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Articles

Exploring the potential of *Pittosporum undulatum* wood: a comprehensive analysis of the main technological properties

Explorando o potencial da madeira de *Pittosporum undulatum*: uma análise abrangente das principais propriedades tecnológicas

Maurício Alves Ramos[I], Silvia Helena Fuente[II], Thales Castilhos de Freitas[III], Kelvin Techera Barbosa[IV], Ernestino de Souza Gomes Guarino[V], Alexandra Augusta Reichert[VI], Marília Lazarotto[I], Rafael Beltrame[I]

[I]Federal University of Pelotas, Pelotas, RS, Brazil
[II]Embrapa Florestas, Colombo, PR, Brazil
[III]Universidade Federal de Juiz de Fora, Juiz de Fora, MG, Brazil
[IV]Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil
[V]Embrapa Clima Temperado, Pelotas, RS, Brazil
[VI]Independent Researcher, Pelotas, RS, Brazil

ABSTRACT

The proliferation of invasive alien species (IAS) such as *Pittosporum undulatum* poses a significant challenge to the stability of natural ecosystems. Its rapid spread makes the eradication and restoration of affected areas unfeasible due to high management costs. This study evaluates the potential to add value to *P. undulatum* wood, looking for ways to transform it into a valuable resource for local communities. To this end, five adult trees were analyzed for their chemical, thermal, calorific, physical, and mechanical properties. The analysis revealed 2.35% extractives, 25.56% lignin, and 0.92% ash content, with a calorific value of 4561.2 kcal/kg. With an apparent specific density 0.655 g/cm³ the mechanical properties included modulus of rupture (MOR) of 58.27 MPa. The perpendicular Janka hardness was 1841 kgf/cm². The wood of *P. undulatum* exhibited properties comparable to commercially available woods, suggesting viability for energy-related applications and the furniture industry, albeit with some limitations. The results indicate the potential to integrate its management with financial returns.

Keywords: Calorific value; Economic return; Invasive alien species; Sustainability; Forest management

RESUMO

A proliferação de espécies exóticas invasoras (EEIs) como o *Pittosporum undulatum* representa um grande desafio para a estabilidade dos ecossistemas naturais. Sua rápida disseminação torna a erradicação e restauração de áreas afetadas inviáveis devido aos altos custos de manejo. Este estudo avalia o potencial de agregar valor à madeira de *P. undulatum*, buscando formas de transformá-la em um recurso valioso para comunidades locais. Para isso, cinco árvores adultas foram analisadas quanto a suas propriedades químicas, térmicas, caloríficas, físicas e mecânicas. A análise revelou 2,35% de extrativos, 25,56% de lignina e 0,92% de cinzas, com valor calorífico de 4561,2 kcal/kg. Com densidade específica aparente de 0,655 g/cm³, as propriedades mecânicas incluem módulo de ruptura (MOR) de 58,27 MPa. A dureza Janka perpendicular foi de 1841 kgf/cm². A madeira do *P. undulatum* mostrou propriedades comparáveis a madeiras comercialmente disponíveis, sugerindo viabilidade para aplicações energéticas e na indústria moveleira, com algumas limitações. Os resultados indicam a possibilidade de integrar seu manejo com retornos financeiros.

Palavras-chave: Poder calorífico; Economia de retorno; Espécies invasoras; Sustentabilidade; Manejo florestal

1 INTRODUCTION

The preservation of natural environments is extremely important due to the various ecosystem services they provide, which ensure the survival of species and, consequently, help maintain the balance of the planet (Zakrzevski; Vargas, 2020). In recent decades, concern over environmental degradation has become more pronounced, reflected in research and strategies aimed at mitigating the negative impacts of human activity (Aronson *et al*., 2020).

Unsustainable human intervention in different ecosystems has led to a significant reduction in natural vegetation cover over the past years (Projeto Mapbiomas, 2020). These interventions are generally the result of expansions for agricultural or urban activities (Millennium Ecosystem Assessment, 2005), causing environmental imbalance that can promote the introduction of invasive alien species (IAS).

The introduction of alien species is a global phenomenon that can have significant ecological consequences. When an alien species becomes invasive, establishing itself in a given area, Therefore, as an alternative for managing invasive species, some can be used to generate resources, thus combining control with income generation, such as for bioenergy production, bioethanol, and furfural, as seen in the case of *Arundo donax* (Amaducci; Perego, 2015; De Bari *et al*., 2020), or for anti-inflammatory properties and honey production, as is the case with *Pittosporum undulatum* (Mendes *et al*., 2013; Moura *et al*., 2023).

Among IAS, *P. undulatum*, commonly known as sweet pittosporum or mock orange, has stood out as a highly impactful invasive plant in various ecosystems worldwide, including in Brazil (Lourenço *et al*., 2011; Mielke *et al*., 2015). Originating from Australia and belonging to the Pittosporaceae family, *P. undulatum* has been widely introduced into different regions due to its ornamental characteristics and adaptability to various soil types and climates (Bellingham *et al*., 2018; Castilhos *et al*., 2020). However, despite its adaptability, it is classified as an invasive species, requiring efficient management strategies.

