Analysis of the Mechanical Properties of Resinated Pinus Pinaster Timber

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Abstract

In a global scenario of increasing the use of wood as a structure, the idea of making quality timber production compatible with other forestry activities, including resin extraction, has arisen. Implementing resin extraction practices can bring various socioeconomic benefits to forest communities during tree growing. However, the effects of resin extraction on wood quality are still unknown. Within this context, this research aimed to evaluate the quality of *Pinus pinaster* timber from resing trees. A total of 238 boards from resin-treated and control trees from two plots located in Galicia were evaluated. Non-destructive and bending tests were carried out according to European standards. The influence of the resin activity on the quality of wood was statistically analyzed. Statistically significant differences between samples of resin and control samples were analyzed for non-destructive, strength, modulus of elasticity, and density parameters. In general, it was observed that the resin activity did not affect the parameters analyzed.

Introduction

Pinus pinaster is a fundamental species for the supply of the processing industry throughout the Atlantic arc.

The expansion of the species in Galicia started in the 18th century. However, it was only at the end of the 19th century that it began to significantly increase its occupied surface due to the growing needs of the forestry industry, mainly sawmills, thus favoring the repopulation activity. As a result, today, this species is used for most of the repopulations of conifers carried out in Galicia, occupying 217,281 ha of a surface under the 4th IFN (MARM, 2011).

In general, the populations of P. pinaster in Galicia are destined for the timber sector (Rodríguez Soalleiro et al., 2007), which is an extensive network that involves several actors within the production chain, from small owners to small (erasers) and large companies, all benefiting from sustainable consumption. However, despite the economic resource provided by the forest masses, the use of wood is one of the activities most affected by forest fires, in addition to different forest pests and diseases, which in the last time are problems aggravated by the fires produced outside extinction capacity, which has repercussions on the discouragement of the forest investor, the small forester and the community, leading to an increase in forest abandonment (Calvo Silvosa et al., 2018).

The incorporation of complementary activities (the collection of fruits, medicinal herbs, or the obtaining of resin and honey) to the exploitation of wood can represent an improvement in the management and conservation of the mountains, in addition to allowing the generation of regular economic activities creating a social value added to the benefiting populations of different products (Picos et al., 2019). One of the complementary activities collected for Galicia in Decree 73/2020, of April 24, is using resin on three species of pine (*Pinus pinaster* Ait., *Pinus radiata* D. Don, and *Pinus nigra* Arnold) before the cutting shift.

In this context, there is an interest in including the resin activity as an ecosystem service added to the management of the Galician mountains, initially planted with a single wood use.

The *Pinus pinaster* is the Spanish species of the genus that best adapts to the use of resin, mainly due to its high productivity and ease of extraction of the product.

The practice of resin has been an activity of great importance during the centuries in the Spanish rural environment, characterized by the extraction of a natural and renewable substance (resin) (Martínez Chamorro, 2016), which gives rise to different substances (trientine and rosin) applicable to numerous everyday products, such as fragrances, flavors, gums, in the case of turpentine, and the manufacture of paints, adhesives or insulating materials, in the case of rosin (Martínez Carreira, 2021).

Although it represents an activity that aims to add value to the hills, in Galicia, the resin is also a residual activity, only implemented in small areas. The use of resin in the Galician community presents a series of weaknesses that make the development of the sector more difficult, from the scarce availability of workers in the trade to the rejection of forest owners because of the possible effects of the use of resin in the quality of the wood, due to the lack of confidence on the part of the manufacturing industry due to possible problems in the technical handling of the material (Camacho Rios, 2013). In the last decades, this concern has been derived in the development of different studies, with the objective of evaluating the possibility of compatibility between the production of wood and the use of resin. In the decades of the 50s and 60s, the Forest Research Center of Lourizán (CIF Lourizán) carried out the first resin experiments in Galicia, analyzing its economic viability and compatibility with the use of wood.

