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Technological Properties of Medium Density Particleboards Produced with Peanut (*Arachis Hypogaea*) and *Pinus Oocarpa* Hulls

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Abstract

Peanut crop waste (hulls), which have a chemical composition similar to wood, can be considered as a source of industrial raw material for the production of particleboard, provided that they are of similar quality to wooden panels. The present study aimed to produce and evaluate the physical and mechanical properties of medium density particleboards made of peanut hulls and pine wood particles bonded with urea-formaldehyde adhesive. The panels did not present satisfactory dimensional stability. The mechanical properties were significantly reduced with the addition of peanut hulls. In general, peanut hulls did not represent a good alternative to be used as a source of raw material for the production of particleboard. The inclusion of new parameters in the production process would be essential to improve the technological properties, such as: new particle geometries, use of paraffin, particle treatments and inclusion of denser species in the composition of the panels.

Keywords: Wood, particle mixture, technological properties, compression ratio, waste.

1. INTRODUCTION AND OBJECTIVES

Particleboards are produced with wood particles and the addition of synthetic adhesives under heat and pressure. According to Iwakiri et al. (2019) the most commonly used species in Brazil are Pinus and Eucalyptus, but other materials that have a chemical composition similar to wood can be used.

Lignocellulosic material waste can be reused by reducing waste (Yanno et al., 2020) and can be used to manufacture new value-added products (Brito et al., 2020). An interesting option is the wastes (hulls) from the peanut crop, which is one of the most important legumes in the world, due to its nutritional properties and important source of vegetable protein and oil (FIESP - Federação das Indústrias do Estado de São Paulo, 2021). Even Zheng et al. (2013) state that peanut hulls have a very slow degradation rate under natural conditions.

China is the main peanut producing and consuming country in the world, representing 38% of global production, estimated at 46.1 million tons in 2020 (FIESP, 2021). In Brazil, São Paulo is the main producing of the grain in the country. In the 2020/2021 crop, the production reached 561.6 million tons, while the total Brazilian production was 597.1 million tons (CONAB - Companhia Nacional de Abastecimento, 2021).

After peanut processing, a large amount of waste (peel) is generated, which constitutes an abundant and accessible resource for the development of recycled products, besides having a chemical composition similar to wood. According to Gatani et al. (2013) depending on the variety of peanut, about 30% of the weight corresponds to the peel. According to FIESP (2021) the volume of peanut hulls produced in Brazil in the last crop in 2020 corresponded to 134 thousand tons. They can be converted into various bio-products, such as biodiesel, bioethanol and have applications in the production of enzymes and hydrogen, degradation of dyes and heavy metals, among others (Duc et al., 2019).

Another interesting use for peanut hulls would be as a source of raw material for the production of panels, in fact, some studies already reported in the literature on peanut hulls particle boards associated or not with other lignocellulosic materials, they have already demonstrated the potential of this waste.

Gatani et al. (2013) used peanut hulls waste to manufacture particleboard panels produced with urea-formaldehyde based adhesive. The material showed potential to be used in indoor environments, as surface coating of homes, agricultural buildings, furniture and decorative sectors.

Barbirato et al. (2014) used peanut shells and wood particles of the itaúba species (*Mezilaurus itauba*) to manufacture hybrid particle boards. They used two-component polyurethane resin based on castor oil and urea-formaldehyde. With the results obtained, it was possible to verify that the incorporation of wood particles provided an increase in the physical-mechanical properties of the particleboard with peanut shell.

Nasser et al. (2020) manufactured high-density panels composed of peanut hulls (*Arachis hypogaea* L.) and bamboo waste (branches and apical part), using two-component polyurethane resin based on castor oil (*Ricinus communis* L.). The performance of the panels complied with the ABNT NBR 14.810-2 and ANSI A208-1 standards, supporting the use of peanut hull waste in the manufacture of particleboard panels for indoor use and allowing the applicability of this through additional value.

Considering that context of avoiding disposals of waste abundantly produced by agroindustry (hull). It's crucial to search solutions to add value to that waste, such as using peanut hull as raw for the production of particleboards. In light of that, this study aimed to evaluate the physical and mechanical properties of particleboards panels made with peanut hulls particles and pine wood bonded with urea formaldehyde adhesive (UF).

2. MATERIALS AND METHODS

2.1. Raw materials and particle sourcing

For the production of the panels, 18-year-old *Pinus oocarpa* trees were used, extracted at the experimental campus of the Federal University of Lavras (UFLA). The trees were felled with a chainsaw and later sectioned into short logs (1 m). From each section, disks were extracted to determine the basic density. The logs were sent to the Experimental Unit for the Production of Wood Panels (UEPAM), located at UFLA. To be transformed into chips with the aid of a band saw. Subsequently, they were dried in the open air until reaching an average humidity of 18% and in a forced air circulation oven until reaching a humidity of around 8%. The peanut hulls were acquired in commercial houses in the center of the city (Lavras).

