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Physico-mechanical properties of Spanish juniper wood considering the effect of heartwood formation and the presence of defects and imperfections

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Abstract

Aim of study: Determining the main physical and mechanical properties of Spanish juniper wood from Soria (Spain) considering the effects of heartwood formation and the presence of defects and imperfections; and comparing the resulting characteristics with similar existing data for other regional softwood species of commercial interest.

Area of study: Berlanga de Duero (Soria, Castilla y León), Spain.

Material and Methods: Wood physico-mechanical performance was determined by Spanish UNE standards in order to provide proper comparisons to other regional softwood species. An individual tree representing average plot characteristics was selected in all eight 10 m radius circular plots that were established well-representing the heterogeneity of this woodland. The age of every tree was determined reading the number of growth rings at the base of each sampled tree. Every physico-mechanical property was assessed at least 4 times for every wood sample type (sapwood and heartwood, whether clear or with the presence of defects) of each tree. Two-way ANOVA was run to assess significant differences in the results. *Post hoc* all pairwise comparisons were performed using Tukey's test ($p < 0.05$).

Research highlights: Spanish juniper wood resulted harder than other regional commercial conifers, and showed semi-heavyweight heartwood and lightweight sapwood; whereas shrinkage figures remarked its great dimensional stability. The high presence of knots within heartwood made it even heavier, harder, and more resistant to compression parallel to grain. A commercial use of this rare precious wood may contribute to juniper forests preservation in the frame of forest sustainable management plans.

Key words: heartwood effect; *Juniperus thurifera* L.; physico-mechanical wood properties; wood classification; wood defects.

Introduction

Spanish juniper (*Juniperus thurifera* L.), which is a species considered as very resistant to adverse environments (Bertaudière *et al*., 2001), makes up one of the most common forests on the Iberian Peninsula. Whereas juniper woodlands are heavily degraded in northern Africa as a result of intensive wood removal (Montès *et al*., 2002); the decline of livestock activities over recent decades have led to the promotion of natural regeneration in Europe (DeSoto *et al*., 2010). Particularly, the largest and best preserved extensions of juniper forests in the world can be currently found in Spain, where adequate conservation practices promoting its regeneration have been implemented by regional and national authorities (Lucas, 1998; Gauquelin *et al*., 1999). In fact, Spanish juniper cover has significantly increased in area from 1960's onwards (MARM, 2008 and 2009). Whether its

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regeneration has been reported explosive on abandoned long-laboured soils (Llorente, 2001), junipers expansion may be limited by the competitive colonization of pines and oaks, which should be preserved (DeSoto *et al*., 2010), fragmentation, aridity, and Global Change (Del Rio and Peñas, 2006; Pueyo and Alados, 2007). Definitely, re-activating the market for juniper wood through the revaluation of potential uses assessing its properties, together with the application of suitable forestry and management practices, may positively contribute to the conservation of these forests.

Despite the great ecological and expanding relevance of these stands, forestry research on the field performance of Spanish juniper has been limited to specific issues assessing growth records and dendrochronological sensitivity (Bertaudière *et al*., 1999; Olano *et al*., 2008; Rozas *et al*., 2008; DeSoto *et al*., 2010) and a few reports regarding its field and ecological performance (Bertaudière *et al*., 2001; Montès *et al*., 2002; Jiménez *et al*., 2005; Pueyo and Alados, 2007), or its conservation status (Gauquelin *et al*., 1999). From the point of view of wood market and industrial applications, juniper wood has not been assessed of great interest as timber, although there have been local primary processing industries interested on its cultivation due to its desirable odour, beautiful colour, and proved very high durability in the open (Peraza, 1964; Lucas, 1998). These properties should be also considered when assessing potential juniper wood applications based upon its mechanical performance. Its poor timber performance has been mainly attributed to the presence of defects due to its harsh growing environments, including strong livestock pressure (Bertaudière *et al*., 2001; Rozas *et al*., 2008); but these forests have not been ever subjected to management practices aiming to produce higher-quality wood.

Regional and private institutions have been recently involved in the promotion of sharing information regarding the performance of juniper species in order to enhance management and conservation policies, promoting local wood processing and crafts factories (CESEFOR, 2006). Considering this framework, the main scope of this research initiative was setting a sound reference for the physical and mechanical performance of Spanish juniper wood. These properties, together to its high durability in the open and its precious aesthetic value (colour and odour), are important to determine potential uses for this wood, which is markedly affected by both heartwood formation and the presence of defects; so both factors were taken into account when measuring these properties and discussing application alternatives. In addition, achieving certification from the Forest Stewardship Council (FSC) has been considered determinant to overcome reluctances to use this wood.