The European project SustForest Plus, carried out by public and private initiatives in Spain, France, and Portugal, emerged with the general objective of resolving the challenges experienced by the resin sector in these three countries. One of the project's specific objectives was to evaluate the quality of the production of resin-treated wood for structural use by comparing the physical-mechanical properties of Pinus pinaster wood from resin-treated trees compared to wood from control trees (CESEFOR, 2019). The study concluded that the resin does not cause losses in the wood's mechanical properties (resistance and stiffness). Concerning the density parameter, however, an increase in value is observed in the wood coming from resinous stones, which could mean positive contributions from a structural point of view. In general, the SustForest project obtained characteristic values of the resistant properties of resin-treated wood within the expected range for Spanish *Pinus pinaster* wood (EN 1912).

Materials And Methods

A total of 238 pieces (118 resin specimens and 120 control specimens) were tested, separated into two subsamples from resinated feet and control feet, as defined below. Before the bending tests, the boards are conditioned in an environment with controlled temperature and humidity until reaching equilibrium humidity (12%).

The non-destructive and bending tests were carried out on rectangular section specimens, with a nominal dimension of 40x110x2500 mm, according to the procedures specified below.

We used two non-destructive techniques: stress wave – MicrosecondTimer - MST (Fakopp, Hungary); and natural frequency – with the Mechanical Timber Grader - MTG (Brookhuis, The Netherlands). The velocities calculated with the data from both equipment are associated with material density values for calculating the Indicator Property (EN 14081-2), which was used in the statistical procedures for the species classification proposal.

Bending tests were carried out according to the procedures defined in UNE-EN 408 (2011). The critical area was selected in each piece, that is, the environment in which the origin of the failure was anticipated, which, as far as possible, was located in the internal area between the load application points. The tensile edge of each specimen(lower edge) was chosen randomly.

Once the bending tests were completed, the density and humidity of the specimens were determined on a slice extracted from each of them. Each of the slices has been taken from the complete section, not including singularities such as knots or resin pockets. The slices were weighed and placed in the oven at a temperature of (103 ± 2)°C. They were kept in the oven, weighing, until the difference in mass between two successive weighings carried out in 2 hours was less than 0.1% (UNE 13183-1 Standard).

The moisture content (MC) of each test piece were used to correct the parameters of indicator property, modulus of elasticity and density according to the reference condition (12% MC) defined by regulations.

The results obtained were statistically analyzed through software. For the correlation between the methodologies used, linear regression models were obtained between the indicator properties and the flexural parameters (modules of elasticity and resistance).

Results

Table 1 presents the values of descriptive (mean, standard deviation and coefficient of variation) and normality (Skewness and Kurtosis) statistics of the Indicator Property (IP) data, obtained in tests with non-destructive techniques (MST and MTG); the modulus of rupture (MOR) and modulus of elasticity (MOE_{GLOBAL} and MOE_{LOCAL}), obtained in the bending tests; and density (ρ) of the resin sample. The values of Skewness and Kurtosis within the range of -2 and + 2 indicate that the data of analyzed present a normal distribution and validate the use of parametric statistical tests for the analysis of the results.

Table 1

Statistical values of mean, standard deviation, coefficient of variation (COV), skewness and kurtosis for bending data (MOE_{GLOBAL}, MOE_{LOCAL}, MOR), density and Indicator Property (IP) obtained by tests with wave vibration technology (IP_{MTG}) and of tension waves (IP_{MST}) of the resinated sample.