One possible approach to managing *P. undulatum* is its utilisation for energy purposes, as documented in Jamaica, where it is used as firewood, and in some islands of the Azores (Goodland; Healey, 1996; Lourenço *et al*., 2011). Given the high costs associated with controlling and eradicating invasive alien species (IAS) (Pimentel *et al*., 2000), adding value to these species can help offset management expenses while generating economic benefits for local communities (Lourenço *et al*., 2011). In this context, *P. undulatum* wood presents potential advantages, as revenues from its use can be reinvested in the conservation of invaded areas.

Beyond its energetic potential, *P. undulatum* wood possesses other characteristics that may make it suitable for industrial applications. Studies on its chemical composition, thermal stability, physical and mechanical properties can provide valuable insights into its broader usability, such as in composite materials, construction, and bioproducts. Further research is necessary to assess these aspects comprehensively (Silva *et al*., 2017). Therefore, the objective of this study is to investigate the potential applications of *P. undulatum* wood by characterising its chemical, thermal, calorific, physical, and mechanical properties.

2 MATERIALS AND METHODS

The *P. undulatum* trees were extracted from a fragment of semideciduous seasonal forest with a high degree of bioinvasion (Karam; Cardoso, 2010), belonging to Embrapa Clima Temperado, located in the Serra dos Tapes in the city of Pelotas, Rio Grande do Sul, Brazil. After receiving the material, logs from five different adult trees, with diameters at breast height (DBH) ranging from 19 cm to 25 cm, were selected for subsequent preparation of specimens in dimensions suitable for chemical, physical, mechanical and biomass energy yield tests. The study was carried out in the Pelotas region, characterized by a temperate climate and a diverse ecosystem. All samples of *P. undulatum* wood were collected in a way that ensured that they were representative and accurately preserved. All tests and chemical characterizations were conducted at the Laboratory of Physical Properties of Wood of the Federal University of Pelotas.

2.1 Physical and mechanical properties

The apparent specific density at 12% was determined in accordance with ASTM D2395 (2022), using the gravimetric method, the test specimens were the same as those used in the mechanical tests taken from the log with DBH as per Equation (1).

$$ME_{12\%} = W / V \quad (1)$$

where: *W* = sample weight; *V* = volume.

For the mechanical property tests, eight test specimens (TSs) take from DBH of were prepared from each tree for the static bending, compression parallel to the grain, and Janka hardness tests, with the latter performed with two measurements on each face (radial and tangential) of the TS, according to the ASTM D143 (2000) standard. The tests were conducted using an EMIC 30kN universal testing machine, located in the Mechanical Properties Laboratory at the Federal University of Pelotas.

2.2 Chemical and calorific properties

The chemical characterisation was carried out based on TAPPI standards (2016), in triplicate for each of the five trees. Wood samples were obtained through milling using a Willey-type knife mill (model MA340 – Marconi) after mechanical testing. Only particles passing through a 40-mesh sieve and retained on a 60-mesh sieve (TAPPI T 257, 2012) were used. The moisture content and ash content were determined according to the TAPPI T-211 standard.

Extractives were obtained by means of a Soxhlet system, using ethanol-toluene (1:2 v/v) as solvents and 8 g of sample (TAPPI T-204) using reagent such as ethyl alcohol P.A.-ACS and toluene P.A.-ACS purchased from Êxodo; for the determination of Klason lignin (TAPPI T-222) using sulfuric acid from Êxodo, 1 g of sample was used. For the quantification of the holocellulose content, 4.5 g of sample (TAPPI T-257) were used sodium hydroxide P.A-ACS and sodium chlorite 25% from Êxodo and glacial acetic acid P.A>-ACS from Synth; for the α-cellulose content (TAPPI T-222), 2 g of sample were used, and hemicellulose was determined by difference.

The thermal properties of *P. undulatum* wood were evaluated through thermogravimetric analysis (TGA) in a controlled nitrogen atmosphere (50 mL/min), with a heating rate of 5ºC/min, ranging from ambient temperature to 600ºC. For this analysis, 2 g of each sample were used. The higher heating value (HHV) was determined after the complete combustion of 0.4 g of a previously dried sample, while the lower heating value (LHV) was calculated using Equation (2) (GOMIDE, 1984), considering a hydrogen content of 2%, as reported by LOURENÇO *et al*. (2011) for *P. undulatum*. Measurements were conducted using an isoperibolic calorimeter, model PARR 6200.

$$PCI = PCS - 600\left(\frac{9H}{100}\right) \quad (1)$$

where: LCV = lower calorific value (kcal.kg^{-1}); HCV = higher calorific value (kcal.kg^{-1}); 600 = enthalpy of water vaporisation at ± 25ºC; H = hydrogen content (% on a dry basis).

3 RESULTS AND DISCUSSIONS

3.1 Physical and mechanical properties

The apparent specific density at 12% moisture content (MEA12%) of Pittosporum undulatum wood had an average value of 0.655 g.cm⁻³ (Table 1). When compared to reforestation species, this value is considered lower than those reported by Acosta *et al*., (2021) for species of the genera Eucalyptus and Pinus. However, it is higher than the values reported by Torres *et al*., (2016) and Talgatti *et al*., (2018), who studied E. camaldulensis and various clones of Eucalyptus from different regions of Brazil.

