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PRELIMINARY STUDY OF *Acacia dealbata* LOGS FOR USE IN CONSTRUCTION: VISUAL CHARACTERIZATION AND NON-DESTRUCTIVE TESTING[♣]

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ABSTRACT

This study provides a preliminary mechanical characterization of minimally processed *Acacia dealbata* logs to assess their potential valorisation as a by-product of invasive species management. A total of 45 logs (90–143 mm diameter) from two harvest seasons groups, spring (17 logs, 2.0 m) and winter (28 logs, 2.4 m), were visually selected and evaluated for dynamic modulus of elasticity using longitudinal stress wave and transverse vibration tests. Testing was conducted in two moisture content states: air-dried (> 12%) and kiln-dried (≈ 12%). Significant differences between the two groups necessitated separate analyses and suggested a relationship between harvesting season and physical-mechanical properties. Although dynamic properties increased post-kiln drying, initial dynamic modulus of elasticity values were lower due to elevated initial moisture content. Visual characteristics exhibited weak correlations with dynamic properties, whereas high correla-

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tions were observed between adjusted dynamic modulus of elasticity values for both moisture states (r > 0,90 for longitudinal stress wave; r > 0,70 for transverse vibration). Adjusted dynamic modulus of elasticity values (18,29/14,00 GPa for longitudinal stress wave; 16,32/12,69 GPa for transverse vibration) were comparable to prior studies and support a potential classification of *Acacia dealbata* (mimosa) logs for structural applications.

Keywords: *Acacia dealbata*, acoustic testing, dynamic modulus of elasticity, small-diameter logs.

INTRODUCTION

The mimosa (*Acacia dealbata* Link), known as Mimosa in Portugal, is an exotic invasive hardwood species native to Australia (Fuentes-Ramírez *et al.* 2011). Its aggressive colonization is due to its high resistance and adaptability to different soils and climates, along with a high growth rate and a large production of viable seeds (Correia *et al.* 2014). In the North of Iberian Peninsula, it can be found in dense, young wild stands (10-20 years old), often on slopes, developing irregular stems and sections (Figure 1a). For its control, applied research has been developed aimed at its valorization: pulp for paper (Santos *et al.* 2006) or biomass (Nunes *et al.* 2022), citing Portuguese experience. Although its shape and small diameter reduce its wood yield (Bukauskas *et al.* 2019) have shown that small diameter logs, used as construction material, can exhibit acceptable structural performance (Figure 1b).

Furthermore, Larson *et al.* (2004) and Green *et al.* (2005) have demonstrated that a low level of processing for this type of material can be advantageous because it does not reduce the exterior resistant material (mature wood) and does not weaken the area surrounding the knots.

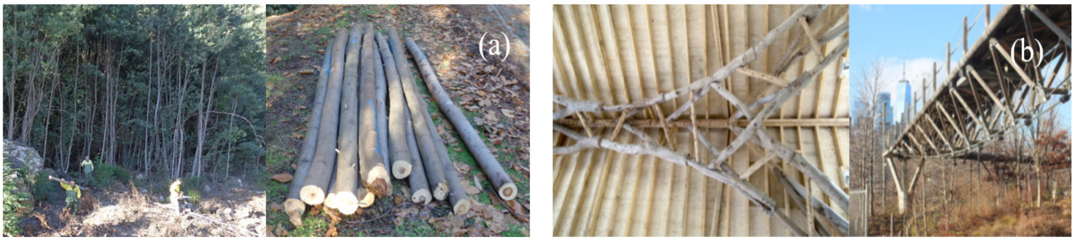


Figure 1: (a) Typical stand and logs of Mimosa; (b) Application in small diameter wood log structures (retrieved of Bukauskas *et al.* 2019)

The mechanical characterization of logs can be based on destructive tests according to standard such as EN 14251 (2003) and ASTM D1036-99 $^{(2017)}$. However, there are currently several non-destructive testing (NDT) techniques that support predictive models of the physical-mechanical performance of standing trees, logs, sawn timber, and all types of wood-based by-products (Schimleck *et al.* 2019).

In addition to not destroying specimens, these techniques offer the possibility of pre-selecting logs in early stages of processing. This can be advantageous when using residual logs from forest control harvesting, or in other cases such as using logs from forest thinning or for the control of overpopulated forests (Wang *et al.* 2002). As Larson *et al.* (2004) demonstrates, well-classified logs can have higher economic value and thus helping to develop a potential supply chain for this type of forest by-products.

Acoustic methods constitute a well-established category of non-destructive testing (NDT) techniques employed to assess stiffness properties in standing trees and logs across various species (Wang *et al.* 2002). These methods rely on analysing stress waves travelling internally through a medium, as these waves are intrinsically linked to the medium's physical and mechanical properties. In an idealized homogeneous, slender, and elongated body, a longitudinal stress wave (LSW) initiated at one end propagates at a constant velocity along its length. This velocity correlates directly with the material's stiffness and inversely with its density. While an unprocessed log might satisfy the slenderness and aspect ratio criteria, it represents a non-homogeneous medium: factors influencing wave propagation must be considered, including cross-sectional shape and size, tapering and curvature of the stem, and the presence of knots.

