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Article

Durabilidad natural de la madera de siete especies forestales de El Salto, Durango

Natural durability of wood of seven forest species of *El Salto, Durango*

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Resumen:

Para sentar las bases de una adecuada utilización de la madera, es importante conocer su durabilidad natural bajo la acción de agentes bióticos y abióticos, por lo que el objetivo de este estudio fue determinarla en madera de *Pinus durangensis, P. cooperi, P. strobiformis, P. teocote, Juniperus deppeana, Arbutus* spp. y *Quercus sideroxyla* procedente de la región de El Salto, Durango, mediante evaluaciones rápidas (microcosmos terrestre y exposición a hongos degradadores). La durabilidad en microcosmos terrestres se consideró como las pérdidas de masa y de módulo de elasticidad dinámico (MOE_{din}). Para la exposición a los hongos solo se tomó en cuenta la pérdida de masa. Los resultados de la durabilidad en microcosmos terrestre, de acuerdo con la Norma Europea EN 350-1, clasifican a la madera en tres categorías: moderadamente durable (*Juniperus deppeana, P. cooperi* y *P. durangensis*), poco durable (*P. teocote*) y no durable (*P. strobiformis, Quercus sideroxyla* y *Arbutus* spp.). En relación a la pérdida del MOE_{din}, las cuatro especies de pino y *Juniperus deppeana* registraron el menor valor, con 8.77 % en promedio; mientras que *Quercus sideroxyla* y *Arbutus* spp. Registraron hasta 25.63 %. En cuanto a la exposición a hongos, *Trametes versicolor* degradó en mayor medida la madera, con 16.15 % de pérdida de masa, destaca *Quercus sideroxyla,* con 32.57 %.

Palabras clave: Hongos degradadores, madera, microcosmos terrestre, módulo de elasticidad dinámica, pérdida de masa, pruebas aceleradas.

Abstract:

In order to lay the foundations for a proper use of wood, it is important to know its natural durability under the action of both biotic and abiotic agents. Therefore, the objective of this study was to determine the natural durability of the wood of *Pinus durangensis*, *P. cooperi*, *P. strobiformis*, *P. teocote*, *Juniperus deppeana*, *Arbutus* spp. and *Quercus sideroxyla* from the region of *El Salto, Durango*, through rapid assessments (soil microcosm and exposure to degrading fungi). The durability in soil microcosms was considered as the loss of mass and dynamic modulus of elasticity (MOE_{dyn}). For exposure to fungi, only the loss of mass was taken into account. According to the European Standard EN 350-1, the results of the durability in the soil microcosm classify the wood into three categories: moderately durable (*Juniperus deppeana*, *P. cooperi* and *P. durangensis*), scarcely durable (*P. teocote*) and not durable (*P. strobiformis*, *Quercus sideroxyla* and *Arbutus* spp.). In relation to the loss of the MOEdyn, the four species of pine and *Juniperus deppeana* had the lowest value, with an average 8.77 %; while *Quercus sideroxyla* and *Arbutus* spp. had up to 25.63 %. As for the exposure to fungi, *Trametes versicolor* degraded the wood to a larger extent, with 16.15 % of mass loss. *Quercus sideroxyla* had a high degree of degradation, with 32.57 %.

Key words: Degrading fungi, wood, soil microcosm, dynamic modulus of elasticity, loss of mass, accelerated testing.

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Introduction

Wood is a major group of soil organic carbon, the structural components of whose cell walls include cellulose, hemicellulose and lignin. This last compound forms a dense matrix that protects the carbohydrates from enzymatic attacks; the pulp is also resistant to decay, particularly in its crystalline form, which is highly ordered. Although there are many agents, both biotic and abiotic, that attack wood, fungi are the main degraders, being the most effective during the degradation process; however, insects, bacteria, algae and marine wood borers cannot be ruled out. On the other hand, the abiotic agents include the action of rain, wind, and solar radiation (Trevisan *et al.*, 2008; Hibbett *et al*., 2016).

No timber species —not even those with a recognized natural durability— are able to withstand the attack of microorganisms indefinitely, since wood is not physiologically functional, due to its nature as an organic material and to the state in which it is used; therefore, it is subject to the following stage of the natural sequence of any living being: deterioration and decay (De Oliveira *et al.*, 2005).

Xylophagous fungi with white, brown and soft rot have been extensively studied, due to their ability to degrade the cell walls of wood, causing great damage and failures in the products in service; however, these organisms also play an important role in the forest ecosystem, where they contribute significantly to the recycling of carbon dioxide, as the residues of its exploitation are attacked and degraded by these fungi (Singh and Singh, 2014).