Table 1 – Average values of apparent specific density at 12% moisture content for wood samples from the five P. undulatum trees

	A1	A2	A3	A4	A5	Average (sd)
$MEA_{12\%}$ g.cm^{-3}	0,649 (0,0294)	0,662 (0,0424)	0,674 (0,0820)	0,608 (0,0503)	0,656 (0,0340)	0,655 (0,0477)

Source: Authors (2023)

In where: SD is standard deviation.

Other studies using *Pittosporum undulatum* wood have observed specific density values varying according to the position within the tree: 0.580 g.cm^{-3} near the pith, 0.600 g.cm^{-3} in the intermediate portion, and 0.610 g.cm^{-3} near the bark. The authors attributed the increase in specific density towards the bark to the pioneering characteristics of the species, which is characterised by rapid height growth, resulting in lighter wood during the early stages. After reaching the canopy, there is greater mass increment to support the tree, thus increasing the wood density.

In a study conducted in Jamaica, where *P. undulatum* is also considered an invasive species and widely used for energy purposes, the basic specific density (BSD) was found to be 0.780 g.cm^{-3}, which is higher than the value found in the present work. In this study, the authors used samples from trees with a diameter of up to 31 cm, which were air-dried for 25 months at approximately 25ºC (Healey; Goodland; Hall, 1992).

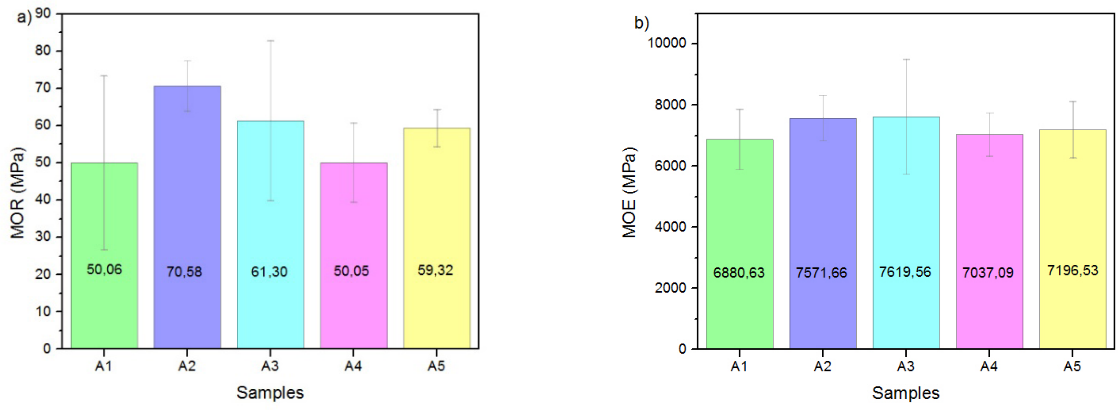
These variations in specific density can be explained by differences in growth conditions and wood preparation methods, which directly impact the physical properties and suitability of the wood for different applications. The higher density observed in Jamaica may indicate greater strength and calorific potential, emphasising the importance of considering local conditions and tree maturity when evaluating the biomass energy yield tests (Tanner, 1980).

The density of wood is a key factor in determining its suitability for different applications. Although the specific density of *P. undulatum* is relatively lower than that of some reforestation species, it still presents promising characteristics for energy and structural uses. Specific density is related to mechanical strength and calorific value, which reinforces the potential of the wood for both direct combustion and applications requiring strength, such as in furniture or light structures. according to Lukas Emmerich *et al*. (2019) Anatomical characteristics significantly affect the structural integrity of wood, with hardwoods influenced by the size, density and distribution of vessels, while softwoods are influenced by the edges of growth rings and resin canals.

The analysis of the mechanical properties of *Pittosporum undulatum* wood is crucial to guide its appropriate use, such as in structural applications or the furniture sector, where mechanical strength is fundamental. The results for static bending, compression parallel to the grain, and hardness are presented in Figures 1-3.

For the modulus of rupture (MOR) in static bending (Fig. 1a), values varied among the samples, with A2 showing the highest value (70.59 MPa) and A1 and A4 the lowest (50.06 MPa), resulting in a variation of 40%, it can be attributed to several factors, such as density, the location from which the wood was sourced, and the chemical composition of the tree. On average, the MOR was 58.27 MPa, similar to that found by Talgatti (2018) for *E. grandis x E. urophylla* hybrids (53.07 MPa), but lower than that of other eucalypts, which reached values above 65.7 MPa (Lobão *et al.*, 2004). The modulus of elasticity (MOE) was more homogeneous among samples (Fig. 1b), with a variation of only 11% and an average value of 7261.10 MPa, which is lower than reported in studies with various *Eucalyptus* species (Beltrame *et al*., 2015; Lima *et al*., 2018; Müller *et al*., 2014; Talgatti *et al*., 2018). These results indicate that *P. undulatum* has potential for use in furniture and civil construction, comparable to species such as *P. elliottii* or *P. taeda* (De Moraes Neto, 2009), and even for musical instruments, like mahogany (*Swietenia macrophylla*) (Stooten, 1987).