Material and methods

Very little information is available reporting forest planning and silvicultural activity in juniper forests, and which are the traditional, actual or potential uses of Spanish juniper wood, besides some wood technological and regional forest service reports.

The sample area is an approximately 70 km^2 gently undulating (0-5% slope) limestone moorland (1020-1090 m altitude) broken up by small ravines covered by a typical mono-specific Spanish juniper forest, with several oaks scattered all around, located in "*Berlanga de Duero*" (Soria, Spain). Soils are chalky, more or less stony and shallow. The Regional Forest Service promoted a post-fire inventory aiming to record the existent stand structure and allowing us to bring down representative trees with unaffected wood in order to assess its properties.

Eight 10 m radius circular plots were established representing the heterogeneity of this woodland, and an individual tree was selected representing the average characteristics of the trees found in each plot. Shorter forked trees and bushy small trunks (<1.3 m) were rejected. Normal and basal cross-sectional diameters of every sampled tree, and their height, were determined by direct dimensional measurement; basal area was estimated by simple equivalent-circle surface calculation; and overbark volume was calculated by Huber's commercial formula dividing the log in 1 m boles. The age of every tree was determined reading the number of growth rings on the polished cross-sectional area at the base of the tree using a binocular magnifier. The samples were wetted for easier reading.

Wood physical and mechanical properties were determined according to Spanish standards (UNE, Table 1) in order to set proper comparisons with other regional wood species. These standards are in wide agreement with most international prescriptions for testing small clear specimens of timber (*e.g.* ASTM International D 143-94 - Reapproved 2000; and D 2395-02). Results were interpreted and classified by

Table 1. Physico-mechanical properties of Spanish juniper (*Juniperus thurifera* L.) wood were determined according to the following Spanish standards (UNE 56 series)

UNE standard	Reference	Specifications / Wood properties
56-528	AENOR* 1978a	Preparation and conditioning of wood specimens
56-529	AENOR 1977a	Moisture
56-531	AENOR 1977b	Specific gravity and Density
56-533	AENOR 1977c	Shrinkage
56-534	AENOR 1977d	Hardness
56-535	AENOR 1977e	Compression parallel to grain
56-542	AENOR 1988	Compression perpendicular to grain
56-537	AENOR 1979	Static bending
56-540	AENOR 1978b	Interpretation of wood physico-mechanical results

*AENOR: Spanish Association for Standardisation and Certification.

UNE 56-540 (AENOR, 1978b), which describes its proper performance and provides reference values to compare different types of wood.

In short, cruciform sampling of specimens with appropriate standard dimensions (20 × 20 mm cross-sections ×30, 40, 60, or 300 mm-long beams) was performed on the merchantable basal bole (≈1.5-2.0 m) of each tree maximizing the number of sample specimens of each type (sapwood and heartwood, whether clear or with the presence of defects) extracted from the cross flitches sawn in the bolts. This protocol is similar to the corresponding ASTM standard for small diameter trees (<300 mm; ASTM International D 5536-94, Reapproved 1999). Lots were drawn to assign which test was going to be carried out before each specimen was extracted from the sawn flitches in order to avoid a systematic sampling bias on the results. Every property was assessed at least 4 times for every wood sample type within a tree; so representative average values of wood quality could be provided. Mechanical tests require longer specimens; thus they were determined a lower number of times (≥3) due to the difficulty of extracting such straight-long specimens for every type of wood. Linear shrinkage tests were only performed using clear specimens. Hardness is prescribed by UNE 56-534 as a modification of Brinell test. Mechanical tests are described to be performed increasing the load until wood failure (UNE 56-535, 37 and 42).

Cross-sectional areas of heartwood (reddish) and sapwood (yellowish) were easily distinguished by their different colour. Although standards prescribe that testing should only be performed using clear specimens, the influence of wood defects on wood performance was also assessed. Wood specimens were previously conditioned to a 12% moisture content equilibrium inside a conditioning chamber at T = 20°C and a 65% relative humidity. Oven-dry weight was obtained when required subjecting samples to T = 103 ± 2°C until constant weight was achieved, *i.e.* 3 days was enough by far.

Two-way ANOVAs were run (SigmaStat 2.0, SPSS Inc.) to assess significant differences. *Post hoc* all pairwise comparisons were performed using Tukey's test ($p < 0.05$).

