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Performance of medium-density particleboards from *Eucalyptus grandis* and *Triticum aestivum* treated with tall oil and citric acid

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: Agro-industrial residues offer a sustainable alternative to mitigate raw material scarcity for particleboard production. Surface treatments with natural products can enhance dimensional stability. This study evaluates medium-density particleboards made from *Eucalyptus grandis* particles and *Triticum aestivum* bran treated with tall oil and citric acid.

Results: Increasing *T. aestivum* proportions improved the compression ratio but reduced dimensional stability, modulus of elasticity, and modulus of rupture. Thickness swelling increased from 18.46% in 100% Eucalyptus particleboards to 41.31% in 100% *T. aestivum* particleboards. The modulus of rupture decreased from 17.86 MPa (100% Eucalyptus) to 5.37 MPa (100% *T. aestivum*). Citric acid improved water absorption but did not affect thickness swelling. In 100% Eucalyptus particleboards, water absorption was 64% (citric acid), 72% (tall oil), and 70% (untreated). In 100% *T. aestivum* particleboards, absorption was 82% (citric acid), 91% (tall oil), and 86% (untreated). The modulus of elasticity was higher in citric acid-treated particleboards (2491 MPa) than in tall oil-treated ones (1903 MPa) for 100% Eucalyptus particleboards, and the same was observed in 100% *T. aestivum* particleboards (784 MPa vs. 259 MPa).

Conclusion: *T. aestivum* residues are a viable alternative for particleboards, especially in moderate proportions (≤50%) combined with Eucalyptus. Higher proportions negatively affect particleboard properties. Citric acid was the most effective surface treatment, while tall oil showed limited benefits. These findings reinforce the feasibility of sustainable particleboards and the importance of optimizing raw material composition and surface treatments.

Keywords: Additives; Forestry and agro-industrial raw material; Natural coverings; board composition; Wood boards.

HIGHLIGHTS

T. aestivum bran increased compression ratio but compromised particleboard stability and strength.
Citric acid reduced water absorption but did not affect thickness swelling in particleboards.
Particleboards with tall oil or citric acid treatments showed reduced MOE and MOR values.
Only particleboards with higher *E. grandis* content met NBR 14810-2 standards for physical properties.

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INTRODUCTION

Medium-density particleboards, made from lignocellulosic particles combined with resin and additives, are versatile and cost-effective alternatives to solid wood. They are widely used in furniture manufacturing and civil construction for applications such as doors, partitions, and decorative elements (Pędzik et al., 2021). In the production process, particles from *Pinus* spp. and *Eucalyptus* spp. are commonly used, primarily due to their rapid growth, short rotation cycles, and high yield rates. Among these, Eucalyptus stands out, covering 7.8 million hectares, which corresponds to 76% of Brazil's total planted forest area. This figure reflects a 41% growth over the last decade, underscoring the growing significance of this crop in the Brazilian forest-based economy (IBÁ, 2024).

Conventional raw materials in producing particleboards are also used in other forest-based sectors, such as cellulose, energy, laminated panels, and fiberboards. Therefore, there is a limited wood supply from forest plantations, combined with the increase in the cost of raw materials, which has affected the production chain (IBÁ, 2022).

The combination of traditional species with forest or agricultural residues has been extensively studied to expand raw material availability, including the use of agro-industrial wastes such as wheat stalks (Oh and Lee, 2012), coffee residues (Araújo et al., 2014), corn straw (Silva et al., 2015), rice husks (Da Silva César et al., 2017), and chemically treated fibrous vascular tissue of acai (De Lima Mesquita et al., 2018).

Replacing *Pinus spp*. and *Eucalyptus spp*. wood in particleboards with by-products applies industrial ecology, an eco-innovation principle, by redirecting waste into raw materials for new products. Caraschi et al. (2009) highlight agricultural waste redirection as a key solution for waste management, meeting particleboard sector demands, and fostering new material production.

Among the various by-products of the food industry, wheat bran stands out as a residue generated during the milling process of wheat grains to produce white flour. Rich in fiber and minerals, wheat bran is commonly used as a raw material for animal nutrition. In some European countries, it is also utilized in paper production and handicrafts, demonstrating its versatility in low-tech and economically viable applications (Canilha et al., 2008). In Brazil, wheat bran production is directly linked to wheat cultivation, which reached approximately 10.5 million tons in the 2022/2023 crop season. This volume reflects a significant increase compared to previous harvests, driven by the expansion of cultivated areas, particularly in Paraná and Rio Grande do Sul, the country's leading wheat-producing regions (CONAB, 2023).