	IP_{MST}	IP_{MTG}	MOE_{GLOBAL}	MOE_{LOCAL}	MOR	densidad
Mean	12780	11069	9776	10400	46	558
Standard Deviation	2148	2100	1930	2249	13	30
COV	17%	19%	20%	22%	28%	5%
Skewness	-0,47	0,50	1,05	-0,04	-0,01	-0,60
Kurtosis	-1,16	-0,85	-1,38	-0,92	-1,08	0,84

Table 2 presents the values of descriptive statistics (mean, standard deviation and coefficient of variation) and normality (Skewness and Kurtosis) of the Indicator Property (IP) data obtained in tests with non-destructive techniques (MST and MTG); of strength (MOR) and modulus of elasticity (MOE_{GLOBAL} and MOE_{LOCAL}) obtained in the bending tests; and density of the boards from the test feet. Skewness and Kurtosis values within the range of -2 and + 2 indicate that the data from IP_{MST}, IP_{MTG}, MOE_{GLOBAL}, MOE_{LOCAL} and density of the sample of control tables present normal distribution. However, the resistance data (MOR) did not present a normal distribution: Skewness value were out from the – 2 and 2 range. Therefore, Outliers values of MOR were identified and eliminated to proceed with the proposed analyses.

Table 1

Statistical values of mean, standard deviation, coefficient of variation (COV), skewness and kurtosis for bending data (MOE_{GLOBAL}, MOE_{LOCAL}, MOR), density and Indicator Property (IP) obtained by tests with wave vibration technology (IP_{MTG}) and of tension waves (IP_{MST}) of the control sample.

	IP_{MST}	IP_{MTG}	MOE_{GLOBAL}	MOE_{LOCAL}	MOR	densidad
Mean	12456	10884	9581	9843	49	546
Standard Deviation	2177	2117	1806	2003	11	38
COV	17%	19%	19%	20%	23%	7%
Skewness	-1,22	-0,96	-0,26	0,28	-3,14	-1,51
Kurtosis	-1,84	-1,32	-1,46	-1,08	0,27	0,18

In general, the values obtained for the two samples are within the same order of greatness. As expected, the Indicator Properties are numerically larger than the modulus of elasticity obtained in flexure. The global moduli of elasticity were also expected to be lower than the local moduli. This behavior was confirmed in both samples. Regarding strength, the control sample presented a mean value slightly (6%) higher than the sample from resinated trees.

For each parameter analyzed (non-destructive, bending and sensity), we obtained frequency distribution graphs (Fig. 1) for the samples of the tables from the resinated and control trees. It is observed that the data distributions of all the parameters studied are similar for the two samples (resinated feet and control feet).

Taking into account the similarity between the distribution of the data obtained for the two samples (Resinated Feet and Witness Feet), the possibility of proposing a statistical analysis for mechanical classification (correlation between methodologies) was considered, considering all the tables as a single sample. The analyses presented below, therefore, refer to a sample of 238 *Pinus pinaster* specimen from resinated and control trees.

Table 3 presents the values of descriptive statistics (mean, standard deviation and coefficient of variation) and normality (Skewness and Kurtosis) of the Indicator Property (IP) data, obtained in tests with non-destructive techniques (MST and MTG); of strength (MOR) and modulus of elasticity (MOE_{GLOBAL} and MOE_{LOCAL}), obtained in the bending tests; and density of all the boards under study (control feet and resinated feet). The values of Skewness and Kurtosis within the range of -2 and + 2 indicate that the IP_{MTG}, MOE_{GLOBAL}, MOE_{LOCAL} data of all the tables in the sample present a normal distribution. However, the IP_{MTG}, MOR and density data did not present a normal distribution: Skewness value out from the range of -2 and 2. For these parameters, outliers were identified and eliminated to proceed with the proposed analyses.

Table 3
Statistical values of mean, standard deviation, coefficient of variation (COV), skewness and kurtosis for bending data (MOE_{GLOBAL}, MOE_{LOCAL}, MOR), density and Indicator Property (IP) obtained by tests with wave vibration technology (IP_{MTG}) and of tension waves (IP_{MST}) of all sample (resin and control).