The property of the wood which makes it resistant to attack by chemical, physical and biological degrading agents without any preservation treatment is known as natural durability (Paes, 2002). The physical, chemical and biological agents —whether jointly or separately— accelerate the deterioration process, and therefore the durability of wood is influenced by the interaction of the chemical composition of its natural protective (extractive) compounds with the environmental conditions (Brischke *et al.*, 2013).

The communities of organisms that destroy wood vary from one place to another and, as a result of their activity, affect factors such as pH, organic matter, soil microflora and microfauna (Brischke *et al.*, 2014); the moisture of the cell wall of wood, since its decomposition does not progress below 25 % (Thybring, 2013), and the variations in both temperature and relative humidity that create favorable or unfavorable conditions for their development (Johansson *et al.*, 2013). The relative humidity that is critical to the development of wood-degrading microorganisms is 80 to 95 %, which in turn responds to other factors such as the ambient temperature, the time of exposure, and the type and conditions of the surface of wood (Viitanen *et al.*, 2010).

Despite the advances in the technology for the protection of wood, consumers still rely on naturally durable wood for the construction of various structures; however, they are unaware of the inherent durability of the species under different environmental conditions, so that the studies on the natural durability of the wood in the face of biological damage are of primary importance, as they constitute the basis for the recommendations for its optimal utilization, based on the conditions of risk in their final installation. This avoids unnecessary expenses for the replacement and excessive use of wood, which positively impacts the permanence of forests by reducing the felling of trees, and, consequently, the threat of deforestation (Paes *et al.*, 2005; Calonego *et al.*, 2010; Sundararaj *et al.*, 2015).

Given the scarce information regarding the natural durability of the local woods of the *El Salto* region, *Durango* State, this work aims to provide information on the level of durability, through rapid laboratory assessments.

Materials and Methods

Natural durability was determined through the soil microcosm and the exposure to xylophagous fungi by the wood of *Pinus durangensis* Martínez, *Pinus cooperi* C. E. Blanco, *Pinus strobiformis* Engelm., *Pinus teocote* Schiede ex Schltdl. & Cham., *Juniperus deppeana* Steud., *Quercus sideroxyla* Humb. & Bonpl. and *Arbutus* spp. Five trees per species were collected in different areas of the region of *El Salto*, *Durango* of which 0.5 m sections from the base of the tree up were used in the development of the test specimens, and, in order to comply with the requirements of the norm, the wood of *Fagus sylvatica* L. was used as a control species.

Exposure to the soil microcosm

The evaluation of the natural durability of wood through the soil was carried out according to the European Pre-Norm 807 (CEN, 2001). The test specimens (55 per species) were rectangular prisms with dimensions of 10 mm × 5 mm × 100 mm in the radial, tangential and longitudinal direction, respectively, without considering the separation of sapwood and heartwood; these were submitted to a process of drying to a constant weight, which was the initial dry weight with a YAMATO™ DNE910 oven. The test specimens were distributed randomly in plastic containers with the soil collected for the experiment; 80 % (80 mm) of their length was buried, with a gap of 20 mm between specimens (Figure 1). The exposure period to a soil microcosm was 32 weeks, and the monitoring was carried out at different stages of decay of the wood, specifically after 8, 16, 24 y 32 weeks of exposure. The soil remained at 80 to 95 % of its water retention capacity. The natural durability of the wood was considered as the mass loss and the loss of the dynamic modulus of elasticity.

Figure 1. Test specimens exposed to the soil microcosm.

Calculation of the mass-loss rate

The procedure consisted in determining the reduction of the mass of the test specimens as a percentage based on the difference between the dry wood mass at the beginning and at the end of the experiment. The loss of mass is calculated by the following formula:

$$Ml = \left(\frac{Iw - Fw}{Iw}\right) * 100$$

Where:

Ml = Mass loss (%)

Iw = Dry weight at the beginning of the experiment (g)

Fw = Dry weight at the end of the experiment (g)

Dynamic modulus of elasticity (MOE_{dyn})

The MOE_{dyn} was calculated in test specimens at the fiber saturation point, placed on two supports at a distance of 0.224 times its length (2.24 mm) from the center, through the induction of vibrations produced by a blow to the mid-point of the test specimen, which were then captured with the help of a microphone and the Vibration program™ software (Divos, 2004). According to Carrillo Parra *et al.* (2011), this method is used to quantify the rot in wood test specimens because the loss of the MOE_{dyn} is much more sensitive than other tests and presents highly significant values, even at the initial stages of deterioration when the mass loss is still low.