The peanut hulls underwent a drying process in a forced air circulation oven until they reached a moisture content of around 5%. A hammer mill was used to transform the pine wood and peanut hulls into particles. The material was classified in a set of sieves, available in the laboratory for particle classification. Each sieve had a different opening (openings of 6.35 mm, 2.83 mm and 0.84 mm). The sieves vibrated and the particles of different sizes were separated. The particles selected for the experiment were those that were retained in the 0.85 mm mesh sieve, as they have the most suitable granulometry for the production of panels. Then the particles were dried in an oven at 3% humidity. The wood and peanut hulls were stored in different plastic bags to avoid contact with moisture, then identified to be used later to manufacture particleboard.

2.2. Basic density and production of medium density particleboards

The basic density of the wood was determined based on the Brazilian Regulatory Standard NBR 11941 (Associação Brasileira de Normas Técnicas, ABNT, 2003). It was not possible to determine the basic density of the peanut hull.

For the production of medium density particleboards, a nominal density of 0.75 $g.cm^{-3}$ and a resin solids content of 12% was established, based on the dry mass of the particles. The UF-based adhesive was applied to the particles, inside a rotary drum gluer, using a compressed air gun. The gluer drum was set to work with 12 revolutions per minute. Then, the glued particles were manually distributed in a wooden box with internal dimensions of 40 x 40 cm to form the mattress and ensure a more homogeneous distribution. According to Nasser et al. (2020) this step is essential to ensure that there are no changes in the properties of the particleboard due to the variation in density between the regions of the mattress.

Then, the cold pre-pressing of the mattress was carried out, in a manual hydraulic press, to remove air and pre-consolidate. Subsequently, the mattress was hot pressed, using steel separators with a thickness of 15.70 mm, in a motorized hydraulic press, with automatic control of temperature, pressure and closing and opening time of the plates.

The parameters of the pressing cycle were the following: 35 $kgf.cm^{-2}$ of pressure, temperature of 160 °C and pressing time of 8 minutes, thus obtaining the panels. Then, they were stored in an acclimatized room (22 ± 2 °C; 65 ± 5% relative humidity) until the mass is stabilized.

2.3. Compression ratio and physical-mechanical tests of medium density particleboards

The compression ratio was calculated by Equation 1.

$$CR = \frac{AD}{BD_P x PP_{\%} + BD_{PH} x PPH_{\%}} \quad (1)$$

Being: CR: compression ratio; AD: apparent density (g.cm^{-3}); BD_P: basic density of the pine particles (g.cm^{-3}); $PP_{\%}$: percentage of the pine particles in the panel; BD_{PH}: basic density of the peanut hulls; $PPH_{\%}$: percentage of the peanut hull particles in the panel.

The physical-mechanical tests evaluated the apparent density (AD), water absorption after 2 hours (WA2h) and 24 hours (WA24h), swelling in thickness after 2 hours (TS2h) and 24 hours (TS24h), modulus of rupture (MOR) and modulus of elasticity (MOE) to static bending and internal board (IB) in accordance with NBR 14810 (ABNT, 2013).

To determine the specific mass, the samples used in the physical and mechanical tests were directly measured. For this purpose, a scale was used to weigh the mass of the samples, in addition to a caliper and micrometer, to measure the dimensions. To perform the physical tests (water absorption and thickness swelling) a recipient with distilled water was used, in addition to a device suggested by NBR 14810 to keep the samples submerged. The samples were weighed and measured before immersion in water and after the process, using a precision balance to obtain the masses and verify water absorption.

The mechanical tests were carried out on a universal testing machine driven by an electromechanical system, computer-controlled, capable of applying forces of up to 30 tons. Standard instrumentation on this machine includes load cells, LVDT and exchangeable test devices.

2.4. Experimental design and analysis of results

A completely randomized design (DIC) was used, with 3 replications per treatment, thus totaling 12 experimental units. The experiment consisted of four treatments based on the composition of mixtures of pine particles and peanut hulls, being: T1 = 100% pine; T2 = 75% pine + 25% peanut hulls; T3 = 50% pine + 50% peanut hulls and T4 = 25% pine + 75% peanut hulls.

Physical and mechanical properties were evaluated. The physical-mechanical properties data were evaluated with the aid of the statistical software Sisvar. Tukey's test (5%) was used to assess the influence of the percentage of peanut hulls in the composition of the panels.