	IP_{MST}	IP_{MTG}	MOE_{GLOBAL}	MOE_{LOCAL}	MOR	densidad
Mean	12617	10976	9677	10118	48	552
Standard Deviation	2164	2106	1867	2142	12	35
COV	17%	19%	19%	21%	26%	6%
Skewness	-1,21	-0,34	0,70	0,41	**-2,03**	**-2,42**
Kurtosis	**-2,06**	-1,48	-1,90	-1,34	-1,08	1,33

For mechanical classification of wood for structural purposes, EN 14081-2 defines a series of statistical procedures that correlate non-destructive variables with the resistant properties of the material (strength, modulus of elasticity and density). The first procedure defined by the document (EN 14081-2) is to obtain linear regressions between the Indicator Properties (IP) and bending and density parameters.

Table 4 presents P-Value, correlation coefficient (R), coefficient of determination (R^2), standard estimation error and the step equations obtained by linear regression analysis between the Indicator Properties (IP) obtained by the two techniques (MST and MTG) – and the density and bending parameters (MOE_{GLOBAL}, MOE_{LOCAL} and MOR).

Table 4

Statistical parameters – P-Value, correlation coefficient (R), coefficients of determination (R^2), standard estimation error, and equations - obtained in the linear regressions between the indicator properties (IPMST and IPMTG) and density and bending properties.

		P-Value	R	R^2	Error	Ecuación
IP_{MST}	MOE_{GLOBAL}	0,00	0,82	67%	1077	$MOE_{GLOBAL} = 843{,}503 + 0{,}700795 * IP_{MST}$
	MOE_{LOCAL}	0,00	0,72	51%	1493	$MOE_{LOCAL} = 1193{,}93 + 0{,}707902 * IP_{MST}$
	MOR	0,00	0,44	19%	11	$MOR = 16{,}8689 + 0{,}00244931 * IP_{MST}$
	density	0,00	0,34	11%	32	$\rho = 484{,}884 + 0{,}00535725 * IP_{MST}$
IP_{MTG}	MOE_{GLOBAL}	0,00	0,93	86%	688	$MOE_{GLOBAL} = 764{,}948 + 0{,}813973 * IP_{MTG}$
	MOE_{LOCAL}	0,00	0,83	68%	1199	$MOE_{LOCAL} = 1036{,}78 + 0{,}830371 * IP_{MTG}$
	MOR	0,00	0,61	38%	10	$MOR = 9{,}31988 + 0{,}00352245 * IP_{MTG}$
	density	0,00	0,42	17%	30	$\rho = 479{,}133 + 0{,}00658405 * IP_{MTG}$

In relation to the models presented in Table 4, there is a statistically significant relationship between the parameters analyzed, with a confidence level of 95.0%, for all cases (P value < 0.05).

The R^2 statistic indicates the percentage of variability of the sample. The correlation coefficients (R) indicate the strength of the relationship between the variables. R values greater than 0.70 indicate that the properties obtained with non-destructive equipment strongly correlate with the modulus of elasticity (global and local) in bending. Although the standard (EN 14081-2) defines that linear regressions must be obtained between Indicator Properties (IP) and all the resistance variables of the material (modulus of elasticity, strength, and density), it is expected that the modulus of elasticity correlates better (higher R^2) with non-destructive methods.

The graphs (Fig. 2) show the linear regressions between the bending properties (MOE_{GLOBAL}, MOE_{LOCAL}, MOR and density) and the indicator properties (IP) obtained by the tests with non-destructive equipment (MST and MTG) in the total *Pinus pinaster* sample. The red points of the graph refer to the resined sample and the blue ones refer to the control sample.

The graphs show the trend lines of the regressions (blue) and two sets of limits for each regression. The inner limits (red lines) establish 95% confidence intervals for the mean values of Y at any selected X. Since the relationships are linear, these limits indicate how well the trend lines have been estimated. The larger the sample, the stricter those limits will be. The outer (black) lines are the 95% prediction limits for new observations. It is estimated that 95% of the additional observations, similar to those in the sample, would be within those limits.