The formula derived from Hearmon (1966) was applied to the theory of vibration in wood (Machek *et al.*, 2001):

$$MOE_{dyn} = \left(\frac{2 * f_n}{\gamma_n * \pi}\right)^2 * \left(\frac{mL^3}{I}\right)$$

$$I = \frac{b * a^3}{12}$$

Where:

MOE_{dyn} = Dynamic modulus of elasticity (MPa)

f_n = Frequency (Hz)

γ_n = $(n+0.5)^2$ = 2.267

π = 3.1416

m = Weight of the test specimen above the fiber saturation point (g)

L = Length of the test specimen (mm)

I = Inertia (mm^4)

a = Thickness of the test specimen (mm)

b = Width of the test specimen (mm)

Calculation of the static modulus of elasticity (MOE)

The MOE was determined based on bending tests with a moisture content in balance with the environment. The test was carried out in a Instron™ universal mechanical testing machine, with a capacity of 60 tons of pressure; the specimen was placed on two supports at a distance of 0.224 times its length (2.24 mm), and was applied at a speed of 1 mm min^{-1} according to the Norm ASTM D 143 (ASTM, 1992). The calculation was made by the following formula (ASTM, 1992):

$$MOE_{est} = \frac{P_1 * L^3}{4 * d * b * h^3}$$

Where:

MOE_{est} = Static modulus of elasticity (kgf cm^{-2})

P_1 = Load at the limit of proportionality (kgf)

L = Light of the test specimen, i.e. separation between supports (cm)

d = Deformation suffered by the test specimen under the load P_1 (cm)

b = Base of the test specimen (cm)

h = Height of the test specimen (cm)

Exposure to xylophagous fungi

In order to determine the natural durability of wood by exposure to xylophagous fungi, the procedure recommended in the European Norm 113 (CEN, 1996) was followed; the utilized fungi were: *Coniophora puteana* (Schumach.) P. Karst, with the reference number is BAM 15 (brown rot fungus), and *Trametes versicolor* (L.: Fr.) Quél., with the reference number CTB 863A (white rot fungus), both provided by the Laboratory of the Department of Molecular Biotechnology of Wood and

Technical Mycology Laboratory of the University of Göttingen, Germany. The dimensions of the test specimens (36 per species) were 10 mm x 5 mm x 30 mm in the radial, tangential and longitudinal direction, respectively; without considering the separation of sapwood from heartwood. The specimens were subsequently subjected to drying at a temperature of 103 ± 5 °C until they attained a constant weight, which was the dry weight at the beginning of the experiment. The test specimens were sterilized in an autoclave for 20 minutes at a temperature of 125 °C. They were then placed in Petri dishes; for this purpose, 50 mL of solidified agar malt were used as culture medium, on which the inoculum of the fungus (1 cm) and 6 specimens were placed on a stainless steel base (Figure 2). The Petri dishes with the specimens were incubated in a grow room with controlled environment for a period of 16 weeks, at a controlled temperature of 20 ± 2 °C and a relative humidity of 65 ± 5 %. The durability is considered only as the mass loss within the period of exposure, which was measured with an OHAUS™ DV214C precision scale.

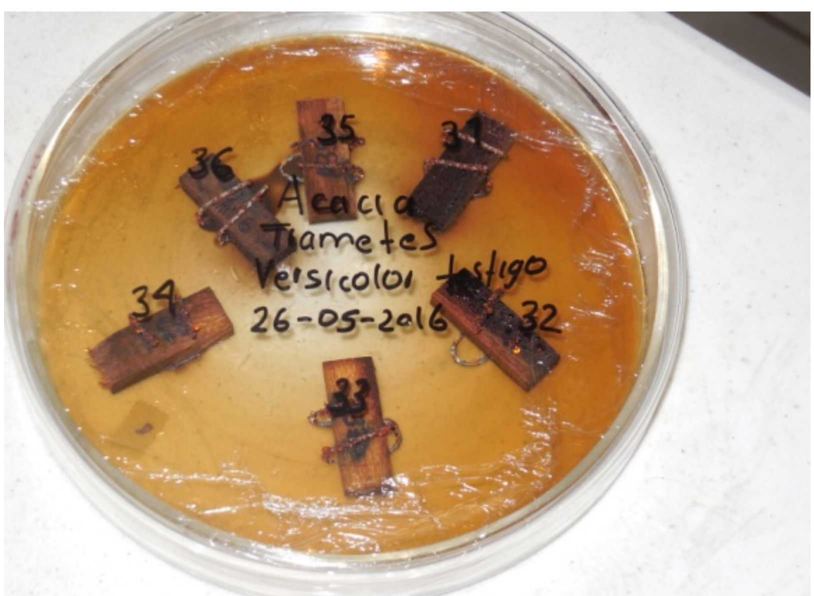


Figure 2. Test specimens exposed to xylophagous fungi.

Classification of the durability of the wood

The natural durability of the wood was classified based on the "X" index, according to the European Norm EN 350-1 (CEN, 1994) (Table 1). The "x" index was determined by dividing the average mass loss of the studied species by the average mass loss of the control species (*Fagus sylvatica* L.) as follows:

$$x = \frac{\bar{y}_{sp}}{\bar{x}_f}$$

Where:

x = "x" index

$\bar{y}_{sp}$ = Average mass loss rate of the species of interest (g)

$\bar{x}_f$ = Average mass loss rate of the control species (g)

Table 1. Index of the durability of the wood.