Wheat bran has shown potential as a raw material for various applications, including enzyme production (Cruz Davila et al., 2022; Lv et al., 2021), carbon source in bioprocesses, mushroom cultivation substrates (Saad et al., 2017), chemical manufacturing (dos Santos and Orlandelli, 2019), and biofuels (Alonso, 2018). Rich in hemicelluloses, cellulose, and lignin, it is a promising material for lignocellulosic products like particleboards (Cassarini et al., 2021).

The adhesive, primarily urea-formaldehyde (UF) resin, is used in particleboard production due to its reactivity and low cost. However, it undergoes hydrolytic degradation in water, releasing toxic formaldehyde (Stark et al., 2010). This has driven efforts to improve dimensional stability by adding resin additives and applying coatings to the particleboards.

Coatings and additives reduce the negative effects on particleboards enhance their aesthetics and durability and can be applied on the surface or during manufacturing (Pace et al., 2018). Several studies have explored this, such as de Cademartori et al. (2020), who applied nanocellulose coatings on medium-density particleboards; Jiang et al. (2023), who studied modification effects on water absorption and strength of wheat straw fibers; and Wang et al. (2024), who evaluated the impact of acid pretreatment and surface modification on wheat straw panels.

Polycarboxylic acids, identified as promising crosslinking agents, have been studied for their ability to carry out esterification reactions with the hydroxyl groups of wood (Welch and Andrews, 1988). Citric acid esterification has emerged as an inexpensive and environmentally friendly method for wood modification, providing improved dimensional stability (Rodrigues et al., 2006; Sutiawan et al., 2021). Following these findings, the viability of citric acid as a treatment agent has been further explored, highlighting its potential for sustainable wood applications (Essoua et al., 2016; Sutiawan et al., 2021).

The use of fatty acids as protective agents for wood has shown promise, as these molecules significantly reduce the capillary water absorption of sapwood (Hyvönen et al., 2006). Tall oil, a natural and renewable oil primarily composed of fatty acids, exhibits low interaction with water molecules, enhancing its potential as a water-repellent agent (Temiz et al., 2008). This repellency has been studied extensively, with Hyvönen et al. (2006), Schultz et al. (2007), and Vivian et al. (2020) demonstrating its effectiveness as a surface treatment for solid wood and particleboards.

The study aimed to evaluate the technological properties of medium-density particleboards produced with *Eucalyptus grandis* particles and *Triticum aestivum* bran in natural and coated with citric acid and tall oil.

MATERIALS AND METHODS

Characterization of raw material

The materials used for the development of the study consisted of *E. grandis* particles supplied by Eucatex Indústria e Comércio (São Paulo, SP, Brazil) and wheat bran provided by Moinho Nordeste (Antônio Prado, RS, Brazil). Additionally, urea-formaldehyde resin and wax emulsion were supplied by Sudati Painéis (Otacílio Costa, SC, Brazil). Tall oil was donated by Resitol Indústria Química (Palmeira, SC, Brazil), while citric acid was commercially obtained from Adicel Indústria e Comércio (≥99.5%, Belo Horizonte, MG, Brazil).

The wood particles of *E. grandis* and *T. aestivum* bran had a basic density of 653 kg.m^{-3} (provided by the donating company) and 167 kg.m^{-3} (Neitzel et al., 2023), respectively, and an average moisture content of 14%. The wood particles were classified by granulometry using a 6-mesh sieve, and only the material that passed through the sieve was used. Subsequently, the lignocellulosic raw materials were dried in a forced-air circulation oven at 80 °C until reaching a moisture content of ± 4%. The urea formaldehyde resin and paraffin emulsion had a viscosity of 318 cP and 402 cP, solids content of 63% and 30%, and pH of 8.90 and 9.1, respectively.

The thermogravimetric analysis of the two raw materials was carried out in an inert environment using equipment from Navas Instruments, model TGA 2000, which worked with a heating rate of 10 °C.min^{-1}, from 25 °C to 800 °C.

