properties MOR (13 MPa), MOE (1600 MPa), and IB (0.35 MPa). The other treatments met the standard requirements for the property MOR (11 MPa), and the remaining treatments were restricted to indoor use in dry conditions.

4. Conclusions

The use of *Acrocarpus fraxinifolius* particles in MDP panels has decrease WA24h and increased TS24h. Therefore, changes in the laboratory production process can improve this property for all the treatments. Panels with higher amounts of *Acrocarpus* obtained a significant improvement in mechanical properties, indicating the feasibility of this raw material in the production of MDP panels. Overall all treatments met the minimum requirements for standardized MDP panels for internal use in dry environments. However, the panels 100% *Acrocarpus* showed potential to be suitable for wider uses, such as use in wet environments. The species *Acrocarpus fraxinifolius* appears as a potential alternative raw material for the production of MDP panels.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Müller, C.; Schwarz, U.; Thole, V. Zur Nutzung von Agrar-Reststoffen in der Holzwerkstoffindustrie. *European Journal of Wood and Wood Products* **2012**, *70*, 587-594, https://doi.org/10.1007/s00107-011-0589-0.

[2] Trianoski, R.; Iwakiri, S.; Matos, J.L.; Prata, J. Physical and Mechanical Properties of Particleboards of Acrocarpus Fraxinifolius Compounds with Different Percentages of Bark. *Ciência florestal* **2013**, *23*, 761-769, http://dx.doi.org/10.5902/1980509812360.

[3] Bufalino, L.; Protásio, T.P.; César, A.A.S.; Mendes, L.M. Modeling of physical and mechanical properties in Australian cedar particleboards. *Floresta e Ambiente* **2013,** *19,* 243-249, http://dx.doi.org/10.4322/floram.2012.029.

[4] Teodoro, R.; Raabe, J.; Wisky Silva, D.; Farinassi Mendes, R.; Mendes, L.M.; Tonoli, G.H.D. Functionally Graded MDP Panels Using Bamboo Particles. *Key Engineering Materials* **2016**, *668*, 39-47, https://doi.org/10.4028/www.scientific.net/KEM.668.39.

[5] Fuentes Salinas, M.; Correa-Méndez, F.; Rosa, A.B.D.; Corona-Ambriz, A. Technical properties of sixteen types of woods from the state of Tamaulipas, which influence on the manufacture of particleboards and fiberboards. *Revista Chapingo Serie Ciencias Forestales y del Ambiente* **2008**, *14*, 65-71.

[6] Martínez, P.E.; García, J.M.M.; Sánches, M.L.H.; Pérez, G.O. Cultivo intercalado de cedro rosado (Acrocarpus fraxinifolius Wight) y suefecto sobre elcontenido de material organicenelsuelo. *Revista UDO Agrícola* **2006,** *6*, 109-113.

[7] Nisgoski, S., Trianoski, R., Muñiz, G. I. B., Matos, J. L. M., Stygar, M. Radial variation of the structures of the wood of Acrocarpus fraxinifolius Wight & Arn. *Floresta e Ambiente* **2012,** *19,* 316-324, http://dx.doi.org/10.4322/floram.2012.037.

[8] Iwakiri, S.; Trianoski, R.; Nascimento, C.C.; Azambuja, R.R.; Campelo, S.R. Ribeiro, R.S. Production of particleboards with mixtures of six species of wood from the Amazon and Pinus taeda. *Floresta* **2016**, *46,* 259-267.