Durability class	**Description**	**Mass loss based on "x"**
1	Very high	x < 0.15
2	High	0.15 > x ≤ 0.30
3	Moderate	0.30 > x ≤ 0.60
4	Low	0.60 > x ≤ 0. 90
5	Not durable	x > 0.90

Source: UNE EN 350-1 (CEN, 1994)

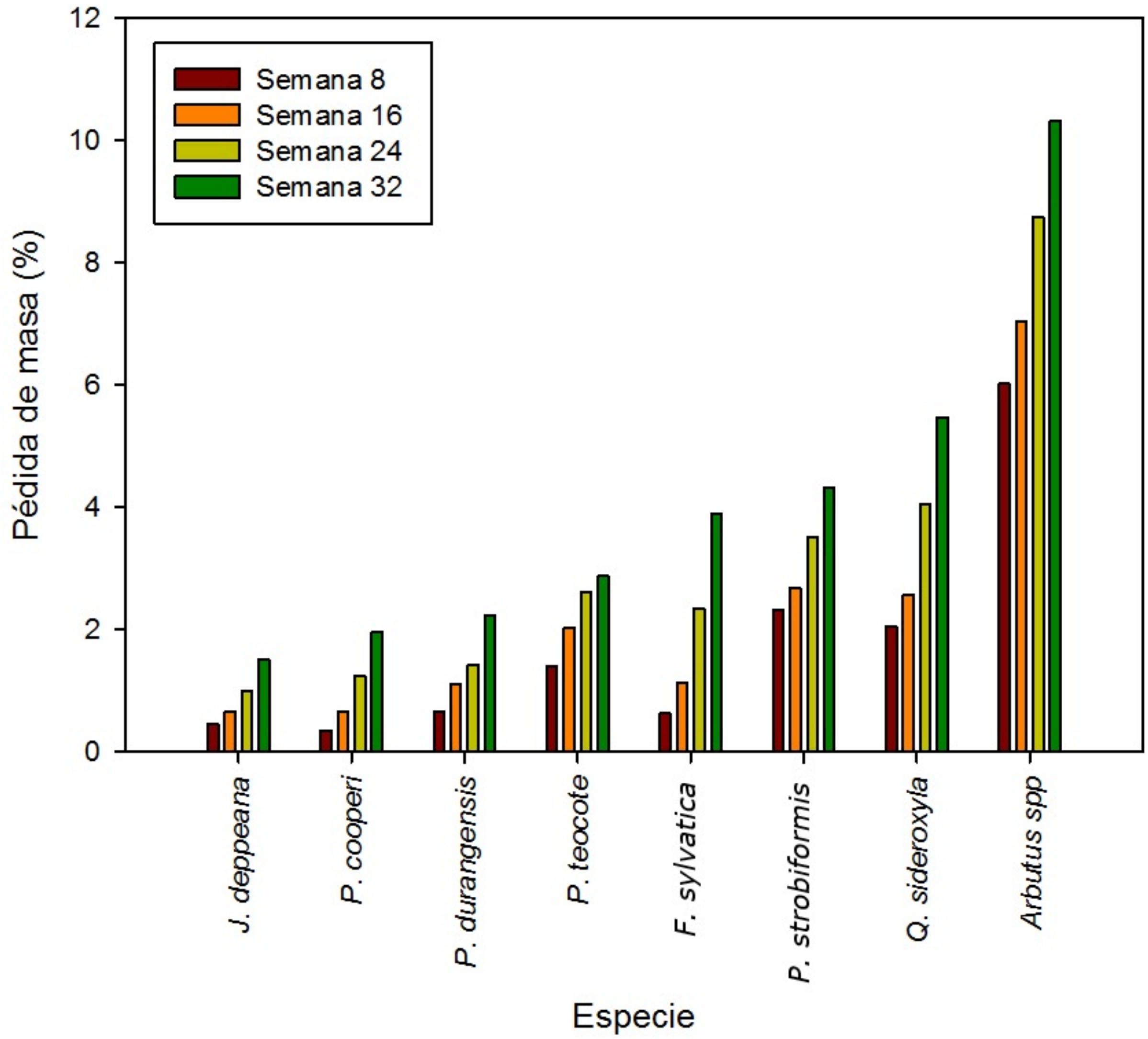
Statistical Analysis

The normality of the data of the mass loss by exposure time of the studied species was determined by the modified Shapiro-Wilks test, designed for the normality contrast. The test showed that the variables mass loss and loss of MOE_{dyn} are not derived from a population with a normal distribution; therefore, in order to detect statistical differences between the mass loss per unit of time of exposure and per species, the Mann-Whitney U test for two independent samples and a non-parametric variance analysis and comparison tests of intervals of the median of Kruskal-Wallis (Kruskal and Wallis, 1952) were carried out, with a significance level of α =0.05. The statistical analyzes were performed using the 2013 InfoStat software (Di Rienzo *et al.*, 2013).