3. RESULTS AND DISCUSSION

3.1. Compression ratio of medium density particleboards

The basic density of the wood was 0,520 g.cm^{-3}. The calculation of the compression ratio was determined based on the value reported by Dourado et al. (2017) who obtained 0.205 g.cm^{-3} for the basic density of peanut hulls.

Table 1. Values of the nominal compression ratio (RCN) and effective compression ratio (RCE) of the panels.

Treatments	RCN	RCE
0% hulls	1.44	1.28
75% pine + 25% hulls	1.70	1.54
50% pine + 50 % hulls	2.08	1.99
25% pine + 75 % hulls	2.68	2.57

There is an increase in the compression ratio (Table 1) of the panels with the addition of the peanut hull. The compression ratio of particleboard should be 1.3-1.6 for its densification and consolidation in the final thickness (Maloney, 1993). Values within this range, such as that obtained in the T1 treatment, would be adequate to obtain good densification and quality of the panels. In relation to the mixtures, none of the produced panels were within the range stipulated as ideal.

According to Andrade et al. (2018) the compression ratio is an important requirement in the mechanical strength of particle board, since panels with higher compression ratio probably will cause higher mechanical properties. On the other hand, Protásio et al. (2013) and Guimarães Júnior et al. (2016) state that it is necessary to observe other parameters related to raw material, such as chemical composition, and to the production process, such as adhesive content.

3.2. Physical properties of medium density particleboards

According to Table 2 it is noted that the apparent density of the panels was not affected by the particle mix composition, because there was no difference between the treatments. The coefficient of variation (CV) indicates that the analysis was accurate, because the value obtained (3.17%) was less than 15%, thus indicating an optimal sampling precision with low data dispersion, in addition the CV is within the limits stipulated by NBR 14810 (ABNT, 2013b), less than 7%.

Table 2. Average values of apparent density (AD), water absorption (WA2H and WA24H) and thickness swelling (TS2H and TS24H) of the evaluated panels.

Treatments	AD	WA2H	WA24H	TS2H	TS24H
	(g.cm^{-3})		(%)		
0% hull	0.67 a	65.05 a	71.97 a	15.63 a	22.46 a
75% pine + 25% hulls	0.68 a	73.21 b	86.72 b	21.59 ab	23.06 ab
50% pine + 50 % hulls	0.71 a	73.04 b	87.85 b	23.32 ab	29.85 ab
25% pine + 75 % hulls	0.72 a	76.71 b	88.24 b	26.98 b	31.12 b
Overall average	0.70	71.75	83.69	21.85	26.63
*CV (%)	3.17	13.91	9.98	18.30	15.93

Averages followed by the same letter in the columns do not differ statistically by Tukey's test (α = 0.05). *CV: Coefficient of Variation.

Based on the results obtained by treatment, the panels can be classified as "medium density", according to NBR 14810 (ABNT, 2013), which classifies panels with values between 0.55 and 0.75 g.cm^{-3}. The importance of this classification lies in its connection with the minimum values of swelling in thickness, water absorption, modulus of elasticity, modulus of rupture, and internal adhesion (Machado et al., 2017).

Also according to Table 2, the values obtained for apparent density were lower than the nominal density (0.75 g.cm^{-3}). This fact can be explained by the loss of inputs (adhesive) and particles during the production of the mattress in the laboratory, in addition to the pre-pressing of the mattress, hot pressing and packaging of the panels, phases in which the volume of the panels may increase and thus decrease the nominal density (Guimarães et al., 2016 and Bazzetto et al. 2019).

It is noted that there is statistical difference for all physical properties (Table 2). In relation to WA 2h and WA 24h, the panels constituted exclusively with pine particles, show a lower rate of water absorption. With the insertion of peanut hulls the values increase, but the treatments T2, T3 and T4 do not differ. For WA 2h and WA 24h, the CV values were less than 15%, indicating, therefore, good sample accuracy.

It is noteworthy that the T1 treatment panels, made with material of higher density (pine), have particles with lower specific surface area (ASE), since the basic density of the pine is higher than the basic density of the peanut hulls. The inverse is observed for the peanut hulls particles with higher ASE. In this case, it is assumed that the adhesive content applied to these particles was not enough to cover all the particles, since they are more numerous due to lower density, thus the adhesive did not form a protective barrier to water absorption. For the particles with lower ASE there was a higher covering capacity, i.e., the particles were waterproofed reducing the absorption rates, in the case of the T1 treatment panels. Thus, the panels constituted with higher proportions of hulls showed high water absorption capacity. The values were higher than those reported in the literature.