[9] Maloney, T.M. *Modern particleboard and dry-process fiberboard manufacturing.* Ed. Freeman, M. San Francisco, **1993**; pp. 689.
[10] Scatolino, M.V.; Silva, D.W.; Mendes, R.F.; Mendes, L.M.Use of maize cob for production of particleboard. iência e Agrotecnologia. **2013**, *37*, 330-337, https://doi.org/10.1590/S1413-70542013000400006.
[11] Scatolino, M.V.; Protásio, T.D.P.; Mendes, R.F.; Mendes, L.M. Thermal stability of Pinus oocarpa and maize cob particleboards. Ciência e Agrotecnologia. **2015**, *39*, 348-354, https://dx.doi.org/10.1590/S1413-70542015000400005.
[12] Mesquita, R.G.D.A.; Mendes, L.M.; Sanadi, A.R.; de Sena Neto, A.R.; Claro, P.I.C.; Corrêa, A.C.; Marconcini, J.M. Urea Formaldehyde and Cellulose Nanocrystals Adhesive: Studies Applied to Sugarcane Bagasse Particleboards. *Journal of Polymers and the Environment* **2018**, *26*, 3040-3050, https://doi.org/10.1007/s10924-018-1189-4.
[13] Silva, D.W.; Scatolino, M.V.; do Prado, N.R.T.; Mendes, R.F.; Mendes, L.M. Addition of Different Proportions of Castor Husk and Pine Wood in Particleboards. *Waste and Biomass Valorization* **2018**, *9*, 139-145, https://doi.org/10.1007/s12649-016-9742-7.
[14] Borysiuk, P.; Jenczyk-Tolloczko, I.; Auriga, R.; Kordzikowski, M. Sugar beet pulp as raw material for particleboard production. *Industrial Crops and Products* **2019**, *141*, https://doi.org/10.1016/j.indcrop.2019.111829.
[15] Mahieu, A.; Alix, S.; Leblanc, N. Properties of particleboards made of agricultural by-products with a classical binder or self-bound. *Industrial Crops and Products* **2019**, *130*, 371-379, https://doi.org/10.1016/j.indcrop.2018.12.094.
[16] Nadhari, W.N.A.W.; Danish, M.; Nasir, M.S.R.M.; Geng, B.J. Mechanical properties and dimensional stability of particleboard fabricated from steam pre-treated banana trunk waste particles. *Journal of Building Engineering* **2019**, *26*, https://doi.org/10.1016/j.jobe.2019.100848.
[17] Scatolino, M.V.; Costa, A.d.O.; Guimarães Júnior, J.B.; Protásio, T.D.P.; Mendes, R.F.; Mendes, L.M. Eucalyptus wood and coffee parchment for particleboard production: Physical and mechanical properties. Ciência e Agrotecnologia. **2017**, *41*, 139-146, https://dx.doi.org/10.1590/1413-70542017412038616.
[18] Scatolino, M.V.; Protásio, T.d.P.; Souza, V.M.; Farrapo, C.L.; Guimarães Junior, J.B.; Soratto, D.; Mendes, R.F.; Mendes, L.M. Does the Addition of Cotton Wastes Affect the Properties of Particleboards? Floresta e Ambiente. **2019**, *26*. https://doi.org/10.1590/2179-8087.030017.
[19] Chalapud, M.C.; Herdt, M.; Nicolao, E.S.; Ruseckaite, R.A.; Ciannamea, E.M.; Stefani, P.M. Biobased particleboards based on rice husk and soy proteins: Effect of the impregnation with tung oil on the physical and mechanical behavior. *Construction and Building Materials* **2020**, *230*, https://doi.org/10.1016/j.conbuildmat.2019.116996.
[20] Farag, E.; Alshebani, M.; Elhrari, W.; Klash, A.; Shebani, A. Production of particleboard using olive stone waste for interior design. *Journal of Building Engineering* **2020**, *29*, 101-119, https://doi.org/10.1016/j.jobe.2019.101119.
[21] Narciso, C.R.P.; Reis, A.H.S.; Mendes, J.F.; Nogueira, N.D.; Mendes, R.F. Potential for the Use of Coconut Husk in the Production of Medium Density Particleboard. *Waste and Biomass Valorization* **2020**, https://doi.org/10.1007/s12649-020-01099-x.
[22] Nicolao, E.S.; Leiva, P.; Chalapud, M.C.; Ruseckaite, R.A.; Ciannamea, E.M.; Stefani, P.M. Flexural and tensile properties of biobased rice husk-jute-soybean protein particleboards. *Journal of Building Engineering* **2020**, *30*, https://doi.org/10.1016/j.jobe.2020.101261.
[23] Prata, J.G. Technological feasibility study of the use of tropical Pinus taeda species for the production of laterally glued panels – EGP. Dissertation of Master, Federal University of Paraná, Curitiba. **2010**, pp. 114.
[24] ABNT-Associação Brasileira De Normas Técnicas. NBR 11941: Madeira – determinação da densidade básica. Rio de Janeiro, **2003**.
[25] ASTM-American Society for Testing and Materials. ASTM D-1037: Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. Philladelphia, **2006.**
[26] DIN – Deutsches Institut für Normung. DIN 52362: Testing of wood chipboards bending test, determination of bending strength. Berlin, Beuth Verlag, **1982**.
[27] ABNT-Associação Brasileira De Normas Técnicas. NBR 148109: Chapas de madeira aglomerada. Rio de Janeiro, **2006.**
[28] Lopes, C.; Nolasco, A.M.; Filho, M.; Dias, C.; Camargo, A. Specific gravity and shrinkage of wood of three species of eucalypts for furniture production. **2011**, *21*, 315-322, https://doi.org/10.5902/198050983235.
[29] Gatchell, G.J.; Heebink, B.G.; Hefty, F.V. Influence of component variables on the properties of particleboards for exterior use. *Forest Products Jonal* **1996**, *16*, 45-59.
[30] Prado, C.A.; Pereira, J.C.D.; Mattos, P.P.; Schaitza, E.G.; Higa, A.R. *Physical and chemical characteristics of Acrocarpus Fraxinifolius wood.* Wight & Arn. Embrapa Florestas, Colombo, (Boletim de Pesquisa e Desenvolvimento, n. 14), **2003.**
[31] Silva, D.; Farrapo, C.; Ribeiro, D.; Mendes, R.; Mendes, L.; Scolforo, J. MDP with particles of eucalyptus and corn straw. *Scientia Forestalis/Forest Sciences* **2015**, *43*, 853-862.
[32] CEN-European Committee for Standardization. EN 312: Particleboards – specifications. Bruxelas, 2**003**.