Using LSW, several researchers have established significant correlations values with mechanical properties obtained from static tests. Wang *et al.* (2002) reported highly significant correlations, for a probability of 99,9 % between the dynamic Modulus of Elasticity (MOE_{LSW}) and static MOE_S for logs harvested from overpopulated North American forests with a coefficient of determination $R^2 = 0,60$ for jack pine (*Pinus banksiana* Lamb.) and $R^2 = 0,75$ for red pine (*Pinus resinosa* Aiton), Rais *et al.* (2014) measured velocity using LSW in logs and boards at different stages of douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) wood processing. They obtained determination coefficients of $R^2 = 0,37$ between velocity (v) in standing trees and dynamic MOE of long logs, and $R^2 = 0,70$ between dynamic MOE of short logs and boards; Papandrea *et al.* (2022) measured the correlation between dynamic/static MOE of *Populus* genre (poplar) logs. They used LSW to determine velocity (v) over 3 one-meter segments and then conducted static tests on clean wood pieces 50 cm long, obtaining very high correlation values, r = 0,61; in sweet chestnut (*Castanea sativa* Mill.) logs, “adjusted” to constant diameter, Vega *et al.* (2019), found out a coefficient of determination between static/dynamic MOE of $R^2 = 0,64$; Llana *et al.* (2020) analysed logs of 4 hardwood species from Ireland, including other factors such as density, DBH (diameter breast height), or the number of annual rings, and found an $R^2 = 0,58$ between dynamic/static MOE, observing that the model with the best fit considered only the species factor.

Another variant of the acoustic method involves studying transverse vibrations (TV). In a beam system with defined boundary conditions, low-energy impacts or ambient vibrations can excite the system, allowing measurement of the natural frequency of the first transverse vibration mode (f). By applying analytical formulations derived from Euler-Bernoulli beam theory, the MOE can be calculated. However, wood-specific irregularities, such as knots or cracks, can influence the signal. While Skatter and Dyrseth. (1997) initially concluded that resonance-based vibration methods were insufficient for detecting defects like knots in logs, more recent findings suggest otherwise.

For example, Opazo-Vega *et al.* (2021) demonstrated that incorporating the analysis of second and third transverse vibration modes enables the detection of critical defects, such as knots and cracks, in dimensioned boards of shining gum (*Eucalyptus nitens* H.Deane & Maiden). Moreover, Wang *et al.* (2001) found more reliable correlation laws using TV than LSW, with $R^2 = 0,85$ for jack pine (*Pinus banksiana* Lamb.) logs and $R^2 = 0,95$ for red pine (*Pinus resinosa* Aiton). Carreira *et al.* (2017), in lemon-scented gum (*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson) logs, and using free boundary conditions, found $R^2 = 0,92$ values between static/dynamic MOE.

Previous research has shown that combining dynamic properties with visual characteristics of logs with minimal processing, results in more robust predictive models. To determine the MOE of timber boards from douglas-fir logs, Wang *et al.* (2013) used a multiple linear correlation by combining the acoustic wave velocity and parameters related to the geometric characteristics of the logs. The lineal correlation reached an $R^2 = 0,40$ while the multiple correlation including the log diameter achieved an $R^2 = 0,50$. However, the relationship between visual characteristics and mechanical performance of logs is not clear: Feng *et al.* (2018) observed that while severe curvature (sweep) affected the wood yield of yellow poplar (*Liridendron tulipifera* L.) logs, it had no significant effects on acoustic wave quality.

As a hygroscopic material, the dynamic properties of wood are related to changes in moisture content (MC). Acoustic velocity decreases with increasing MC and slows above the fibre saturation point (FSP). Density, on the other hand, decreases at a rate that is directly proportional to moisture loss. Therefore, although MOE increases with MC reduction, it does so conditioned by the non-convergence of both factors, as demonstrated by Chan *et al.* (2011) and Montero *et al.* (2015).

In the book “Building with Hardwood,” Merz *et al.* (2021) conducted an in-depth analysis of the potential hardwood species to contribute to an increased timber supply and availability in response to demand. They placed particular emphasis on the physical and mechanical advantages inherent to these wood types. However, studies on the physical properties of *Acacia* genre wood species are still scarce. In a study conducted by Martins *et al.* (2020) the average density values of 647 kg/m^3, average MOE and bending strength respectively equal to 13900 MPa and 65 MPa for blackwood (*Acacia melanoxylon* R.Br.) from Portugal. In Chile, a technical report from the Forest Institute (Pinilla *et al.* 2019) indicates the mimosa (*Acacia dealbata* Link) exhibits superior physical properties compared to the reference species for construction use monterey pine (*Pinus radiata* D.Don). The report reveals average density values of 495 kg/m^3, 11515 MPa MOE, and 65,7 MPa bending strength for this species, which are higher than those reported for monterey pine (*Pinus radiata* D.Don).

This work forms part of a broader study that aims to develop the mechanical characterization of small diameter (100-150 mm) logs mimosa (*Acacia dealbata* Link) with minimal processing to valorize them as a residue from forest management. The specific objective of this stage is to analyse the effects of visual characteristics, moisture content (MC), and drying methods (air-drying and kiln-drying) on their dynamic properties, particularly the dynamic modulus of elasticity (MOE). In the short term, the consolidated results of this phase will provide a reference for comparison with destructive testing. In the medium to long term, these findings may reinforce existing strategies for managing invasive alien species, thereby contributing to more economically and environmentally sustainable forest management practices (Lorenzo and Morais 2023).

MATERIALS AND METHODS

The logs were collected from the Peneda Gerês National Park, northern Portugal, where the abundant growth of mimosa poses a threat to biodiversity and native tree species (Monteiro *et al.* 2017). Logging was carried out with the rangers of the "Instituto da Conservação da Natureza e das Florestas" (ICNF) of Portugal. Sixty-five young Mimosa trees with diameters ranging from 100 to 150 mm, minimal misalignment, and fewer visible knots were preselected. These were felled and collected in 2 groups. One in spring 2022 (1st), with 34 specimens of 2 m in length, and the other in winter 2022 (2nd), with 31 specimens of 2,4 m in length.