Results and discussion

The survey performed by the Regional Forest Service showed that, even though most of the trees were closely over 125 years old, an irregular stand structure of diameters was found in the area, outlining that management practices for livestock foraging shaped this forest in the past (Olano *et al.*, 2008). Furthermore, the slow growth of this species was stressed to $0.12 \pm 0.06\ m^3 \cdot ha^{-1} \cdot year^{-1}$ (overbark wood) in the area; and the stand on deeper soils showed much greater stand stock figures (≈1000 trees · ha^{-1}) than on stonier ones (<350). Particularly, the characteristics of the trees sampled to test the physical and mechanical performance of Spanish juniper wood were very similar (Table 2).

The results of the measured wood physical and mechanical properties, and the significance of the found differences between heartwood and sapwood, whether showing defects or not, are reported in Table 3; while mean clear-wood figures for main regional commercial softwood species are compared in Table 4 (Cigalat and Soler, 2003), and its classification (UNE

Table 2. Characteristics of Spanish juniper (*Juniperus thurifera* L.) trees sampled in "*Berlanga de Duero*" (Soria, Spain) to assess physical and mechanical performance of the wood

Plot	UTM	Dendrometric characteristics of the trees				
		Height (m)	Age (years)	DBH (cm^2)	Basal area (cm^2)	Overbark vol. (m^3)
1	504617, 4588534	6.8	134	17.25	233.6	0.0693
2	504862, 4588033	5.2	212	24.00	452.2	0.1533
3	505287, 4587439	5.1	127	17.25	233.6	0.0693
4	505385, 4588113	5.0	154	21.00	346.2	0.1112
5	505358, 4588253	5.2	194	20.25	321.9	0.1019
6	504734, 4588563	5.4	148	16.25	207.3	0.0601
7	505170, 4588297	3.5	224	10.12	80.4	0.0192
8	505358, 4588254	4.9	134	15.25	182.6	0.0516
	Mean	5.1	166	17.67	257.2	0.0795
	standard deviation	0.9	38	4.19	113.7	0.0413

DBH = diameter at breast height; vol. = volume.

Table 3. Physical and mechanical properties of Spanish juniper (*Juniperus thurifera* L.) wood from *"Berlanga de Duero"* (Soria, Spain) considering sapwood and heartwood, whether clear or with defects and imperfections

	Sapwood		Heartwood	
	wood with defects	**clear wood**	**wood with defects**	**clear wood**
Specific gravity based on green volume (S_g)	0.405 ± 0.040^{B}	0.415 ± 0.035^{B}	0.590 ± 0.065^{A}	0.545 ± 0.055^{A}
Specific gravity based on oven-dry vohune (S_d)	0.445 ± 0.035^{B}	0.460 ± 0.040^{B}	0.645 ± 0.060^{A}	0.595 ± 0.050^{A}
Wood density at 12% moisture content (kg · m^{-3})	485 ± 45^{B}	495 ± 50^{B}	675 ± 70^{A}	625 ± 60^{A}
Shrinkage in volume (%)	10.1 ± 1.2	10.5 ± 0.7^{A}	8.5 ± 1.0	8.6 ± 0.8^{B}
Radial shrinkage (%)		6.2 ± 0.5^{A}		4.8 ± 0.6^{B}
Tangential shrinkage (%)		4.4 ± 0.4^{A}		3.7 ± 0.5^{B}
Radial hardness	2.97 ± 0.83^{Ba}	2.61 ± 0.66^{Bb}	4.89 ± 1.19^{Aa}	4.03 ± 0.78^{Ab}
Tangential hardness	3.29 ± 0.80^{B}	3.80 ± 0.58^{B}	5.98 ± 0.84^{A}	5.03 ± 0.97^{A}
Static bending (N · mm^{-2})	54.23 ± 9.71^{Ab}	89.53 ± 7.16^{Aa}	34.62 ± 21.67^{Bb}	62.86 ± 18.63^{Ba}
Compression parallel to grain (N · mm^{-2})	34.03 ± 4.31^{Bb}	41.29 ± 6.86^{Ba}	41.29 ± 6.37^{Ab}	48.25 ± 5.39^{Aa}
Compression perpendicular to grain (N · mm^{-2})	7.85 ± 0.69	7.75 ± 0.78	8.14 ± 0.59	8.43 ± 0.39

Values are mean ± standard deviation at 12% moisture, with the exception of specific gravity based on green volume, and total shrinkage, which requires saturation moisture. Capital (sapwood/heartwood) and lowercase (clear/with defects) letters identify homogeneous groups discriminated by Tukey's test ($n = 8$; $P < 0.05$) within each considered factor. No significant interaction between both factors was found.