Figure 1 – Static bending resistance: modulus of rupture (MOR) (a) and modulus of elasticity (MOE) (b) for *P. undulatum* wood. Vertical lines represent the standard deviation

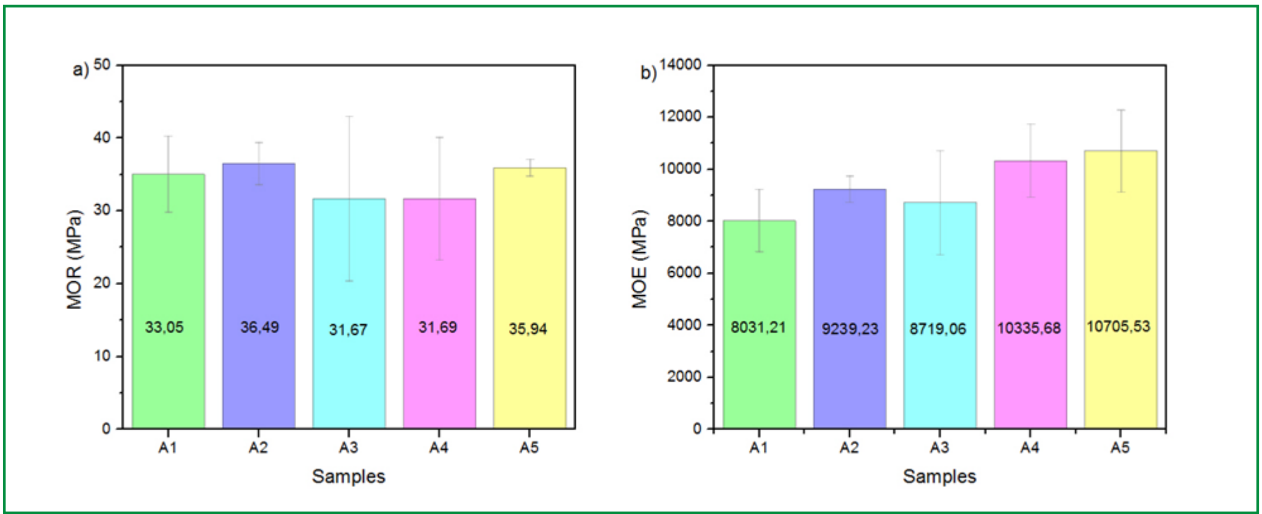


Source: Authors (2023)

The analysis of compression parallel to the grain provides important insights into the suitability of wood for applications involving axial loads, such as beams and furniture legs. With an average MOR of 34 MPa (Fig. 2a) and MOE of 9406 MPa (Fig. 2b), the results of this study indicate significant mechanical performance for the analyzed wood. Although the MOR values are consistent with those found by Müller *et al*. (2014) for *Eucalyptus benthamii*, the higher elasticity (MOE) observed in this study suggests that the wood may possess flexibility characteristics that make it particularly suitable for structural applications.

The comparison with data from Lobão *et al*. (2004), who reported higher MOR and MOE values for *Eucalyptus spp.*, highlights the variability among different wood species and underscores the importance of considering these differences when selecting materials for specific projects. This variation can impact not only strength but also durability and behavior under loads, which is crucial for ensuring the safety and efficiency of structures. Additionally, the fact that Arroyo *et al*. (2023) reported the highest MOR value for the wood of *Calophyllum sp.* indicates that there are species that surpass the strength characteristics of common woods, such as those from the *Eucalyptus* genus.