Particleboard production

The experimental plan was characterized by 15 treatments, which were composed of different proportions of *E. grandis* and *T. aestivum* (100% *E. grandis*, 75%:25%, 50%:50%, 25%:75%, and 100% of *T. aestivum*) and two surface treatment products, citric acid, and tall oil, in addition to the control treatment without application of product on the surface. Each treatment consisted of 3 particleboards, totaling 45.

The particleboards were manufactured with a nominal density of 750 kg·m^{-3} and dimensions of 400 × 400 × 15 mm. The adhesive system comprised 12% urea-formaldehyde resin and 1% paraffin emulsion. The production process included cold pre-pressing at 0.49 MPa for 15 minutes, followed by a hot pressing cycle at 180 °C and 3.9 MPa for 10 minutes. The particleboards were composed of a single layer.

Application of surface treatments and particleboard properties

The particleboards in nature (without coating) and those that had been subjected to the application of tall oil were stored in a climate chamber at a temperature of 20 °C ± 3 °C and relative humidity of 65% ± 5% until constant mass, while the particleboards to which citric acid had been applied received the solution immediately after leaving the press.

The citric acid was prepared with water in a magnetic stirrer in a ratio of 40:60, i.e., 169 g of citric acid and 254 mL of water per particleboard. The 40 wt.% citric acid ratio was adapted from the study by Sutiawan et al. (2021).

For tall oil, three sequential applications of 50 g each were made (25 g on each side of the particleboard), totaling 150 g per particleboard. This methodology was based on the work of Antunes et al. (2019).

The physical and mechanical properties of the particleboards were determined according to the procedures described in NBR 14810-2 (2018). The compression ratio was defined as the ratio between the density of the particleboard and the density of the raw material used, according to the established proportions.

Data analysis

The results obtained in the evaluation of the particleboard properties were subjected to verification of the normality of the data distribution by the Shapiro-Wilk test and verification of homogeneity by the Bartlett test. Once the assumptions were met, analysis of variance (ANOVA) was performed, and if necessary, the Scott Knott test with 5% significance. The average values obtained for the technological properties of the particleboards were compared with the parameters defined by NBR 14810-2 (2018) for type P2 particleboards for non-structural use, indoors and in dry conditions.

RESULTS

Thermogravimetric analysis

Figure 1 presents the mass loss curves as a function of increasing time and temperature. Five degradation bands were observed for the *E. grandis* particles and four for the *T. aestivum* bran.

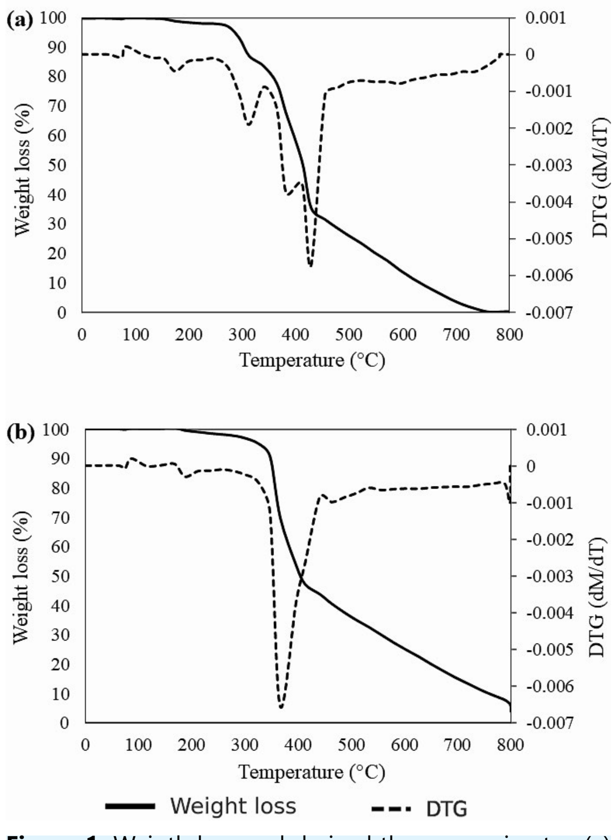

Figure 1: Weigth loss and derived thermogravimetry. (a) *E. grandis*, (b) *T. aestivum*.

In the *E. grandis* particles, the first degradation occurred at 48 °C, while in the *T. aestivum* bran, this degradation was recorded at 63 °C. The second degradation was observed at 154 °C for *E. grandis* and 170 °C for the *T. aestivum* bran. The third degradation band occurred at approximately 280 °C for *E. grandis* and 380 °C for *T. aestivum*.