56-540) is provided in Table 5. Reference values for Spanish juniper wood provided by national technical reports (Peraza, 1964) are within the range of clear Spanish juniper wood variation and classification (Tables 3-5) measured in "*Berlanga de Duero*" (Soria, Spain).

In short, sapwood covered the 28 ± 6% of the xylem cross sectional area, while heartwood added up the rest 72%. Defects and imperfections (knots mainly, plus rot or bark pockets due to lobed growth and past trunk trauma, ring shakes and cross grain) resulted more frequent in heartwood than in sapwood, accounting for the 48 ± 12% and the 35 ± 8% of the tested specimens, respectively. This high degree of wood defects and imperfections has been reported to be intrinsic to junipers morpho-physiological behaviour in response to severe environments (hard topographical, soil and climatic conditions, as well as strong livestock and human pressure) (Bertaudière *et al.*, 2001; Rozas *et al.*, 2008); although there is no record to date reporting

Table 4. Physical and mechanical characteristics (12% moisture) of small clear specimens of wood from main regional market species (in Cigalat and Soler, 2003) compared to Spanish juniper (*Juniperus thurifera* L.) wood nronerties. Including reference bibliographic values (Peraza, 1964)

	Juniperus thurifera			***Pinus nigra***	***Pinus pinaster***	***Pinus sylvestris***
	Sapwood	**Heart-**	**Reference**			
Wood density ($kg \cdot m^{-3}$)	495	625	648	580	540	520
Shrinkage in volture (%)	10.5	8.6	12.6	11.8	14.5	12.9
Tangential shrinkage (%)	6.2	4.8	—	6.6	7.6	6.8
Radial shrinkage (%)	4.4	3.7	—	3.2	4.1	3.8
Tangential to radial shrinkage	1.40	1.29	—	2.04	1.85	1.79
Radial hardness	2.61	4.03	3.80[a]	2.20	2.70	2.00
Static bending ($N \cdot mm^{-2}$)	89.53	62.86	103.66	101.99	76.49	98.07
Compression parallel to grain ($N \cdot mm^{-2}$)	41.29	48.25	50.70	44.13	38.25	48.54
Compression perpendicular to grain ($N \cdot mm^{-2}$)	7.75	8.43	–	8.83	5.88	9.02

[a] Tangential hardness.

Table 5. Classification according to UNE 56-540 (AENOR, 1978b) of the physical and mechanical properties (12% moisture) of small clear specimens of wood from main regional market species (in Cigalat and Soler, 2003) compared to Spanish juniper (*Juniperus thurifera* L.) wood oronerties. Includin reference bibliographic values (Peraza, 1964)

	Juniperus thurifera			***Pinus nigra***	***Pinus pinaster***	***Pinus sylvestris***
	Sapwood	**Heart-**	**Reference**			
Wood density ($kg \cdot m^{-3}$)	Light	Semi-	Heavy	Semi-heavy	Semi-heavy	Semi-heavy
Shrinkage in vohune (%)	Small-Medium	Small	Medium	Medium	Medium	Medium
Radial hardness	Semi-hard	Semi-hard	Semi-hard[a]	Semi-hard	Semi-hard	Semi-hard
Static bending ($N \cdot mm^{-2}$)	Low	Low	Low	Low	Low	Low
Compression parallel to grain ($N \cdot mm^{-2}$)	Medium	High	High	High	Medium	High

[a] Tangential hardness.

management practices aiming to produce high-quality wood.

Significant differences were addressed between sapwood and heartwood specific gravity figures, whether showing imperfections or not (Table 3), which would be in part expected considering that the processes involved in heartwood formation imply the deposition of chemical substances (Bamber, 1976). As a result, clear heartwood resulted a 30% heavier than clear sapwood; and differences between wood with defects were even higher (45%). In addition to heartwood formation, the observed higher presence of defects in heartwood, knots particularly, may also contribute to explain such differences (Oh *et al.*, 2009); including a higher presence of compression wood that is formed around knots (*e.g.* Bengtsson, 2000). While heartwood, whether clear or with the presence of defects, was classified as heavyweight (600-700 $kg \cdot m^{-3}$) by its wood density figures according to UNE 56-540, all sapwood was ranked as lightweight (400-500 $kg \cdot m^{-3}$). Comparatively, clear heartwood showed similar slightly lower figures to previous bibliographic reference figures, but still higher to some extent than those values reported for other softwoods of local commercial interest (Table 4).