After being transported to the laboratories of the University of Minho, Guimarães, they were visually characterized, and the qualitative rating proposed by Ranta-Maunus (1999) was used as a reference for selecting forty-five logs, 17 from the first group (1st) and 28 from the second (2nd), with a minimum diameter of 90 mm and maximum of 143 mm (standard deviation, SD = 10,53). The 20 discarded logs were stored for use subsequent tests, while the selected logs were stacked under protected conditions, indoors, without any adjustment processing, thus maintaining their natural irregular stem.

Two rounds of non-destructive tests (NDT) were conducted on the material, employing the Longitudinal Stress Wave (LSW) and Transversal Vibration (TV) methods. The first round of testing was performed on all logs with bark intact after an air-drying period had been completed. Moisture content (MC) values were recorded as exceeding the reference threshold of 12 % MC (MC > 12 %), although varying significantly between the first and second group. The second round of testing was conducted after drying all logs in an oven until reaching a moisture content close to 12 %. A drying program designed for *Eucalyptus* genre was used and executed in industrial drying kilns at a sawmill in Porto, Portugal. Artificial drying facilitated the bark removal of 1st group samples, whereas in the 2nd group, the bark remained intact and well-bonded.

Moisture content measurement

After felling the trees, to determine the green MC, discs were extracted, and according to ISO 13061-1 $^{(2014)}$, an MC of 70,90 % (SD = 5,78 %) was determined for the logs of the first group (1st of spring) and 46,61 % (SD = 6,25 %) for the second group (2nd of winter).

During both testing rounds and before each testing, a Protimeter SurveyMaster® BLD5365 electrical resistance moisture meter was employed to measure the moisture content (MC). It is important to note that the manufacturer specifies that measurements exceeding 30 % should be considered relative. Additionally, studies such as Dietsch *et al.* (2015) indicate that electrical resistance moisture meters can be inaccurate over the PSF (> 30 %). Calibration was performed using approximately 30 mm thick slices from the bottom part of the 34 specimens in the first group. After saturating them in water, they were stored in a climatic chamber (T = 20 ± 0,5 °C, RH = 60 ± 5 %).

Regular measurements of mass and moisture content were taken with the moisture meter until a constant mass was reached. The moisture content was determined for each measurement lower 30 %, according to ISO 13061-1 $^{(2014)}$, and then correlated with each moisture meter measurement, obtaining a coefficient of determination $R^2 = 0,89$. A final adjustment expression was applied uniformly to all measurements, including those above the 30 % threshold.

As mentioned, during the first round of testing (MC > 12 %), disparities in moisture content (MC) were observed between the two groups. These differences can be attributed to variations in harvest timing, the duration and environmental conditions of air-drying, and the availability of testing equipment. The first group, harvested in spring, underwent a longer period of air-drying during the dry months (spring-summer).

The TV testing for this group was conducted two months post-harvest, while the LSW testing occurred five months post-harvest. In contrast, the second group, harvested in winter, experienced a shorter air-drying period under colder conditions. LSW testing was conducted one month after harvest, and the TV testing, due to equipment availability, was performed at two distinct times: one and a half months and three months post-harvest. For the second round of testing (MC ≈ 12 %), after kiln drying, all logs had reached moisture content levels close to 12 %.

Visual characterization

The EN 14251 (2003) standard outlines testing methods for determining specific properties of structural roundwood, such as bending strength or the modulus of elasticity in bending. In addition, the determination of moisture content, density and dimensions is specified and provides reference definitions for the visual characterization:

Apparent Diameter (mm): diameter of the circle with the same circumference as the actual circumference in the measurement section. A mean value of measurements was calculated over 5 sections: both ends, quarter, centre, and three-quarters of the trunk length.

Ovality (%): the ratio between the major and minor diameters of a specific section. The section at 1000 mm from the base of the log was considered.

Sweep (mm/2m): the maximum distance over the concavity of the arc formed, describing the level of misalignment in relation to a reference straight line over 2 m.

Taper (mm/m): indicates the reduction in section over the length of the log from the average diameter of the lower and upper major and minor diameters.

Other indicators were also included:

Knot Ratio (%): It is the ratio between knot width and diameter. For this purpose, knots are identified on each log, and the largest knot is selected. Two knot ratios were determined, one for the entire piece (k_{all}) and one for the central third of the specimen (k_{cen}).

Non-destructive testing

Figure 2: (a) Longitudinal Stress Wave and (b) Transverse Vibration testing.

Figure 2a shows tests and devices used for Longitudinal Stress Waves (LSW), and Figure 2b shows the tests of Transverse Vibration (TV), both performed before (MC > 12 %) and after drying (MC ≈ 12 %). Before to each test, the moisture content (MC) of each log was measured at three points located at a quarter, half, and three-quarters of its length using the moisture meter. The average of these points determined a global MC, and according to the procedure described in section 2.1, an MC was inferred for LSW and TV.