The fourth degradation band was recorded at 382 °C for the *E. grandis* particles and at approximately 500 °C for the *T. aestivum* bran. Finally, the fifth degradation band was observed at around 400 °C for the *E. grandis* particles. The final mass loss occurred at 735 °C for *E. grandis* and between 743 °C and 799 °C for the *T. aestivum* bran.

Physical properties

The particleboards produced with different compositions of *E. grandis* and *T. aestivum* bran showed average density values (Figure 2a) that did not differ statistically, regardless of the surface treatment applied. Furthermore, no significant differences were observed between surface treatments within the compositions of *E. grandis* and *T. aestivum* bran for the apparent density of the particleboards.

The average compression ratio increased significantly with higher proportions of *T. aestivum* bran, especially above the 50:50 ratio (Figure 2b). On the other hand, surface treatments did not significantly affect the average compression ratio within each composition.

Water absorption and thickness swelling were influenced by the particleboard compositions (Figures 2c and 2d). For particleboards without surface treatment and with tall oil, water absorption increased significantly with 25% *T. aestivum* bran in the composition. For particleboards treated with citric acid, water absorption increased from 50% *T. aestivum* bran in the composition. In other words, the surface treatment with citric acid significantly reduced water absorption in particleboards with 100% and 75% *E. grandis* particles. Conversely, no surface treatment affected thickness swelling, which was higher in particleboards with higher proportions of *T. aestivum* bran.

Mechanical properties

The gradual increase in the proportion of *T. aestivum* bran reduced the modulus of elasticity (MOE) of the particleboards, particularly in compositions equal to or greater than 75%. For the modulus of rupture (MOR), the reduction varied depending on the surface treatment applied. In particleboards without coating, the reduction was more pronounced in compositions equal to or greater than 75%; with citric acid, in compositions equal to or greater than 50%; and with tall oil, in compositions equal to or greater than 25% (Figure 3).

Regarding the effect of surface treatment within the different proportions of *E. grandis* and *T. aestivum* particles, particleboards treated with citric acid exhibited lower average MOR values than those without coating in compositions of 25%, 50%, and 75% bran. Particleboards treated with tall oil showed significantly lower results in all proportions, except for particleboards made exclusively of *E. grandis* particles.