Guler et al. (2008) produced particleboards with peanut hulls and pine wood (nominal density of 0.70 g.cm^{-3} and UF-based resin was used). They used the following mix proportions: 0%, 25%, 50%, 75% and 100%. The values found were lower than those obtained in this work. The highest water absorption rate was observed in the panels consisting of 75% peanut hulls and 25% pine particles, with average results equivalent to 63.3% and 73.9% for WA 2h and WA 24h, respectively. Gatani et al. (2013) produced peanut hulls panels with 10% UF resin content. They used specific pressure of 25 MPa and temperature of 100 °C. The panels had an average density of 0.70 g.cm^{-3}. The authors obtained an absorption rate of 70% in 24 hours.

The same trend was observed by Barbirato et al. (2014) when working with panels made of peanut hulls and itaúba wood (nominal density of 0.80 g.cm^{-3}). Noted that panels with 100% wood particles or 20% peanut hulls evidenced higher absorption rates in 2 hours and those made with 40% or 100% peanut hulls particles showed the highest values. For the WA 24h, the lowest values were due to the composites manufactured with 100% of itaúba wood particles or with 20% of peanut hulls, being the highest values from the materials manufactured with 40% or 100% of peanut hulls particles. For the panels made with particles glued with UF adhesive and proportions of 80% peanut hulls and 20% itaúba wood, the authors obtained 62.81% for WA 2h and 79.02% for WA 24h. NBR 14810 (ABNT, 2013) does not establish a minimum requirement for the water absorption rate.

In relation to the values of TS 2h and TS 24h (Table 2) significant differences were found between the treatments. As higher proportions of waste were added, there was an increase in the values of TS 2h and TS 24h, thus affecting the dimensional stability. For TS 2h, the control treatment showed the lowest average, as expected, and differed significantly from treatment T4, which showed a less satisfactory result. Treatments T2 and T3 showed intermediate behavior. The same trend was observed for TS 24h. CV values between 15%

and 20% indicate good precision of the samples and average dispersion of the data.

A similar trend was observed by Brito et al. (2020) when working with panels made with particles of bamboo material and agricultural waste (sugarcane bagasse) in different proportions (0, 25, 50, 75 and 100%). The particles were glued with 10% UF based adhesive and nominal density of 0.65 g.cm^{-3}. The authors observed a significant increase in the values as the proportion of sugarcane bagasse in the panels increased. This situation was justified by the increase in the compression ratio, resulting from the addition of sugarcane bagasse particles, which resulted in higher swelling values, due to the larger number of particles under pressure in the press and that, exposed to moisture, release tensions that result in high dimensional changes. Another factor would be the increase in sorption sites, since peanut hulls were used in larger quantities, which increased the hygroscopicity of material.

Barbirato et al. (2014) also described the same behavior. The authors found that the lowest values for TS 2h and TS 24h were characteristic of the panels made with 100% itaúba wood and the highest values were observed for those made with 100% peanut hulls. They concluded that the progressive addition of peanut hulls in the panels provided an increase in the swelling of the panels in both evaluated times. Guller et al. (2008) observed the same trend, that is, as the proportion of peanut hulls in the composition of the panels increased, so did the TS. The values found were 10.16 to 13.78% for TS 2h and 12.66 to 19.84% for TS 24h, lower than those obtained in this study.

According to Iwakiri et al. (2010) panels with higher compression ratio result in higher values of water absorption and swelling in thickness after 24 hours of immersion, negatively influencing the dimensional stability of the panels. This statement is consistent with the behaviour of the panels observed in the present research. The dimensional stability of particleboards can be improved by increasing the adhesive content or applying some type of treatment to the particles, such as heat treatment (Brito & Bortoletto Júnior, 2019). The use of paraffin emulsion is also mentioned, which tends to give greater dimensional stability to the panels.

The NBR 14810 (ABNT, 2013) stipulates a maximum value of 18% for the TS of medium density particleboards, and thus none of the treatments met this requirement.

3.3. Mechanicals properties of medium density particleboards

It can be seen that there was a difference between treatments for all mechanical properties evaluated (Table 3).

Table 3. Average values of modulus of rupture (MOR), modulus of elasticity (MOE) and internal board (IB) of the evaluated panels.

Treatments	MOR (MPa)	MOE (MPa)	IB (MPa)
0% hulls	9.44 a	1430.91 a	0.54 a
75% pine + 25% hulls	6.88 b	961.79 b	0.57 a
50% pine + 50 % hulls	6.24 b	823.82 b	0.28 b
25% pine + 75 % hulls	4.26 c	668.35 b	0.22 b
Overall average	6.71	971.22	0.41
Coefficient of Variation (%)	8.00	14.70	8.14

Averages followed by the same letter in the columns do not differ statistically using the Tukey test ($\alpha = 0.05$).