LSW tests were conducted on each log arranged horizontally. On the bottom of the log, a series of 3 groups of 5 regular blows, in the longitudinal log direction were made with a 1,1 kg hammer model 086D20 by PCB Piezotronic. Near the impact area, an accelerometer model 352B by PCB Piezotronic of 1000 mV/g ± 5 % was fixed perpendicular to the sapwood area, connected with the hammer to a data acquisition card plugged into the laptop to record the response signals (Figure 2a). The acquired data were analyzed through a Fourier Transform and the first longitudinal stress wave resonant frequency (*f*), LSW was determined in Hertz, Hz. Including the length of the log, L in m, the longitudinal wave velocity (v) in m/s, was obtained based on Equation 1:

$$v = 2L\, f_{LSW} \quad (1)$$

The density (ρ) in kg/m³ was determined for each log both before (MC > 12 %) and after oven drying (MC ≈ 12 %), and prior to each NDT test (LSW and TV). The logs were weighed, and their volume was measured by calculating the area of the mean apparent diameter times by the length. Using the expressions described by Unterwieser and Schickhofer (2011), the velocity value was adjusted to a reference MC of 12 %, obtaining an adjusted velocity value, v_{adj} for both before (MC > 12 %) and after drying (MC ≈ 12 %). Using the adjustment proposed by EN 384 (2016), the density value was adjusted to a reference MC of 12 % for a range between 10 % and 18 %, inferring an adjusted density value, for both drying conditions. With this, the different dynamic Modulus of Elasticity (MOE $_{\text{LSW, adj}}$) for both drying conditions were inferred using the generic expression (Equation 2):

$$MoE_{LSW} = v^2 \rho \quad (2)$$

The TV tests (Figure 2b) were conducted within a closed, isolated enclosure. The logs were suspended at the nodal points by 1800 seconds using two-meter-long springs to decouple the system from external frequencies to establish boundary conditions for free-free ends. Five accelerometers were fixed on each log at equivalent distances to better distinguish the first vertical modal shape. For the MC > 12% test, a high sensitivity (10000 mV/g ± 10%) Piezotronic model 393B12 PCB accelerometer was used to measure ambient vibration. By testing MC ≈ 12 %, lower sensitivity accelerometers (model 352B by PCB Piezotronic of 1000 mV/g ± 5 %) were used, and a little hit was applied to the log at 600 seconds. The accelerometers were connected to the data acquisition device and to the laptop. The data was analysed using modal analysis software to determine the values of each log's first vertical resonant frequency. To determine the dynamic Modulus of Elasticity (MOE TV), the expression derived from the Euler-Bernoulli theory applied to the natural frequency of the first mode in bending of a beam under free boundary conditions was used (Equation 3):

$$MOE_{TV} = \frac{4\pi^2 f_1^2 m L^3}{4{,}74 I} \quad (3)$$

Where f_1 is the first vertical resonant frequency in Hz, *m* is the mass of the beam in kg, *L* is the length in m, and *I* is the centroidal moment of inertia in mm⁴. Finally, the dynamic Modulus of Elasticity was adjusted, $\text{MOE}_{\text{TV, adj}}$ to a reference value of 12 % using the expressions of Unterwieser and Schickhofer (2011) for before (MC > 12 %) and after drying (MC ≈ 12 %).

Statistical analysis

A descriptive statistical analysis was conducted to evaluate the physical and dynamic characteristics, as well as the experimental results. After verifying the assumptions, all statistical tests were performed with a 95 % (p <0,05) confidence level. To compare group means, independent samples t-tests were employed.

Correlations between variables were assessed using Pearson's correlation coefficient (r), interpreted in accordance with Mukaka (2012). For the analysis of visual characteristics, the independent variables included all visual attributes (ovality, taper, sweep, all knots, and centre knots), while the dependent variables were the dynamic elasticity moduli under two moisture content conditions: MOE LSW ($MC > 12$ %), MOE LSW ($MC \approx 12$ %), MOE TV ($MC > 12$ %), and MOE TV ($MC \approx 12$ %). To evaluate the influence of moisture content (MC) as an independent variable on dynamic properties, the dependent variables analysed included velocity (v), density (ρ), and frequency (f). All statistical analyses were conducted using the Real Statistics add-in for Microsoft Excel® 2021.

RESULTS AND DISCUSSION

Visual characterization

Independent sample t-tests were performed for each visual characteristic to evaluate differences between the two sample groups (1st and 2nd). Results showed no statistically significant differences ($p > 0,05$) for Diameter, Ovality, Taper, or Sweep. Consequently, the analysis was conducted on the whole dataset. As expected, visual characteristics exhibited high variability due to the natural heterogeneity of specimens and minimal log processing. Table 1 summarizes the mean values for each visual characteristic across all samples.

Table 1: Visual characteristics of all specimens.

	Apparent Diameter	Ovality, 1 m	Taper	Sweep	Knot/diameter All, k_{all}	Knot/diameter Central, k_{cen}
	(mm)	(%)	(mm/m)	(mm/2m)	(%)	(%)
Mean	106,37	8,72	6,70	33,17	12,42	9,30
SD	8,67	5,82	2,05	13,95	7,66	7,76
CoV (%)	8,15	66,72	30,56	42,04	61,71	83,49
Max.	123,57	20	10,37	70,97	36,84	36,84
Min.	89,57	0	2,32	9,88	0	0

SD: standard deviation; CoV: coefficient of variation; Max: maximum value; Min: minimum value.

Based on the classification criteria by Ranta-Maunus (1999), 18 % of logs (n = 8) were classified as grade "A," meeting thresholds of Ovality < 10 %, Taper < 5 mm/m, and Knot Size < 25 % of the diameter. The remaining 82 % (n = 37) were classified as grade "B," characterized by Ovality between 10-20 %, Taper between 5-10 mm/m, and Knot Size < 30 %. Only one log satisfied the Sweep criterion (<10 mm/2 m). A box plot (Figure 3a) compares dynamic modulus of elasticity (MOE) values for grades "A" and "B" (to $MC \approx 12$ %) measured using Longitudinal Stress Wave (LSW) and Transverse Vibration (TV) methods.