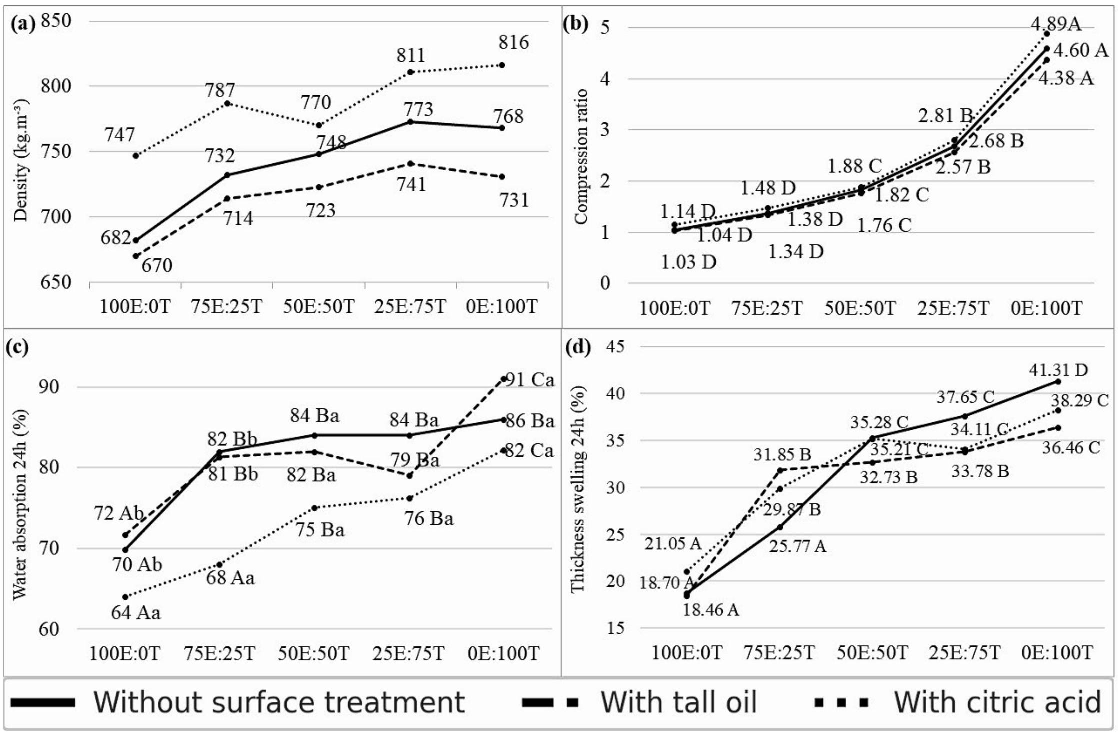

Figure 2: Physical properties of particleboards in nature and with surface treatment. (a) Density, (b) Compression ratio, (c) Water absorption, and (d) Thickness swelling. Legend: E: *E. grandis*. T: *T. aestivum*. Means followed by the same capital letter indicate that there was no statistically significant difference between the different compositions of the particleboards within the same surface treatment, while means followed by the same lowercase letter indicate that there was no statistically significant difference between the particleboards with/without surface treatment within the same composition of *E. grandis* and *T. aestivum*; both by the Scott Knott Test.

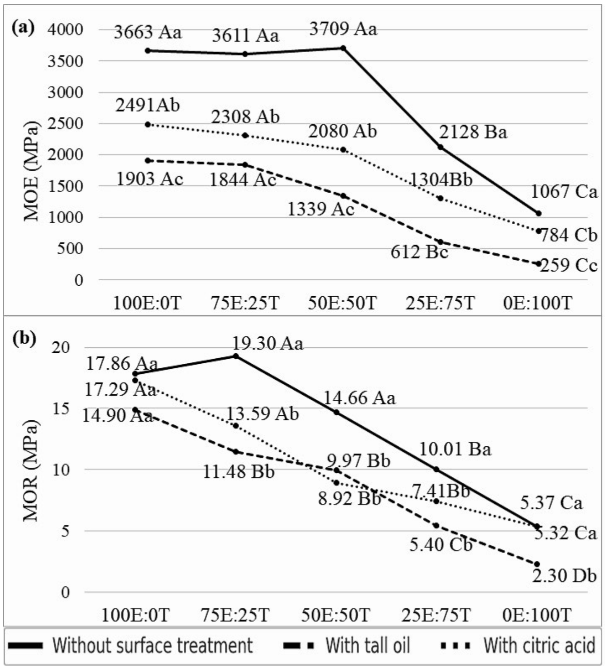

Figure 3: Modulus of elasticity (a) and bending strength (b) of particleboards in nature and with surface treatment. Legend: E: *E. grandis*. T: *T. aestivum*. Means followed by the same capital letter indicate that there was no statistically significant difference between the different compositions of the particleboards within the same surface treatment, while means followed by the same lowercase letter indicate that there was no statistically significant difference between the particleboards with/without surface treatment within the same composition of *E. grandis* and *T. aestivum*; both by the Scott Knott Test.

For MOE, particleboards without coating exhibited the highest averages, followed by particleboards treated with citric acid, which showed intermediate values, and particleboards with tall oil, which recorded the lowest values.

In the internal bond (Figure 4), a reduction in particleboard strength values was also observed as the amount of *T. aestivum* bran increased, particularly at proportions equal to or greater than 50% in particleboards without surface treatment and with tall oil, and at proportions equal to or greater than 25% in particleboards with citric acid. Regarding surface treatment, there was no statistically significant difference among the particleboards within each composition of *E. grandis* particles and *T. aestivum* bran.

DISCUSSION

Thermogravimetric analysis

In general, *E. grandis* particles and *T. aestivum* bran exhibited thermal stability up to approximately 250 °C, with a mass loss of around 10%. Above this temperature, a more pronounced mass loss was observed, indicating that exposing these raw materials to higher temperatures can lead to a loss of structural integrity due to the thermal degradation of their fundamental components.