Results and Discussion

Exposure to the soil microcosm

Mass loss. The mass loss rate varied in terms of exposure time and species, with average percentages of 4 % in *J. deppeana*, *P. cooperi*, *P. durangensis*, *P. teocote*, *F. sylvatica* and *Pinus strobiformis*, and of 5 and 10 % for *Q. sideroxyla* and *Arbutus* spp., respectively (Figure 3).



Pérdida de peso = Mass loss; *Especie* = Species; *Semana* = Week.

Figure 3. Mass loss rate by species.

The lower mass rate of the wood of *Juniperus deppeana* is due to the content of extractives (Eller *et al.*, 2010; Shortle *et al.*, 2010; Kirker *et al.*, 2016) that are the non-structural components of wood, often concentrated in the heartwood and acting as lines of defense against biological attacks. However, the content of extractives varies greatly, not only from one tree to another but within a single tree. According to Kirker *et al*. (2013), the wood of *Juniperus virginiana* L. has a moderate to very high natural durability, but when the extractives are removed from the wood, its durability decreases, sometimes to the point of being classified as low. *Juniperu*s wood poles with 56 years of service in contact with the ground have been recorded in the state of Oregon (Morrell *et al.*, 1999); this is due to their valuable source of extracts that provide a high inhibitory effect on the growth of *Trametes versicolor* and *Gloeophyllum trabeum* (Pers.) Murrill (Mun and Prewitt, 2011).

The opposite behavior in *Arbutus* spp. and *Quercus sideroxyla*, whose wood exhibits less durability, can be explained by the fact the extractives contain no toxic elements to cope with xylophagous agents (Carvalho *et al.*, 2016). Brischke and Rolf-Kiel (2010) point out that the classification of the durability of the European oak (*Quercus* spp.) as "high" has been under discussion for a long time, since the results of different comparative studies have clearly shown a lower durability, especially when it is exposed to the soil; however, they identified the role of the radial cracks of the wood —where its decay actually begins— as the most important factor.

Herrera *et al*. (2006) point out that the wood, like all organic materials, is subject to destruction by various agents, and that from the moment a tree is cut, it becomes dead tissue that is coveted by various organisms, which influence its degradation. Likewise, Nájera-Luna *et al*. (2010) evaluated the mass loss in the wood of four forest species in the region of the *Salto*, *Durango*, by prolonged exposure to two types of substrata and recorded average values of mass loss in the wood of *Pinus strobiformis* de 7.26 %, in *Pinus durangensis de* 4.44 %, in *Quercus sideroxyla* 5.71 %, and 5.95 % in *Quercus laeta* Liebm. These results are similar to those obtained in the present study.

The Kruskal-Wallis non-parametric analysis of variance for the loss of mass of the evaluated species was significant ($p<0.0001$), with no statistical differences between species. The comparison test for the median intervals showed that the lowest mass loss occurs in *Juniperus deppeana*, and the highest, in the *Arbutus* spp. According to the classification of the European Norm EN 350-1, the wood of *J. deppeana*, *P. cooperi* and *P. durangensis* belongs to class 3 (moderately durable); *P. teocote* wood is rated as belonging to class 4 (durable), and the wood of *Pinus strobiformis*, *Quercus sideroxyla* and *Arbutus* spp. is regarded as class 5 (non-durable) (Table 2).

The lower mass loss rate of the wood of the genus *Pinus* spp. exposed to the soil is accounted for by the fact that the conifers contain only lignin composed of guaiacyl monomers (Blanchette *et al.*, 1990). Typically, guaiacyl lignin predominates in the cell walls of *Abies alba* Mill., *Pinus sylvestris* L., *Pseudotsuga menziesii* (Mirb.) Franco and *Taxus baccata* L., in higher concentrations in the latewood tracheids (Baum, 2001). Guaiacyl lignins are predominantly products of coniferyl alcohol polymerization; whereas guaiacyl-syringil lignins are composed of variable parts of guaiacyl and syringil aromatic cores, along with small amounts of p-hydroxyphenyl (Fengel and Wegener, 1989). The proportions of these monomers vary between types of individual cells and layers of the cell wall and they exert a strongly influence on the durability and on their susceptibility to degrading fungi (Fukazawa, 1992).

Table 2. Non-parametric analysis of variance for mass loss in the soil microcosm.