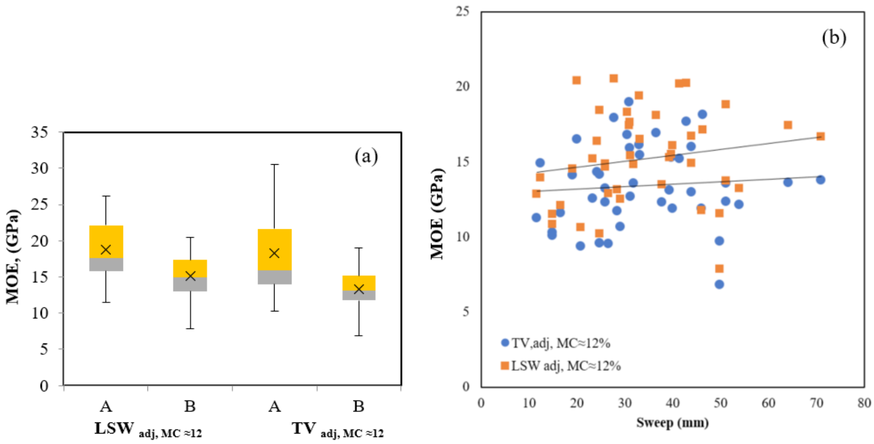


Figure 3: (a) Boxplot to visualise the relation between both dynamic MOE for each grade "A" (higher quality) and grade "B" (lower quality). (b) Scatter plots of the relationship between both dynamic adjusted MOE and the "Sweep" variable for all specimens.

Despite observable trends, the small sample size for grade "A" reduced statistical power, and data dispersion remained high. Independent samples t-tests revealed no significant differences ($p > 0,05$) between grades "A" and "B." Correlation analyses between visual characteristics and dynamic MOE at MC ≈ 12 % yielded no significant relationships. For example, Ovality and Taper showed negligible Pearson correlation coefficients (r = 0,09 and r = 0,14, respectively; $p > 0,05$). Knot characteristics (k_{all} and k_{cen}) also exhibited low correlations, with the highest value being r = -0,46 for k_{cen} without knots (p > 0,05). Figure 3b presents scatter plots of Sweep versus dynamic MOE for the entire sample, showing negligible correlations (r = 0,17 for LSW, r = 0,08 for TV; $p > 0,05$). These findings align with previous research (Vries and Gard 2008), highlighting the limited predictive power of visual characteristics for mechanical properties.

Significant differences between groups

Despite similar visual characteristics, significant differences were observed in the dynamic properties of the two groups according to harvesting season. Table 2 summarizes independent samples t-test results comparing means before and after drying, considering adjusted values.

Table 2: T-test results for independent samples between 1st (17 logs) and 2nd (28 logs).

LSW				TV	
$v_{adj, MC>12}$	$v_{adj, MC\approx12}$	$\rho_{adj, MC>12}$	$\rho_{adj, MC\approx12}$	$MOE_{TV, adj, MC>12}$	$MOE_{TV, adj, MC\approx12}$
$t_{(43)} = 5,12$	$t_{(43)} = 2,88$	$t_{(43)} = 4,79$	$t_{(43)} = 3,80$	$t_{(41)} = 0,65$	$t_{(43)} = 3,19$
$p < 0,05^{*}$	$p < 0,05^{*}$	$p < 0,05^{*}$	$p < 0,05^{*}$	$p = 0,26^{ns}$	$p < 0,05^{*}$

*Significative for t-test; ^{ns} not significative; v, ρ, Velocity and density variable.

For LSW analysis, significant differences ($p < 0,05$) in velocity (v) and density (ρ) were observed at MC > 12 %, with higher v in the 1st group and higher ρ in the 2nd group. However, adjusted MOE differences were insignificant ($p = 0,17$), though this result should be interpreted cautiously, as the MC in the 2nd group exceeded the fibre saturation point (FSP), rendering the EN 384 (2004) adjustment inapplicable. Notably, after drying (MC ≈ 12 %), all LSW parameters, including density, were found to be significantly higher in the 1st group.

For TV analysis, no differences between both MOEs were found before drying ($p = 0,26$), but significant differences were observed post-drying ($p < 0,05$). Despite shared origins and minimal visual differences, both groups differed in dynamic properties and MOE values. Several factors could explain these differences:

Log Length difference: The logs in the first group measured 2 m, and those in the second group were 2,4 m. Although length determines wave velocity, it is relative, and other factors, such as the position of nodes in the transversal vibration test, were defined as a function of length. Consequently, this is unlikely to explain the differences.

Bark Retention: Initial measurements (MC > 12 %) were conducted with bark logs, and they confirmed the observed trend. Post-drying measurements (MC ≈ 12 %) have differed: the 1st group was debarked, and the 2nd group retained bark. Bark presence likely contributed to moisture gradients undetected by moisture meters. However, the difference in mean velocity (v), for instance, between before and after drying was greater in the 2nd group, so this argument is unclear.

Harvest Season: Logs harvested in spring exhibited higher dynamic MOE than winter-harvested logs, contrary to trends reported in the literature (Dimou *et al.* 2017; Möttönen *et al.* 2004). This discrepancy suggests potential species-specific or environmental influences over logs' physical-mechanical properties. Beyond this discussion, spring-harvested logs offer practical advantages, such as easier debarking, while winter-harvested logs often retain bark adhesion post-drying (Chahal *et al.* 2020).