The first degradation range for *E. grandis* particles is attributed to the loss of adhesion water present in the cell wall, as also observed by Mopoung et al. (2021) in *Eucalyptus spp*. chips and by Gonçalves et al. (2022a) in *E. robusta* and *Corymbia citriodora*. For *T. aestivum* bran, the first degradation range can be attributed to the release of volatile compounds and adsorbed water, similar to what was observed by Ramos et al. (2024), who recorded temperatures between 30 °C and 94 °C during the first degradation when studying pumpkin peel. The greater initial thermal stability of *T. aestivum* bran, evidenced by the first degradation at 63 °C, may be related to the lower amount of adsorbed water compared to *E. grandis* particles.

The second degradation range for *E. grandis* particles can be attributed to the elimination of low molecular weight compounds and the onset of hemicellulose degradation, while for *T. aestivum* bran, it is related to the degradation of various

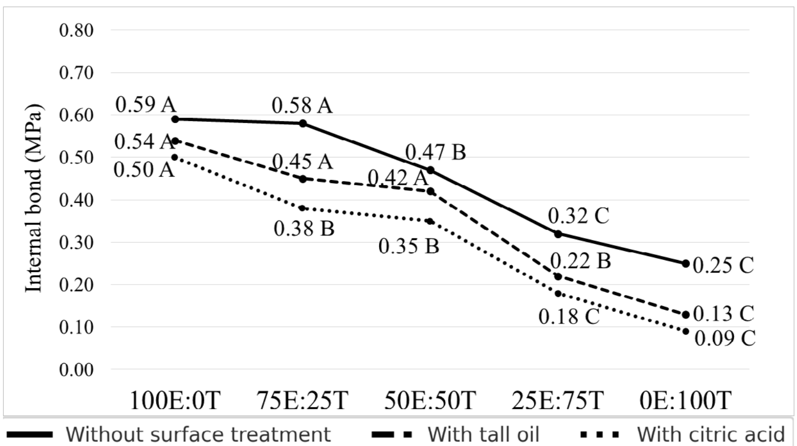

Figure 4: Internal bond of particleboards in nature and with surface treatment. Legend: E: *E. grandis*. T: *T. aestivum*. Means followed by the same capital letter indicate that there was no statistically significant difference between the different compositions of the particleboards within the same surface treatment by the Scott Knott Test.

polysaccharides such as hemicellulose and starch (Tomczak et al., 2007). The higher temperature observed in the second degradation range for *T. aestivum* bran may be explained by the mass loss of sugars present in wheat, such as starch, which requires a higher amount of energy for the depolymerization of its chains and the breakdown of its monomers.

The third degradation range for *E. grandis* particles occurred due to the degradation of hemicellulose and cellulose fractions (Morán et al., 2008). Maarasyid et al. (2024), while studying the mass loss of *Eucalyptus spp*. leaves, also associated with the third range, around 231 °C, with hemicellulose degradation. For *T. aestivum* bran, the third range occurred at a higher temperature (380 °C) but was also associated with hemicellulose and cellulose degradation. At this temperature, the breaking of carbon-oxygen and carbon-carbon bonds occurs, releasing carbon monoxide and carbon dioxide (Da Silva Martins et al., 2015).

In the fourth degradation range, the mass loss for *E. grandis* particles occurred due to cellulose degradation (380 °C). Maarasyid et al. (2024) reported a temperature of 326 °C, while Vinhas et al. (2023) recorded values between 315 °C and 450 °C for the same degradation range. For *T. aestivum* bran, this range was observed at a higher temperature (500 °C), attributed to lignin degradation, possibly reflecting the interaction among lignocellulosic constituents.

The fifth degradation range for *E. grandis* particles (400 °C) is associated with the degradation of lignin components. Tavares et al. (2022) observed that lignin degradation starts at 400 °C, becoming fully carbonized at 560 °C. The final mass decline was observed at 735 °C for *E. grandis* particles and between 743 °C and 799 °C for *T. aestivum* bran, associated with the ash content of the raw materials (Corradini et al., 2009).

These differences in behavior during the thermogravimetric analysis highlight the influence of chemical composition on the thermal properties of the materials. Although both materials are of lignocellulosic origin, the results indicate differences in their chemical structures, suggesting that the interaction with the adhesive during particleboard pressing may occur differently between the raw materials, consequently influencing the physical and mechanical properties of the particleboards.