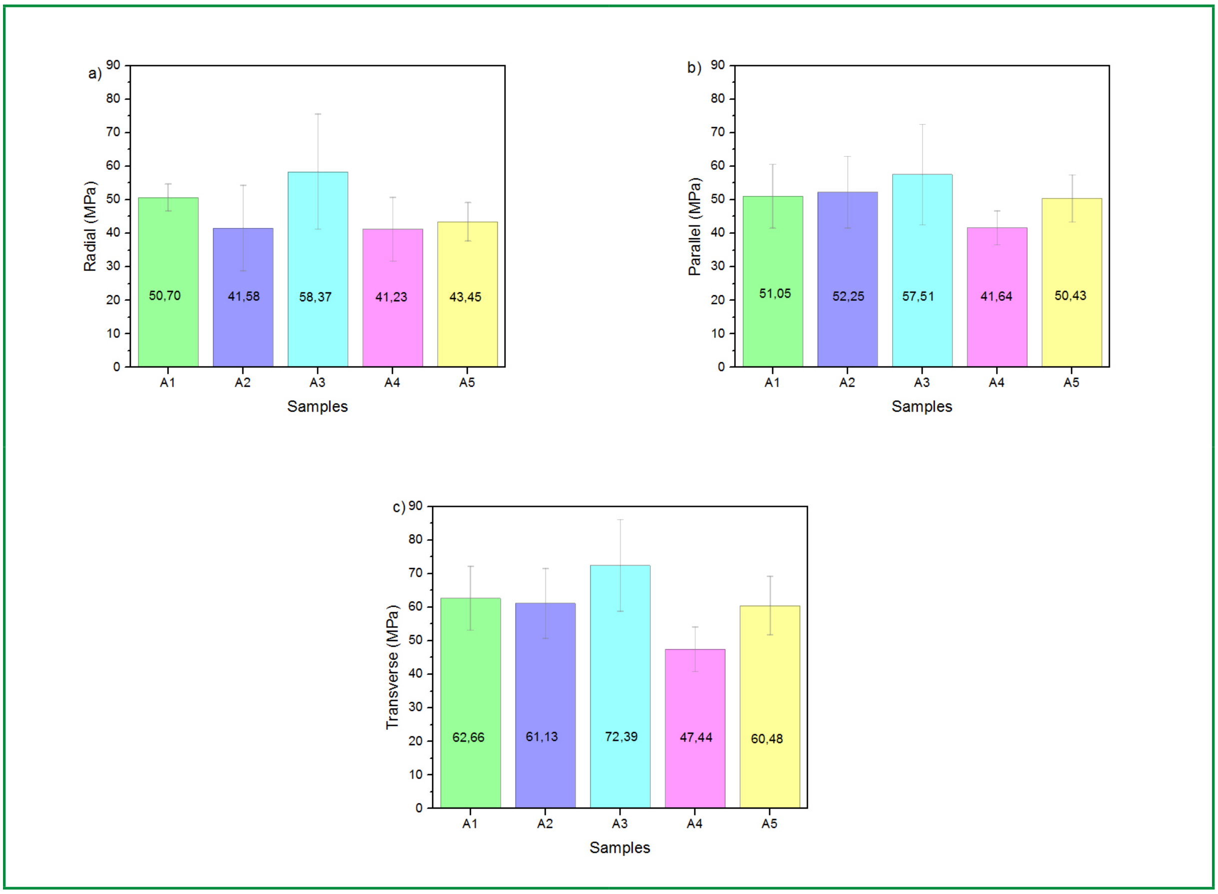
Figure 2 – Compression resistance: modulus of rupture (MOR) (a) and modulus of elasticity (MOE) (b) for *P. undulatum* wood. Vertical lines represent the standard viation for each tree



Source: Authors (2023)

For wood hardness, results show an average of 47 MPa for radial hardness (Fig. 3a) and 50 MPa for parallel hardness (Fig. 3b), with variations of up to 41% among samples. These values are lower than those reported by Gallio *et al*. (2016) for *E. benthamii*, where radial hardness was 65.4 MPa and parallel hardness was 73.7 MPa. The transverse hardness (Fig. 3c) was 60 MPa, lower than the 73 MPa reported for *E. benthamii*, but similar to values obtained by Leonello *et al*. (2012) for *Hevea brasiliensis* clones.

Figure 3 – Janka hardness resistance: radial (a), tangential (b), and end (c) for *P. undulatum* wood. Vertical lines represent the standard deviation for each tree



Source: Authors (2023)

The results confirm the potential of *P. undulatum* wood for use as biomass energy, due to its calorific value comparable to other commercial species and low ash content. In addition, the mechanical properties suggest its feasibility for use in the furniture and construction sectors, as well as in control and management programmes for this invasive species. However, caution must be taken when removing mature individuals, as clearing can increase seedling recruitment and cause further invasions. Management should be planned alongside environmental agencies, combining species control with ecological restoration plans and income generation for local communities.

3.2 Chemical and calorific properties

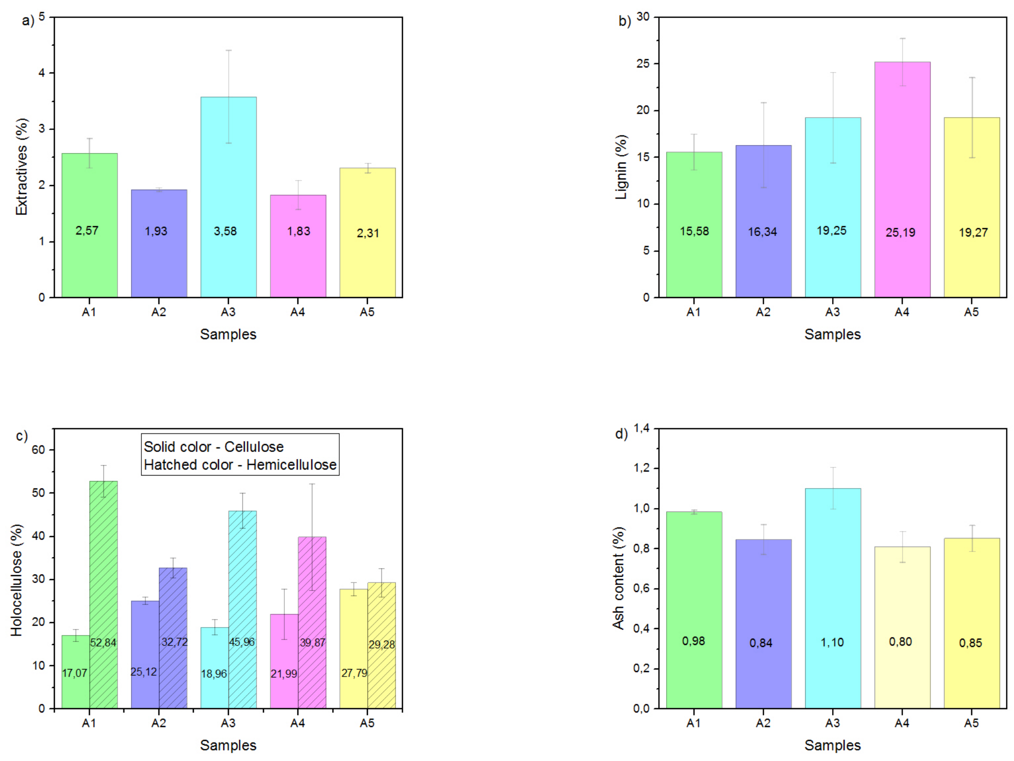
The evaluation of the chemical properties and calorific value of plant species is essential for understanding their potential as renewable energy sources. The calorific value, which measures the amount of energy released during combustion, is influenced by factors such as the chemical composition of the biomass, including ash content, lignin, and cellulose (Gama *et al*., 2019).