In relation to the MOR it was observed that the T1 treatment showed higher average value. With the addition of the percentages of 25, 50 and 75% of peanut hulls in the panel composition, there were losses in mechanical strength equivalent to 27.12, 33.9 and 54.87%, respectively. The lowest performance was verified for the panels manufactured with 25% pine and 75% peanut hulls.

The panels of treatments T2, T3 and T4 did not differ. It is also noteworthy that the percentages of peanut hulls inserted in the composition of the panels of 25, 50 and 75% were able to reduce the MOE in 32.8, 42.45 and 53.29%, respectively and the coefficients of variation obtained for the mechanical properties indicate optimum sample precision.

As previously commented, probably the adhesive content was not enough to cover the peanut hulls particles, which resulted in fragility points in the structure of the panel at the moment of application of the force, proven by the low strength values of the modulus of rupture and modulus of elasticity.

Similar trends were reported in the literature as Guler et al. (2008) and Nasser et al. (2020). Guler et al. (2008) found that increasing the percentage of peanut hulls in the composition of the panels significantly decreased the mechanical properties. The values obtained for the MOR ranged between 9.90 and 15.54 MPa and for the MOE the values found were between 1,276.76 and 2,145.71 MPa. Nasser et al. (2020) observed that the increment of peanut hulls in the composition of the panels was also responsible for a reduction in the strength of MOR and MOE. For the MOR the composition of the panels with 100% bamboo particles showed the highest value and the composition with higher content of peanut hulls evidenced the lowest value. For the MOE, the authors observed that the highest value was obtained for the panels with 90% bamboo and 10% peanut hulls and the lowest value was obtained for the composition with higher content of peanut hulls.

The values obtained by Barbirato et al. (2014), considering the composition of 80% peanut hulls and 20% wood and

UF-based adhesive, were higher in relation to treatment 4, which is the treatment that is closest to this composition.

Some factors may explain the difference between the results in this research and the values reported in the literature such as: material density, panel density, parameters of the pressing cycle, adhesive, moisture content of the mattress, geometry and thickness of the particles, among others, which can directly influence the quality of the panels. NBR 14810 (ABNT, 2013) stipulates for medium density particleboards and produced with the urea-formaldehyde adhesive minimum values of 1,800.00 MPa for the MOE and 11.00 MPa for the MOR. Thus, none of the panels met the requirements of the standard

Furthermore, according to Table 3 it is observed that there was a difference between the treatments for the IB property. For the panels of treatments T1 and T2 there was statistical equality, i.e., the addition of 25% peanut hulls particles in the composition of the panel did not influence the IB, compared to those constituted only with pine particles. The panels composed with 50 and 75% of peanut hulls showed the lowest values, with significant reduction in the bonding quality around 54.55 MPa. The results obtained for the MOR and MOE prove the low bonding quality, through the reduction of internal board in panels with higher proportions of peanut hulls.

As previously commented, this probably occurred due to the compression ratio. During the formation of the mattress there was the need for a greater amount of peanut hulls, due to the low density of the particles, which consequently increased the ASE, resulting in lower availability of adhesive and low bonding quality.

Nasser et al. (2020) also reported a decrease in the IB values of the panels with the inclusion of peanut hulls. The values were similar to those obtained by Guller et al. (2008). In panels with proportions of 100, 75, 50, 25 and 0% of peanut hulls, the authors obtained values between 0.32, 0.32, 0.35, 0.48 and 0.50 MPa, respectively. The NBR 14810 (ABNT, 2013) stipulates for medium density particleboards the value of 0.40 MPa for the IB property, thus the panels of the T2 treatment with 25% peanut hulls meets the requirement, in addition to the control panels (T1).

4. CONCLUSIONS

There was an increase in physical properties with the insertion of pine particles in the composition of the panels, reducing dimensional stability. The mechanical properties (MOR and MOE) were also significantly reduced with the addition of peanut particles in the composition of the panels. None of the treatments met the requirements of NBR 14810 (ABNT 2013) for such properties.

For internal board only the panels constituted with 25% of peanut hulls reached the minimum value specified by NBR 14810 (ABNT 2013), besides the panels of the control treatment. In general, peanut hulls did not represent a good alternative to be used as a source of raw material for the production of particleboard. The inclusion of new parameters in the production process would be essential to improve the technological properties, such as: new particle geometries, use of paraffin, particle treatments and inclusion of denser species in the composition of the panels.

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