Species	Average mass loss rate (%)	"x"	Standard deviation (%)	Medians (%)	Average intervals*	DF	H	p
Juniperus deppeana Steud.	1.51	0.39	0.48	1.52	16.09 a			
Pinus cooperi C.E.Blanco	1.96	0.50	0.91	1.54	24.64 ab			
Pinus durangensis Martínez	2.24	0.57	0.90	2.19	29.82 abc			
Pinus teocote Schiede ex Schltdl. & Cham.	2.87	0.74	1.21	2.85	40.27 bcd			
Fagus sylvatica L.	3.90	Na	2.54	2.70	46.73 cde	7	56	<0.0001**
Pinus strobiformis Engelm.	4.32	1.11	2.16	5.20	52.00 de			
Quercus sideroxyla Humb. & Bonpl.	5.47	1.40	1.70	4.82	64.55 ef			
Arbutus spp.	10.32	2.65	2.31	11.04	81.91 f			

"x" = Index of durability of the wood; NA = Not applicable; *Intervals with the same letter are not significantly different, Kruskal Wallis (α =0.05); ** Significant at 5 %. DF = Degrees of freedom; H = Statistical value of the Kruskal Wallis test.

Loss of the MOE_{dyn}. The analysis of variance, the non-parametric Kruskal-Wallis test for the loss of MOE_{dyn} in the wood exposed to the soil showed significant differences ($p<0.0001$). The wood of *Pinus* spp. and *Juniperus deppeana* exhibited the lowest values of MOE_{dyn} (from 8.09 to 9.52 %), while the highest values (17.75 to 29.07 %) corresponded to the wood of *Fagus sylvatica* L., *Quercus sideroxyla* and *Arbutus* spp. (Table 3). According to Gatto *et al.* (2012), both the intrinsic factors of wood —such as the anatomical (size of the fibers and frequency of lightning), physical (specific weight and moisture content) and morphological (types of wood and grain angle) properties— and the degree of deterioration of the wood have a direct impact on the propagation of ultrasound waves. Sotomayor (2014) and Halabe and Franklin (1998) point out that the use of non-destructive methods for determining alterations in the wood due to its degradation by both biotic and abiotic factors is based on the measurement of the speed of the mechanical waves through the structure, since in the presence of an alteration of the wood —for example, the deterioration of the woody tissue or collapse of the material—, the speed of the wave mechanics will vary as a consequence of the change in the structure of the material, which results in a reduction of its elastic properties, in this case, in the modulus of elasticity calculated on the basis of the speed and density of the material. Furthermore, according to Blanchette *et al.* (1990), the transmission speed of a mechanical wave in wood is based on its ability to store and dispel energy. Each species of wood has a density, a wave speed and a specific modulus of elasticity, all of which are related to the chemical composition and the morphology of each wood.

Machek *et al*. (1997) point out that the MOE_{dyn} is a good indicator for assessing the mass loss in wood with signs of deterioration or decay, even during the early stages of the infestation, without a marked decrease in the mass loss rate. Schmidt (2006) establishes that mass loss is mainly due to the intensive degradation of carbohydrates by soft rot fungi, which can cause a loss of up to 50 % of the efforts of flexion, with only 5 % of mass loss.

Table 3. Non-parametric analysis of variance for the loss of MOE_{dyn} in soil microcosms.

Species	Average loss of MOE_{dyn} (%)	Standard deviation (%)	Medians (%)	Average intervals*	DF	H	p
Pinus cooperi C.E.Blanco	8.09	3.75	7.98	25.27 a	7	53	<0.0001**
Pinus strobiformis Engelm.	8.31	2.04	7.49	26.64 a			
Pinus teocote Schiede ex Schltdl. & Cham.	9.00	3.21	9.17	31.36 a			
Juniperus deppeana Steud.	8.94	1.78	9.00	32.00 a			
Pinus durangensis Martínez	9.52	2.99	8.46	33.00 a			
Fagus sylvatica L.	17.75	7.73	16.29	60.64 b			
Quercus sideroxyla Humb. & Bonpl.	22.18	8.44	23.31	68.18 b			
Arbutus spp.	29.07	6.64	29.82	78.91 b			

*Intervals with the same letter are not significantly different; the Kruskal Wallis (α = 0.05); ** Significant at 5 %; DF = Degrees of freedom; H = Statistical value of the Kruskal Wallis test.

According to Carrillo Parra *et al*. (2011), the reduction rate of MOE_{dyn} resulting from the deterioration in the structure of the wood caused by the organisms present in the microcosm during week sixteen is 79 % for *Fagus sylvatica* and 40 % for *Pinus sylvestris*; on the other hand, the values of loss of MOE_{dyn} in *Prosopis laevigata* Humb.& Bonpl. ex Willd. M. C. Johnst. ranged between 12 and 24 % in the different evaluated sites. In the present study, only maximum values below 29 % were obtained for loss of the MOE_{dyn}.