The extractive content of *Pittosporum undulatum* wood was, on average, 2.35% (Fig. 4a), which is similar to the values observed for plantation species such as *Eucalyptus grandis* and *Eucalyptus pellita* (Acosta *et al*., 2021; Abd Hilmi *et al*., 2023). In other studies involving eucalyptus clones, higher values have been reported, ranging from 2.9% to 6.7% (Castro *et al*., 2016; Ramos *et al*., 2023). This variation occurs due to the composition and content of extractives, which can vary significantly depending on several factors, such as species, position within the tree, age, heartwood/sapwood ratio, among others (Burger; Richter, 1991; Gama *et al*., 2019).

There is an inverse relationship between the extractive content and charcoal yield (Pereira *et al*. 2013a). The higher the extractive content, the lower the charcoal yield, as extractives present in young trees are easily degraded at low temperatures. On the other hand, the higher number of extractives in the heartwood, resulting from tree ageing, contributes to an increase in the higher calorific value (Castro *et al*., 2016; Protásio *et al*., 2013).

His average lignin content of *Pittosporum undulatum* wood was 20.56% (Fig. 4b), with individual values of 15,58%, 16,34%, 19,25%, 25,19%, and 19,27% for samples A1, A2, A3, A4, and A5, respectively. These values fall within the average range for hardwood species and are comparable to those reported for hybrid clones of *Eucalyptus urophylla x E. grandis*, *E. camaldulensis x E. grandis*, and *E. camaldulensis x E. urophylla*, which range from 20% to 33% (Castro *et al*., 2016; Dos Santos *et al*., 2016; Ramos *et al*., 2023).

Figure 4 – Average percent of each tree for: a) extractives, b) lignin, c) holocellulose (cellulose and hemicellulose), and d) ash. Note, vertical lines represent the standard deviation of each tree



Source: Authors (2023)

Among the analysed samples, A4 had the highest lignin content (25%), suggesting a high biomass energy yield tests for combustion. Lignin has a higher calorific value compared to other wood components, such as cellulose and hemicellulose, making it a key component for energy applications.

Among the structural components of wood, lignin has the highest resistance to thermal degradation (Pereira *et al*., 2013b). Therefore, a higher lignin content is associated with better quality and yield of charcoal due to its high fixed carbon content and thermal stability (Protásio *et al*., 2013).

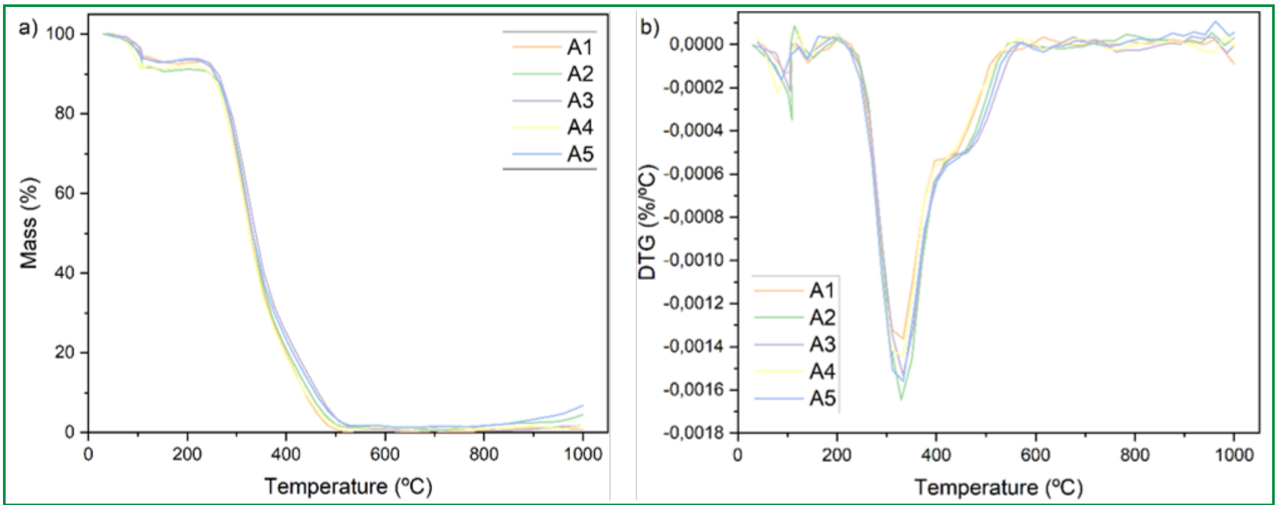
Figure 4c shows the average values of cellulose (22.19%) and hemicellulose (40.15%), resulting in a total holocellulose content of 62.34%. This value is similar to the results of 63% and 65% reported by Ramos *et al*. (2023) and Dos Santos *et al*. (2016), respectively, in studies on eucalyptus wood. In both studies, the authors concluded that the species studied had biomass energy yield tests. It is worth noting that hemicellulose and cellulose are thermally less stable than lignin, which may result in lower charcoal yield for samples with higher holocellulose content (Gama *et al*., 2019).