Physical properties

All particleboards were classified as medium density, within the 600-800 kg.m^{-3} range established by the reference standard, except the panels produced with 75% and 100% *T. aestivum* bran treated with citric acid, which showed values slightly above 800 kg.m^{-3}. Regarding the nominal density (750 kg.m^{-3}), most particleboards fell within ± 5% of the target value, except for untreated particleboards and those with tall oil in the 100% *E. grandis* composition, as well as panels with 75% and 100% *T. aestivum* treated with citric acid. This discrepancy is common in laboratory studies on particleboards and is attributed to challenges in controlling process conditions.

The highest compression ratio values observed in particleboards with higher proportions of *T. aestivum* bran were due to its low density (167 kg.m^{-3}) compared to *E. grandis* particles (653 kg.m^{-3}). Similar trends have been observed in studies utilizing agro-industrial raw materials combined with wood particles, such as sugarcane bagasse (Soares et al., 2017), wheat (Akutagawa et al., 2020), and wheat residues (Vega Villarruel et al., 2023).

Compression ratio values above 1.3, as recommended by Maloney (1993), are associated with particleboards exhibiting satisfactory strength and stiffness but compromised dimensional stability due to increased densification and hygroscopic swelling. In this study, treatments with 25% or more of *T. aestivum* bran met the minimum parameter established by Maloney.

The gradual increase in water absorption and thickness swelling with higher proportions of *T. aestivum* bran can be attributed to its lower density, requiring a greater amount of material to achieve the desired particleboard density. This results in increased exposure to hydrophilic sites, promoting water absorption (Barbirato et al., 2014; Carvalho et al., 2015; Machado et al., 2017; Guimarães Jr. et al., 2016; Farooqi et al., 2019). High absorption and thickness swelling are also linked to the chemical composition of *T. aestivum*, which has a low lignin content and high holocellulose, reducing the particleboards hydrophobicity (Lee et al., 2020; Halvarsson et al., 2008; El-El-Kassas and Mourad, 2013; Karade, 2010).

As observed in other studies, the substitution of wood particles with non-conventional raw materials compromises dimensional stability. Vega Villarruel et al. (2023) reported similar results with *P. oocarpa* and wheat residues, Gonçalves et al. (2022b) with rice husk and *P. taeda*, and Ferreira et al. (2019) with coffee husk.

Particleboards with *T. aestivum* bran did not meet the maximum thickness swelling limit of 22% established by NBR 14810-2 (2018).

Mechanical properties

The reduction in the average MOE and MOR values with the increasing proportion of *T. aestivum* bran in the particleboards is attributed to its chemical composition, which differs from traditional wood particles. It has lower levels of lignin and cellulose, higher ash and extractive content, and elevated concentrations of protein and starch (Neitzel et al., 2023). These characteristics directly interfere with the adhesion between the bran and the adhesive, negatively impacting the particleboard properties (Roffael, 2016; Bardak et al., 2017). Similar reductions in MOE and MOR were reported by Vega Villarruel et al. (2023) for particleboards made with *Pinus oocarpa* residues and wheat bran.

Other studies using unconventional raw materials from the agricultural sector or agro-industrial residues combined with wood particles in particleboard production have also shown reductions in MOE and MOR values, such as Duran et al. (2023) with sugarcane bagasse, Scatolino et al. (2019) with cotton residues, and Tupciauskas et al. (2021) with hemp and wheat straw.

The morphology of *T. aestivum* bran should also be considered, as it differs from other materials derived from bark and agro-industrial residues. The outer layer of wheat is deformed during processing, leaving the remaining individual layers with low adhesion between them, which may limit performance under load (Neitzel et al., 2023). Wheat bran particles with less uniform structures may not interact adequately with adhesives, compromising particleboard integrity (Kollmann and Côté, 2013).

The reduction in the average MOE and MOR values for particleboards treated with citric acid can be explained by the chemical components of the wood, lignin, and cellulose, which are softened during particleboard pressing, consequently determining the bonds between fibers/particles (Wang et al., 2024). When citric acid treatment is used, the dissolution of non-crystalline materials such as hemicellulose and the amorphous region of cellulose may occur, where depolymerization happens in the amorphous region through the breaking of β-(1,4) bonds between the saccharide units of cellulose (Xu et al., 2020).