The limited sample size warrants caution in interpreting these results. Future research should incorporate robust datasets and destructive testing to validate these findings.

Effects of moisture contents over dynamic properties

Each test's measured moisture content (MC) align well with the air-drying durations and environmental conditions specific to each group. These results are consistent with findings by Simpson and Wang (2004), which correlate air-drying rates of conifer logs to factors such as relative humidity and temperature. Figure 4 presents the recorded MC values for both groups.

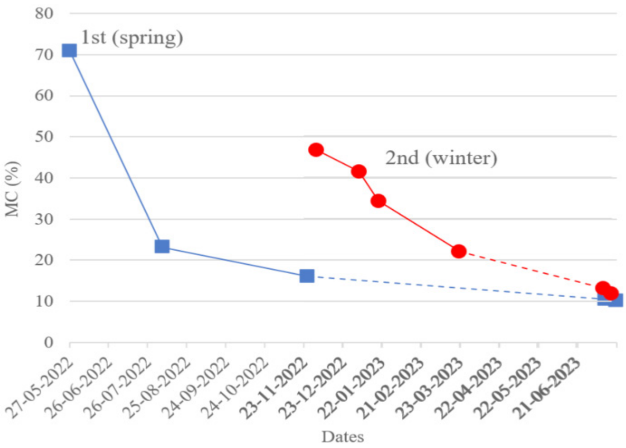


Figure 4: MC measurements since harvesting date per each group (1st and 2nd). Note: The dashed line indicates no information due to the logs being kiln-drying before the last measurement (MC≈12 %).

Rapid moisture reduction was observed in the first group, and average MC values well below the fiber saturation point (FSP) were achieved within a short period. Starting from an initial green MC of 70,90 % (SD = 5,78 %), the group reached an MC of 22,55 % (SD = 6,31 %) after two months of drying, as measured in the transverse vibration (TV) test. By five months, the longitudinal stress wave (LSW) test recorded an MC of 16,15 % (SD = 2,21 %), reflecting reduced variability.

In contrast, the second group, harvested in winter and dried under colder, more humid conditions, showed a slower reduction in MC. Despite starting with a lower green MC of 46,61 % (SD = 6,25 %), this group remained above the FSP for longer. After one month of drying, the LSW test indicated an MC of 41,47% (SD = 4,86 %). The TV test recorded a mean MC of 30,45 % (SD = 7,39 %). However, these tests were conducted in two moments due to TV equipment availability: a partial sample (one-third) tested at 1,5 months post-harvest had an average MC of 34,39 % (SD = 3,97 %), still above the FSP; by three months, the remaining samples (two third) achieved an MC of 22,19 % (SD = 4,99 %), falling below the FSP

Kiln-drying brought all samples to approximately 12 % MC. However, differences in data dispersion were observed between the groups. With unbarked logs during drying, the first group achieved an MC of 10,44 % (SD = 0,58) for LSW and 10,03 % (SD = 0,50) for TV. In contrast, the second group, where bark remained intact, exhibited higher variability with MC values of 13,17 % (SD = 1,99) for LSW and 11,91 % (SD = 1,98) for TV. This difference may be attributed to the influence of bark on drying dynamics. The bark likely restricted moisture transport, creating moisture gradients within the logs. As Tomczak *et al.* (2020) observed, bark limits drying by impeding longitudinal water transport toward the open ends of the log.

Figure 5a, Figure 5b, Figure 5c illustrates the relationships between MC, dynamic properties, and density. After kiln drying, MCs near 12 % correlated with increased dynamic property values and reduced data dispersion, consistent with previous findings (Chan *et al.* 2011; Unterwieser and Schickhofer 2011). Correlation analysis revealed negligible associations ($r < 0,3$, $p > 0,05$) between MC and dynamic properties. However, two exceptions were observed: Velocity (v) in the 2nd group for MC > 12 % showed a low negative correlation ($r = -0,37$, $p < 0,05$), and density in the 2nd group at MC ≈ 12 % showed a low positive correlation ($r = 0,49$, $p < 0,05$).

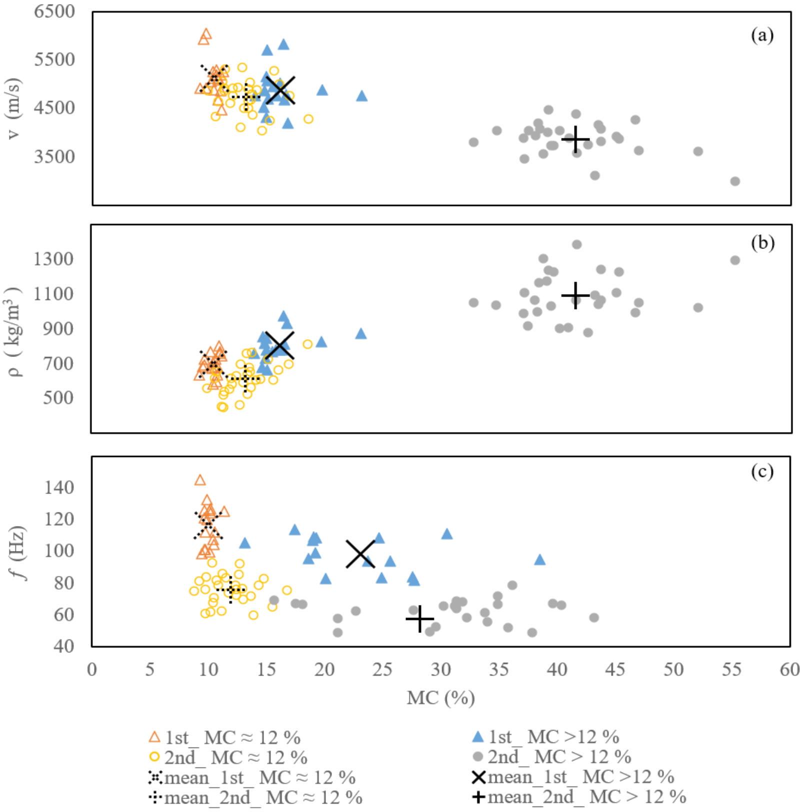


Figure 5: Relationship of MC (%) to (a) velocity *v*, (b) density ρ and (c) frequency, *f* values without adjustment, for 1st and 2nd group before (MC>12 %, only air-drying) and after kiln drying (MC≈12 %).