Exposure to xylophagous fungi

Mass loss by species of fungus. The non-parametric Mann-Whitney U test determined that the loss of mass was statistically significant (p = 0.0081) for the type of fungus used in wood degradation (Table 4). Kollmann and Côté (1968) point out that the different activity of xylophagous fungi is the cause of the existence of different enzymes, because, while the parasitic xylophagous fungi feed on the compounds of the juice, the saprophytic xylophagous fungi feed on the cell wall; the latter attack to the cellulose preferably, while the former attack the lignin. For this reason, the higher or lower mass loss rates observed in species of the present work can be attributed to them.

Carrillo-Parra *et al.* (2011) evaluated the durability of *Prosopis laevigata*, through exposure to degrading fungi, their results show a 1.38 % reduction of wood degradation by *Coniophora puteana*, and that the mass loss caused by *Trametes versicolor* decreased by 1.45 %. In the present study, the mass loss induced by *C. puteana* was lower by 25 % than that caused by *T. versicolor*. This is accounted for by the efficiency with which the fungi degrade the polysaccharides contained in lignin, as the assimilation of the remaining polysaccharides by white rot fungi after the ligninolisis, with conventional systems of glycosyl hydrolases that contain both endo-and exoactive enzymes, is better. On the other hand, brown rot fungi also degrade the lignocellulose efficiently, but their biodegrading systems are less complete (Hatakka and Hammel, 2011).

Table 4. Mann-Whitney U non-parametric test for mass loss due to exposure to fungi.

Fungus	Average mass loss rates (%)	Standard deviation (%)	Medians (%)	Average intervals*	U	p
Coniophora puteana (Schumach.) P. Karst	3.96	4.25	2.11	85.88 a	5628	0.0081**
Trametes versicolor (L.: Fr.) Quél.	16.15	21.35	4.01	107.13 b		

*Intervals with the same letter are not significantly different, Mann-Whitney U (α=0.05). ** Significant at 5 %; U = statistical value of the Mann-Whitney U test.

Mass loss caused by *Coniophora puteana*. The results of the Kruskal-Wallis non-parametric analysis of variance showed significant differences (p<0.0001), which indicates that the mass loss differs between species. The wood of *Arbutus* spp., *Quercus sideroxyla* and *Fagus sylvatic*a exhibited the greatest losses, while *P. durangensis*, *P. strobiformis*, *P. cooperi* and *Juniperus deppeana* had lesser losses. Based on the above findings, the durability of the wood of *P. durangensis*, *P. strobiformis*, *P. cooperi* and *Juniperus deppeana* was classified, according to European Norm EN 350-1, as very high, within the durability class 1; that of *P. teocote* wood, was rated as high (class 2); that of *Arbutus* spp. wood, as moderate (class 3), and that of *Quercus sideroxyl*a wood, as low (class 4) (Table 5).

Table 5. Non-parametric analysis of variance for mass loss due to exposure to *Coniophora puteana* (Schumach.) P. Karst.

Species	**Average mass loss rates (%)**	**"x"**	**Standard deviation (%)**	**Medians (%)**	**Average intervals***	**DF**	**H**	**P**
Pinus durangensis Martínez	0.37	0.03	0.69	0.20	17.17 a			
Pinus strobiformis Engelm.	1.44	0.12	2.73	0.67	29.25 ab			
Pinus cooperi C.E.Blanco	0.84	0.07	0.56	0.75	30.42 ab			
Juniperus deppeana Steud.	0.92	0.08	0.62	0.66	31.33 ab			
Pinus teocote Schiede ex Schltdl. & Cham.	2.39	0.20	1.54	2.38	46.83 bc	7	74	<0.0001**
Arbutus spp.	6.05	0.51	1.72	5.94	67.42 cd			
Quercus sideroxyla Humb. & Bonpl.	7.76	0.65	1.73	8.28	76.17 d			
Fagus sylvatica L.	11.87	Na	2.44	11.73	89.42 d			

"x" = Index of durability of the wood; NA = Not applicable; *Ranges with the same letter are not significantly different, Kruskal Wallis (α =0.05). ** Significant at 5 %; DF = Degrees of freedom; H = Statistical value of the Kruskal Wallis test.

Mass loss caused by *Trametes versicolor*. Table 6 summarizes the Kruskal-Wallis non-parametric analysis of variance for mass loss. Significant differences between the evaluated species are observed. The use of the test of comparison of the median intervals shows the existence of two statistically different groups: *Arbutus* spp., *Quercus sideroxyla* and *Fagus sylvatica* had the highest average mass loss (30.67 %), while the lowest corresponded to *Juniperus deppeana*, *P. durangensis*, *P. teocote* and *P. strobiformis* (0.97 %). Based on the European Norm EN 350-1, the wood of J*uniperus deppeana*, *P. durangensis*, *P. teocote* and *P. strobiformis* is classified as very durable (class 1); the wood of *P. cooperi* and that of *Arbutus* spp. belong to class 3 of durability (moderately durable), and the wood of *Quecus sideroxyla* is classified as scarcely durable (class 4).