The energetic performance of a given wood species is not only influenced by its holocellulose content but also by other factors, such as ash content. In general, high ash content is undesirable, not only because it causes damage to equipment (Protásio *et al*., 2013), but also due to its negative correlation with the calorific value (Gama *et al*., 2019). Figure 4d shows the ash content present in the samples of *P. undulatum*, which was, on average, 0.92%. This value is higher than that reported by Nones *et al*. (2015), who found 0.34% for *E. benthamii*, but lower than that observed for native *Copaifera arenicola* wood (1.9%) studied by Gama *et al*. (2019). These authors concluded that *Copaifera arenicola* shows biomass energy yield tests, despite its higher ash content. The wood density of this species is 0.614 g/cm³, similar to that of *Pittosporum undulatum*, which is relevant considering its high ash content, indicating an important relationship between the biomass composition and its energy properties.

The thermogravimetric analysis (TGA) and Derivative thermogravimetric (DTG) curves of *P. undulatum* wood are shown in Figures 5a-b. The TG curves exhibited similar behaviour for all five trees, with two distinct regions (Fig. 5a). In Region I, water elimination occurs (~100 ºC) along with the thermal decomposition of low molecular weight compounds present in the amorphous regions of the wood (~140 ºC). The thermal decomposition of structural components, such as lignin and crystalline cellulose, occurs in Region II, between 180 ºC and 573 ºC (Zhou *et al*., 2017), with a maximum mass loss (~41%) around 330 ºC, as observed in Fig. 5b.

This pronounced thermal degradation occurred at a lower temperature compared to that found by Andrade *et al*. (2019) in their study of *Hovenia dulcis* wood for energy use, and by Araújo *et al*. (2018) in their research on *Cenostigma macrophyllum* and *Eucalyptus* sp. The high hemicellulose content (Fig. 4c) likely contributed to the lower thermal stability of *P. undulatum* wood, as hemicelluloses are composed of amorphous, low molecular weight compounds that degrade more readily at lower temperatures (Poletto *et al*., 2012).

Figure 5 – Thermogravimetric curves (left) and thermogravimetric derivatives (right) of the samples



Source: Authors (2023)

It is worth noting that these thermal properties indicate that *P. undulatum* wood may be a good candidate for energy applications, where a rapid release of energy is needed, such as in direct combustion processes for heat generation. Detailed thermal characterisation is essential to understand how the chemical composition affects the thermal decomposition behaviour, enabling the optimisation of its use as a renewable energy source.

The average higher calorific value (HCV) of *P. undulatum* wood was 4561.2 kcal. kg^{-1}, while the lower calorific value (LCV) was 4453.2 kcal.kg^{-1} (Table 2). These values are lower than those reported by Lourenço *et al*. (2011) for *P. undulatum* in Portugal, which obtained 4875 kcal.kg^{-1} for trunks and branches. This difference can be attributed to environmental conditions and wood composition, as the author did not specify the age of the material analysed (Brand; Muñiz, 2010; Leite *et al*., 2014; Gama *et al*., 2020).

Table 2 – Higher calorifc value (HCV) and lower calorific value (LCV) of *Pittosporum undulatum* wood

Tree	**HCV (kcal.kg^{-1})**	**LCV (kcal.kg^{-1})**
A1	4656 ± 5.055	4548 ± 5.055
A2	4629 ± 7.177	4521 ± 7.177
A3	4519 ± 64.254	4411 ± 64.254
A4	4564 ± 38.996	4456 ± 38.996
A5	4438 ± 11.745	4330 ± 11.745
Average	4561.2	4453.2

Source: Authors (2023)

When comparing the HCV of *P. undulatum* with other species, it was observed that the wood of this invasive alien species presented, in some cases, similar or superior values. The HCV of *P. undulatum* was higher than that of *Mimosa scabrella*, approximately 15 years old, cultivated in an agroforestry system (Friederichs *et al*., 2015), *Eucalyptus benthamii*, 13 years old from commercial plantations (Nones *et al.,* 2015), and *Pinus elliottii*, 22 years old from windbreak plantations (Balloni, 2009). However, the HCV was lower when compared to *Hovenia dulcis*, from individuals with no information on age or DBH (Rigatto *et al*., 2001), and *Acacia mearnsii*, three years old from commercial plantations (Eloy *et al*., 2015).