It can be observed in the linear regression graphs that the distribution of the data from the resinated (red points) and controls (blue points) trees are very similar, which indicates that the resin activity does not affect the efficiency of the mechanical classification of *Pinus pinaster* wood.

Conclusions

In general, numerical and distribution differences are not appreciated in the data obtained in the characterization and mechanical classification of the wood from resinous feet and testicles.

The average values of the resistant properties (MOE_{GLOBAL}, MOE_{LOCAL}, MOR and density) did not present numerically significant differences between resinated and control material of both origins. The frequency distributions of the two samples are similar.

Regarding the mechanical classification, the correlation coefficient values (R2) between the indicator properties (IP_{MTG} and IP_{MST}), and the resistant properties (MOE_{GLOBAL}, MOE_{LOCAL}, MOR and density) obtained for the total sample of tables are within the expected limits, which indicates that the acoustic parameters are not influenced by resin activity.

Declarations

FUNDING

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CONFLICTS OF INTEREST/COMPETING INTERESTS

Not applicable

AVAILABILITY OF DATA AND MATERIAL

Not applicable

CODE AVAILABILITY

Not applicable

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Figures

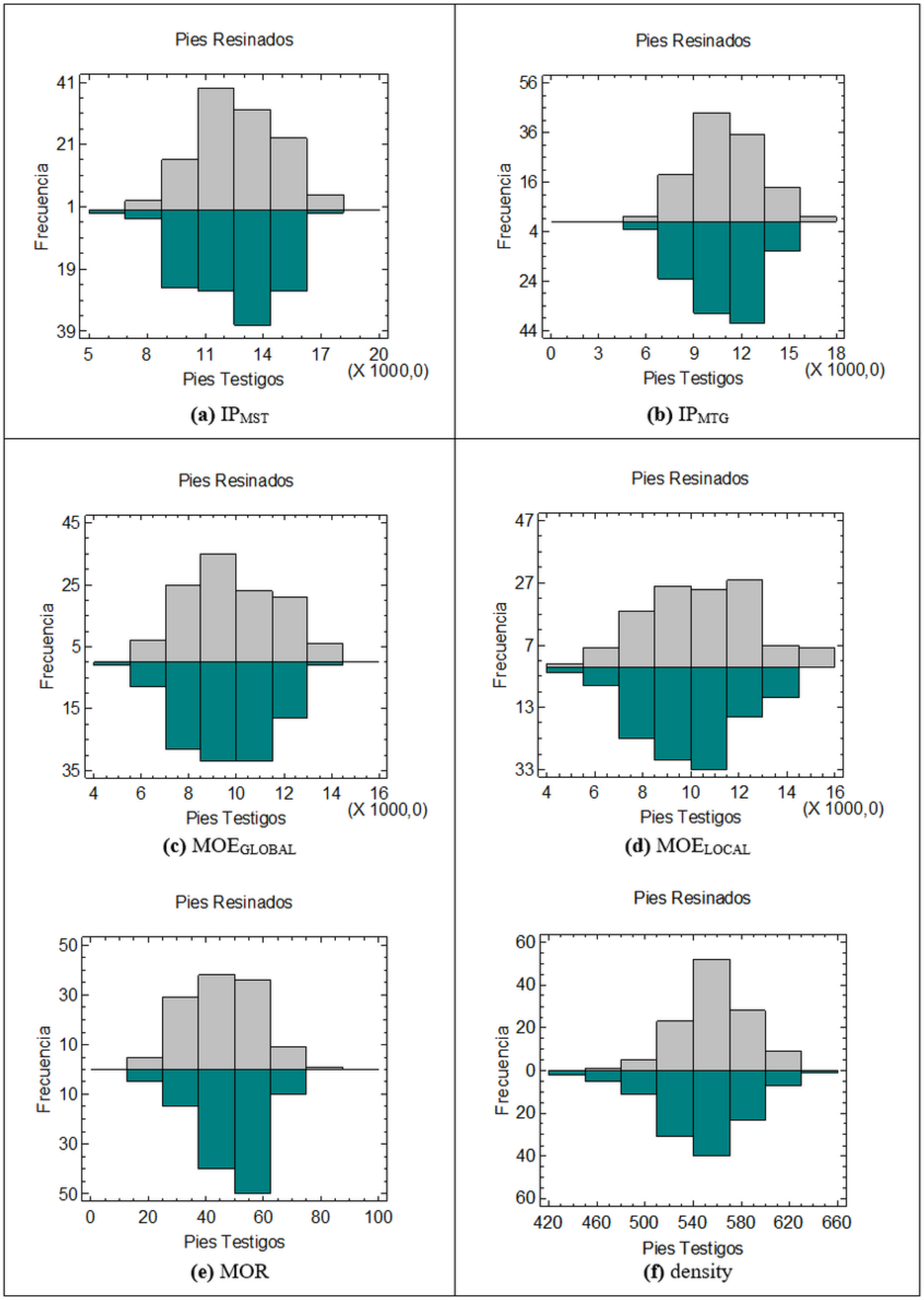

Figure 1

Histograms of non-destructive parameters - **(a)** IP_{MST} and **(b)** IP_{MTG} -, of bending - **(c)** MOE_{GLOBAL}, **(d)** MOE_{LOCAL}, (e) MOR - and of (f) density for resin and control *Pinus pinaster* samples.

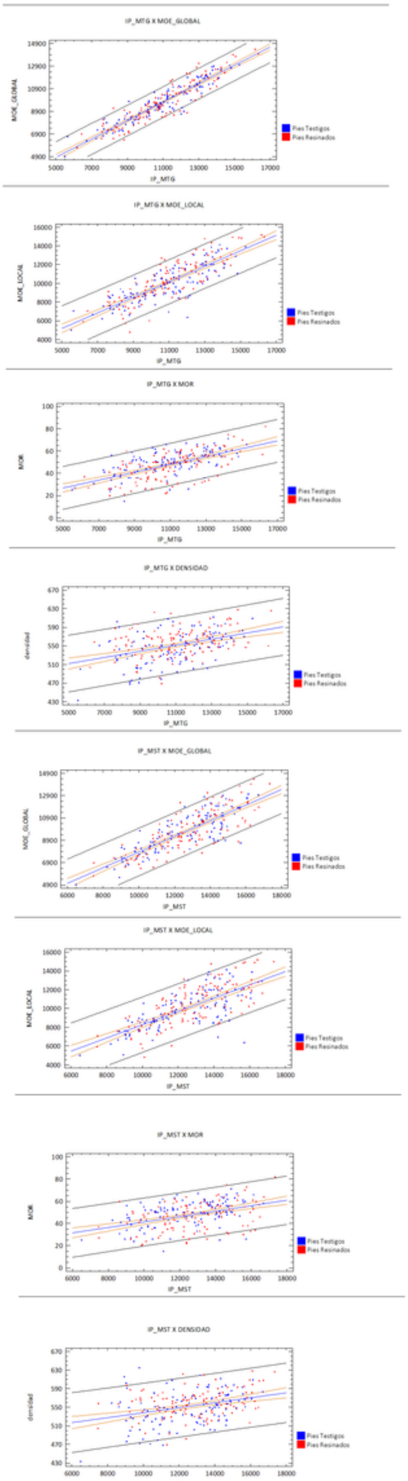

Figure 2

Gráficos de las regresiones lineales entre entre las propiedades resistentes (MOE_{GLOBAL}, MOE_{LOCAL}, MOR y densidad) y las propiedades indicadoras (IP) obtenidas por los ensayos con los equipos no destructivos (MST y MTG) en la muestra total de tablas de Pinus pinaster.