Table 6. Non-parametric analysis of variance for mass loss due to exposure to *Trametes versicolor* (L.: Fr.) Quél.

Species and fungus	Average mass loss rates (%)	"x"	Standard deviation (%)	Medians (%)	Average intervals*	DF	H	P
Juniperus deppeana Steud.	0.60	0.01	0.59	0.76	21.75 a	7	64	<0.0001**
Pinus durangensis Martínez	2.06	0.04	3.49	0.55	25.42 a			
Pinus teocote Schiede ex Schltdl. & Cham.	1.07	0.02	1.15	0.60	26.50 a			
Pinus strobiformis Engelm.	2.74	0.06	2.64	1.96	35.75 ab			
Pinus cooperi C.E.Blanco	18.30	0.37	21.08	4.96	55.75 bc			
Arbutus spp.	22.85	0.47	20.94	16.45	64.92 cd			
Quercus sideroxyla Humb. & Bonpl.	32.57	0.66	15.99	34.96	74.17 cd			
Fagus sylvatica L.	49.00	Na	18.05	40.60	83.75 d			

"x" = Index of durability of the wood; NA = Not applicable; *Intervals with the same letter are not significantly different, Kruskal Wallis (α =0.05). ** Significant at 5 %. DF = Degrees of freedom, H = Statistical value of the Kruskal Wallis test.

Carrillo-Parra *et al*. (2013) determined the natural durability of 10 native taxa of northeastern Mexico by exposing them to *Trametes versicolor* and *Coniophora puteana*. Their results show mass loss rates of 7.1 to 54.1 % due to *Trametes versicolor*, and of 6.3 to 48.5 % due to *Coniophora puteana*. *Ebenopsis ebano* (Berland.) Barneby & J. W. Grimes exhibited the lowest mass loss rates with both fungus species, while *Fagus sylvatica* had the highest. Brischke *et al.* (2017) assessed the minimum moisture threshold in the wood allowing the start of the fungal decay in *Picea abies* (L.) H.Karst. and *Fagus sylvatic*a, with *Coniophora puteana* and *Trametes versicolor* under real simulation in various exposure scenarios. They confirmed that the wood-destroying Basidiomycetes can degrade the wood to a high relative humidity in the absence of any external source of liquid water, since the fungi were able to cause significant degradation in moisture contents considerably below the fiber saturation point.

Conclusions

According to the European Norm EN 3501, the durability of the wood of *Juniperus deppeana*, *P. cooperi* and *P. durangensis* resulting from the soil microcosm was classified as moderate, and that of *P. teocote* wood, as low, while the wood of *P. strobiformis*, *Quercus sideroxyla* and *Arbutus* spp. was rated non-durable.

The wood of *Quercus sideroxyla* and *Arbutus* spp. experienced a 25 % loss of dynamic modulus of elasticity in the soil microcosms; while the four *Pinus* species and *Juniperus deppean*a lost 9 % of elasticity.

The highest degradation of wood by type of fungus was obtained with *Trametes versicolor*, with an average loss of mass of 16 %, while the average mass loss with *Coniophora puteana* was of 4 %.

When exposed to *Coniophora puteana*, the durability of the wood of *P. durangensis*, *P. strobiformis*, *P. cooperi* and *Juniperus deppeana* is classified as very high; that of

P. teocote wood, as high; that of *Arbutus* spp., as moderate; and that of *Quercus sideroxyla*, as low.

When exposed to *Trametes versicolor, the* wood of *Juniperus deppeana*, *P. durangensis*, *P. teocot*e and *P. strobiformis* is classified as highly durable; *P. cooperi* and *Arbutus* spp., as moderately durable; and *Quercus sideroxyla* as scarcely durable.

For applications in which the wood must be in direct contact with the ground, the wood of *Juniperus deppeana*, *Pinus cooperi* and *Pinus durangensis* is recommended, as they exhibited the best natural durability when exposed to soil microcosms and to degrading fungi. As for the rest of the species, it is recommended that they be used in protected environments where the contact with wood-degrading agents is minimized.

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Ricardo de la Cruz-Carrera: field and laboratory work, drafting of the manuscript; Artemio Carrillo Parra: support in the field and laboratory work, methodological aspects, editing of the manuscript and revision of the manuscript; Juan Abel Nájera Luna: support in field work, data analysis, editing of the manuscript; Francisco Cruz Cobos: data analysis and review of manuscript; Francisco Javier Hernández: data analysis and revision of the manuscript; Jorge Méndez González: review of the manuscript and suggestions in regard to the results and the discussion.

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