An increase in wave velocity of 5,23 % (Figure 5a) was observed in the first group and 22,80 % in the second, with the latter experiencing a greater relative change due to more significant water loss from logs with MC > FSP. Density (Figure 5b) decreased by 13,03 % and 43,63 % for the first and second groups, respectively, proportional to water loss.

At MC ≈ 12 %, mean wave velocities were 5087,87 m/s for the first group and 4772,15 m/s for the second. Both values exceed those reported for hardwood species. For example, Llana *et al.* (2020) reported velocities of 3257 m/s (alder), 4136 m/s (ash), 3791 m/s (birch), and 3475 m/s (sycamore). Similarly, Papandrea *et al.* (2022) recorded velocities ranging from 3877 m/s to 4413 m/s for poplar logs, while Omonte and Valenzuela-Hurtado (2020) reported a maximum average velocity of 3760 m/s for shining gum (*Eucalyptus nitens* H.Deane & Maiden). These reference values, measured in the green state (MC > 30 %), were not adjusted for MC.

Although due to the difference in lengths, the frequency values (*f*) are not comparable between both groups, it is possible to observe an intragroup increase: with the reduction of the moisture content, an increase of 18,70 % and 21,93 % is observed for the 1st and 2nd group, respectively (Figure 5c). For the dynamic MOE values (Table 3) of the TV tests they remained lower than those reported by Carreira *et al.* (2017) for lemon-scented gum (*Corymbia citriodora* (Hook.) K.D. Hill & L.A.S.Johnson), a hardwood species with an average MOE of 22,53 GPa (for a MC = 18,20%).

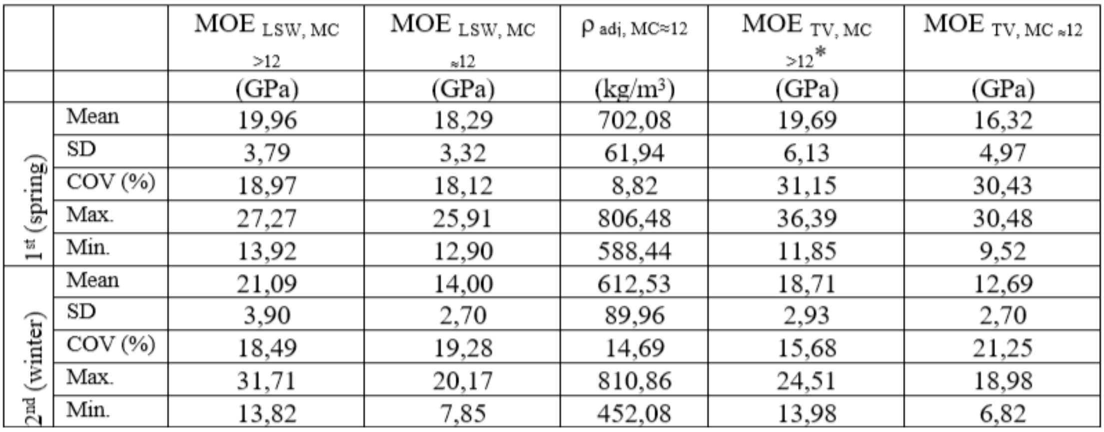
Dynamic modulus of elasticity results

The adjusted dynamic MOE values for both testing techniques (LSW and TV) at MC > 12 % and MC ≈ 12 % were presented in Table 3. To evaluate the correlation between the two NDT methods across all specimens (1st and 2nd groups), Pearson's coefficient was calculated, yielding r = 0,89 ($p < 0,05$), which indicates a high positive correlation. Considering only MC ≈ 12 %, the MOE values obtained from LSW were approximately

10 % higher than those from TV for both groups.

Significant differences ($p < 0{,}05$) were determined through paired samples t-test between the adjusted MOE values before and after drying. MOE decreased after drying, but the extent of these changes differed between the groups aligned with moisture content variation. LSW decreased by 8,35 % in the 1st and 33,62 % in the 2nd groups, with MC differences of 5,71 % and 28,30 %, respectively. TV decreased by 17,11 % in the 1st group and 32,21% in the 2nd group, with MC differences of 13,02 % and 18,54 %, respectively. Moisture content directly affects mass (m) and density (ρ), consequently determining dynamic MOE.

Table 3: Adjusted results of dynamic MOE for Longitudinal Stress Waves and Transverse Vibration before (MC>12) and after kiln-drying (MC≈12). Added also density values after kiln-drying.