The analysis of HCV and LCV values indicates that *P. undulatum* wood has potential for energy use, comparable to other species already utilised for this purpose. Furthermore, the lignin content, as discussed earlier, contributes to the higher calorific value of the wood, reinforcing its potential as biomass for combustion and energy generation. The relationship between chemical components, such as lignin and cellulose, and the calorific value suggests that *P. undulatum* could be a viable alternative, especially considering its invasive nature and the need for controlled management.

In comparison with other biomass sources, the wood of the invasive alien species (IAS) *Pittosporum undulatum* showed calorific values similar to sawdust briquettes from exotic tree species such as *Eucalyptus grandis* and *Pinus sp.*, and the native species *Tabebuia impetiginosa*, as well as the herbaceous biomass of *Pennisetum purpureum* (Table 3).

Table 3 – Comparision of the higher calorific value (HCV) and basic specific mass (BSM) *Pittosporum undulatum* with other species and biomasses

Wood			
Author	**Species**	**HCV (kcal kg^{-1})**	**BSM (g cm^{-3})**
Friederichs *et al*., 2015	*Mimosa scabrella*	4400	0.57
Nones *et al*., 2015	*Eucalyptus benthamii*	4194	0.5
Balloni, 2009	*Pinus elliottii*	4323	0.47
Current research, 2024	***Pittosporum undulatum***	**4561**	**0.58**
Lourenço *et al.,* 2011	*Pittosporum undulatum*	4875	-
Rigatto *et al* 2001	*Hovenia dulcis*	4534	0.54
Eloy *et al* 2015	*Acacia mearnsii*	4577	0.47
Leite *et al*, 2014	*Coffea arabica*	4675	0.69

Source: Authors (2023)

For charcoal, it is well known that calorific efficiency is generally higher compared to non-carbonised biomass, due to the increased fixed carbon content in the wood through thermal treatment (Almeida; Rezende, 1982). As expected, all listed charcoal species had a considerably higher HCV than the IAS wood evaluated (Table 3). Although the charcoal from *P. undulatum* was not studied here, future research on this energy application is recommended, considering the promising results for higher calorific value and basic specific density, which were similar to or even higher than those of commercially used species typically employed for energy production.

This assessment reinforces the potential of *P. undulatum* as a viable alternative for energy production, whether as biomass for direct combustion or as charcoal. The utilisation of this invasive species can be particularly beneficial, not only for its biomass energy yield testsbut also for the ecological advantage of reducing its prevalence in invaded areas.

4 CONCLUSIONS

- *P. undulatum* wood exhibits characteristics that allow its use in various sectors, adding value to this invasive species while contributing to its control.
- The chemical composition reveals a high holocellulose content (62.34%) and significant lignin content, which influences its thermal stability and potential for bioenergy applications.
- The thermal and calorific properties indicate a promising calorific value, comparable to other energy species, making it a viable option for biomass combustion and energy production.
- The physical and mechanical properties demonstrate adequate strength and stability, comparable to commercially used species such as *Pinus elliottii* and *Pinus taeda*, supporting its application in civil construction and furniture.
- The density and acoustic properties suggest potential for musical instrument production, given its similarity to mahogany, a widely used species in this sector.
- Sustainable management strategies are essential to prevent further spread of this invasive species, and its commercial use can serve as an economic incentive for conservation and ecological restoration programs.

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Authorship Contribution

1 Maurício Alves Ramos

Wood Industry Engineering

https://orcid.org/0009-0001-9225-7633 • mauricioaramos@gmail.com

Contribution: Conceptualization; Data Curation; Formal analysis; Investigation; Methodology, Software, Visualization, Writing – original draft preparation, Writing – review & editing

2 Silvia Helena Fuente

Forestry Engineer

https://orcid.org/0000-0002-8387-3450 • silviahfuente@hotmail.com

Contribution: Conceptualization; Data curation; Writing – original draft preparation, Writing – review & editing

3 Thales Castilhos de Freitas

Forestry Engineer

https://orcid.org/0000-0001-7362-5237 • thales.castilhos@gmail.com

Contribution: Conceptualization; Writing – original draft preparation; Writing – review & editing

4 Kelvin Techera Barbosa

Forestry Engineer

https://orcid.org/0000-0001-9894-703X • kelvintecherabarbosa@gmail.com

Contribution: Conceptualization; Data curation; Software; Writing – original draft preparation; Writing – review & editing

5 Ernestino de Souza Gomes Guarino

Forestry Engineer

https://orcid.org/0000-0001-8286-4889 • ernestino.guarino@embrapa.br

Contribution: Funding acquisition; Investigation; Writing – original draft preparation; Writing – review & editing

6 Alexandra Augusta Reichert

Independent researcher

https://orcid.org/0000-0001-9371-4050 • alereichert94@yahoo.com.br

Contribution: Investigation; Writing – original draft preparation; Writing – review & editing

7 Marília Lazarotto

Master student in Environmental Sciences

https://orcid.org/0000-0003-0621-6120 • marilia.lazarotto@ufpel.edu.br

Contribution: Funding acquisition; Resources; Writing – original draft preparation; Writing – review & editing

8 Rafael Beltrame

Master student in Environmental Sciences

https://orcid.org/0000-0001-6352-0052 • beltrame.rafael@yahoo.com.br

Contribution: Conceptualization; Data curation; Funding acquisition; Resources; Writing – original draft preparation; Writing – review & editing

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