It is also important to note that the decomposition of citric acid into unsaturated acids occurs when heated to 175 °C and that the reaction mechanism between wood components and the acid involves two-step esterification. First, the hydroxyl groups of the carboxylic groups in the polycarboxylic acid are dehydrated to form an anhydride, and then the hydroxyl groups of the wood and the anhydride undergo a nucleophilic substitution reaction to form an ester. It is believed that crosslinking reactions between the polycarboxylic acid and the wood did not occur, as the citric acid was sprayed onto the hot surface of the particleboard after pressing, and the temperature was insufficient for ether bond formation (Nitu et al., 2022). Similarly, Lee et al. (2020), studying the modifying and binding effect of citric acid, reported that its use led to a reduction in MOR. Šefc et al. (2012) reported that *Roupala montana Aub.* wood modified with citric acid did not show significant improvements in MOR and MOE properties.

For the particleboards treated with tall oil, the reduction in MOE and MOR was attributed to the presence of an oily surface even days after application, indicating that the oil negatively interfered with adhesion. When oils interact with the adhesive, they can reduce the strength and deformation of the polymer, consequently decreasing intermolecular friction between adhesive components. According to Parakar et al. (2021), with the variable composition of fatty acids, the ozonolysis reaction produces mono-, di-, and triols when in contact with resins, generating a portion of unreacted oil. However, this portion can reduce cohesive strength, which would explain the low values found.

Regarding compliance with the minimum parameters established by NBR 14810 (2018) for non-structural particleboards for indoor use under dry conditions, it was observed that only particleboards with a high proportion of *E. grandis* in their composition with *T. aestivum* bran met the minimum requirements of 1600 MPa for MOE and 11 MPa for MOR. In this regard, noteworthy are particleboards without surface treatment with up to 50% *T. aestivum* bran and particleboards treated with citric acid and tall oil with up to 25% *T. aestivum* bran.

Regarding the internal bond of the particleboards, other studies have also reported a significant reduction when incorporating agro-industrial residues, such as Oh and Lee (2012), who produced particleboards with wheat stalks. In addition to the factors mentioned in the discussion of MOE and MOR, which also influenced internal bonding, Alade et al. (2022) described that the significant reduction can be attributed to the low compatibility between wheat bran and urea-formaldehyde resin. This incompatibility occurs due to the presence of a waxy outer layer and the low porosity of the bran, which hinders the resin's penetration into the raw material, as well as its pH and buffering capacity.

The pH and buffering capacity of raw materials are critical for adhesive interaction, as acidity affects curing and bonding behavior. Most adhesive systems require a specific pH range and buffering capacity for proper curing (Alade et al., 2022). Wheat bran has an almost neutral pH but a buffering capacity three times higher than other residues, such as barley and oat husks (Neitzel et al., 2023). This high buffering capacity complicates the definition of the pH range, leading to unstable adhesive behavior. During the bonding process, clumps formed in the wheat bran, reducing the adhesive's wettability and causing poor distribution, which decreased internal bond values (Guimarães Jr. et al., 2016).

The only treatments that met the minimum requirement of 0.35 MPa, as specified by NBR 14810-2 (2018), were those composed of up to 50% *T. aestivum* bran, regardless of the surface treatment applied.

CONCLUSION

The study identified significant differences in the thermal degradation profiles of *Eucalyptus grandis* particles and *Triticum aestivum* bran, with the integrity of both materials compromised at temperatures exceeding 250 °C. Particleboards with higher proportions of *T. aestivum* bran exhibited an increased compression ratio but suffered reductions in dimensional stability, modulus of elasticity (MOE), and modulus of rupture (MOR). While citric acid improved water absorption, it did not significantly affect thickness swelling, and tall oil failed to enhance either dimensional or mechanical properties. Only particleboards with a higher *E. grandis* content complied with the requirements of the NBR 14810-2 standard, underscoring the necessity for further research to optimize surface treatments and enhance the compatibility of alternative raw materials in particleboard production.

In conclusion, *T. aestivum* bran demonstrates potential as an alternative raw material for particleboard production, particularly in proportions of up to 50%, irrespective of the surface treatment applied. Nonetheless, adjustments to treatments or proportions are essential to improve its final properties and ensure compliance with quality standards.

AUTHORSHIP CONTRIBUTION

Project Idea: A.B. C.; P. D. R.

Funding: P. D. R.

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Processing: A. S. S.; R. O. S.

Analysis: A. S. S.; A.B. C.

Writing: A. S. S.; C. A. C.

Review: A.B. C.; C. A. C.; P. D. R.

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