		$MOE_{LSW, MC >12}$	$MOE_{LSW, MC \approx 12}$	$\rho_{adj, MC \approx 12}$	$MOE_{TV, MC >12}$*	$MOE_{TV, MC \approx 12}$
		(GPa)	(GPa)	(kg/m³)	(GPa)	(GPa)
1st (spring)	Mean	19,96	18,29	702,08	19,69	16,32
	SD	3,79	3,32	61,94	6,13	4,97
	COV (%)	18,97	18,12	8,82	31,15	30,43
	Max.	27,27	25,91	806,48	36,39	30,48
	Min.	13,92	12,90	588,44	11,85	9,52
2nd (winter)	Mean	21,09	14,00	612,53	18,71	12,69
	SD	3,90	2,70	89,96	2,93	2,70
	COV (%)	18,49	19,28	14,69	15,68	21,25
	Max.	31,71	20,17	810,86	24,51	18,98
	Min.	13,82	7,85	452,08	13,98	6,82

SD: standard deviation; COV: coefficient of variation; Max: maximum value; Min: minimum value; ρ, density; * Note: due to data issues records, the analysis was conducted on only 16 of the 17 specimens in the 1st group and 25 of the 28 in the 2nd group.

However, Pearson correlation values for adjusted MOE obtained via LSW, measured before (MC > 12 %) and after drying (MC ≈ 12 %), were very high: r = 0,93 ($p > 0{,}05$) for the 1st group and r = 0,97 ($p > 0{,}05$) for the 2nd group. The TV technique also showed high correlations for adjusted MOE: r = 0,81 ($p > 0{,}05$) for the 1st group and r = 0,76 ($p > 0{,}05$) for the 2nd group. These findings suggest that MOE values can be reliably determined in logs with varying moisture contents (above or below the FSP), with LSW testing providing more consistent results. While a linear regression model could enhance predictive accuracy by correlating MOE values to specific moisture contents, developing such a model falls outside the scope of this preliminary research. Further validation against static test results is required to confirm its reliability and practical applicability (Figure 6).

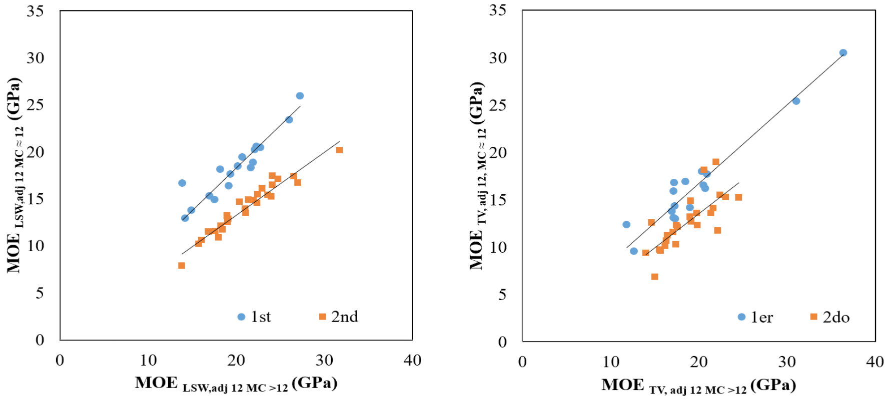


Figure 6: Relationship between adjusted MOEs with MC > 12 % and MOE ≈ 12 % for LSW and TV.

Finally, although the sample size was limited, preliminary strength classifications were assigned based on EN 338 (2003) standards. The 5th percentile MOE ($E_{0,05}$) and density (ρ_k) values at MC = 12 % suggest that 1st Group meets D40 classification for density (ρ_k = 597,58 kg/m³) and D60 (LSW) and D50 (TV) for $E_{0,05}$. The 2nd Group does not meet the minimum density requirement for any hardwood class (ρ_k = 457,85 kg/m³) but meets $E_{0,05}$ requirements for D50 (LSW) and D40 (TV).

CONCLUSIONS

The preliminary results suggest that *Acacia dealbata* Link (mimosa) logs, a residual material from forest management, have the potential for structural applications, contributing to economic and environmental sustainability forest practices. The dynamic modulus of elasticity (MOE) values obtained through longitudinal stress wave and transverse vibration testing were comparable to those of reference species. Additionally, logs harvested in spring met the D40 classification for structural use according to EN 338 (2003).

These findings indicate that harvest season may influence mechanical performance, making it a relevant parameter for pre-selecting logs in forest management. Spring-harvested logs exhibited higher dynamic MOEs values, air dried faster, and allowed easier debarking, to providing economic and environmental advantages. Although no significant correlations ($p>0,05$) were observed between visual classification and dynamic properties, other studies highlight that defect such as knots and sweeps may affect mechanical performance, so validation through destructive testing is necessary.

MOE values from the longitudinal stress wave were ~10% higher than those from transverse vibration, and there was a strong correlation between the two methods ($r = 0,89$; $p > 0,05$). Strong correlations ($r > 0,90$ for LSW; $r > 0.70$ for TV) between pre- and post-drying MOE values suggest that non-destructive techniques can estimate dynamic MOE at a standardized 12% moisture content from higher MC measurements. However, instrumental limitations recommend measurements below the fiber saturation point.

Authorship contributions

M. S-U.: Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, software, resources, supervision, validation, visualization, writing-original draft, writing-review & editing. A. O-V.: Conceptualization, data curation, formal analysis, methodology, supervision, writing-original draft, writing-review & editing. C. M.: Data curation, formal analysis, supervision, validation, visualization, writing-original draft, writing-review & editing. D. M.: data curation, writing-original draft, writing-review & editing. B. F.: Supervision, validation. J. L. L.: Conceptualization, supervision, validation, writing-original draft, writing-review & editing. J. M. B.: Conceptualization, data curation, investigation, methodology, supervision, validation, visualization, writing-original draft, writing-review & editing.

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