Shrinkage in volume resulted significantly greater in sapwood (10.0-10.5%) than in heartwood (8.5-9.0%), which could be expected from its differential configuration based on the presence of living tissue in sapwood and deposited organic substances in heartwood (*e.g.* Boshard, 1967). No differences were induced by the presence of defects (Table 3). These shrinkage figures in volume are considered as small-medium (UNE 56-540), which addresses that drying will only generate some minor cracks in the logs, and are typical of fine textured wood suitable for carpentry, cabinets, wood carving and turnery, as described in UNE standard 56-540 for wood classification; which are well-known traditional uses for this wood based on its high durability, nice perfume and beautiful colour (Peraza, 1964; Lucas, 1998). Both tangential and radial shrinkages of sapwood resulted also significantly greater (6.2 and 4.4%, respectively) than for heartwood (4.8 and 3.7%). Particularly, the greatest significant shrinkage difference between heartwood and sapwood was measured in the tangential direction. Finally, tangential to radial shrinkage ratios (1.30 for heartwood and 1.40 for sapwood) resulted lower than typical values of other woody species (>1.5-2.0; Table 4), denoting very good dimensional stability, heartwood particularly, which may partially explain the reference for its suitability to be used in parquet flooring (Lucas, 1998).

Hardness provides the ability of wood to withstand indentations from harder bodies (*e.g.* heels or furniture feet), scratching, and wear. Spanish juniper sapwood was classified as semi-hard (2-4; UNE 56-540); while heartwood resulted significantly harder (>4) than sapwood regardless the presence of defects, and tangential hardness was soundly greater than radial (≈25% average) for every type of wood. Although the presence of defects seems to enhance wood hardness in general, a further analysis of the tested specimens showed a strong relationship between this hardness improvement and knot occurrence. While sapwood and heartwood with any kind of defect (including knots) were about a 15% and 20% harder in average than clear wood in the radial dimension, respectively; specimens just with knots enhanced radial hardness up to the 75% for sapwood, and 50% for heartwood. The potential contribution of compression wood around knots should be considered regarding this particular (*e.g.* Bengtsson, 2000).

Although all types of Spanish juniper wood fall in the low static bending category (<1100 kg · cm^{-2}) according to UNE 56 540, heartwood showed a significant lower value (45-55%) than sapwood and, moreover, clear wood exhibited much higher figures (65-80%) than wood specimens with defects (Table 3); resulting that clear sapwood (89.53 ± 7.16 N · mm^{-2}) was much closer to the medium static bending category (1100-1800 kg · cm^{-2}). Available technical information reports even higher values (100-110 N · mm^{-2}) for Spanish juniper wood (Peraza, 1964; García *et al.*, 1997). Nevertheless, clear wood showed similar values to other conifer species of commercial interest in the region (Tables 4 and 5).

While the presence of defects may be expected to cause lower bending resistance (Zhou and Smith, 1991; Wang and Lin, 1996; Shan-Qing and Feng, 2007), it has been recently outlined how bending resistance decreases as wood is closer to the pith and higher in the tree (Lundstrom *et al.*, 2007; Palacios *et al.*, 2008). Despite the slow growing character of the species, the higher presence of juvenile wood, which mechanical resistance is well-known to be lower than in wood formed further from the pith, may partially explain this particular (Panshin and De Zeeuw, 1970). The number of rings included in the tested section (Palacios *et al.*, 2008) and the presence of mature or younger wood (Evans *et al.*, 2000) have been related to a higher bending resistance as well. In short, higher branches and younger wood are intended to suffer stronger wind, whereas wood closer to ground is devoted to provide greater support to self-loading (Niklas, 1997; Bruchert *et al.*, 2000). Although heartwood formation is somehow implicitly related to these results, no specific studies have been really found separating conifer heart- and sapwood properties. The underlying mechanism explaining how heartwood formation processes affect these properties requires further attention.

Compression parallel to grain was significantly higher in heartwood than in sapwood (?15-20%), and the presence of defects implied a significant resistance loss (≈15-20%). While clear heartwood falls in higher resistance figures (>450 kg · cm^{-2}; UNE 56-540), all other wood types showed medium values (350-450 kg · cm^{-2}). No significant difference was found for compression perpendicular to grain (≈7.75-8.50 N · mm^{-2}). Both resistances to compression showed similar values to those reported for other regional conifers (Tables 4 & 5). Considering its very high durability in the open (Peraza, 1964; Lucas, 1998), Spanish juniper logs may be used as posts in fences, props and poles, as reported in historical records (*e.g.* the still-standing foundations of the Roman Bridge over River Ebro in Zaragoza, Spain; or its use in typical rural constructions in Ibiza, Spain).

Conclusions

— Both the formation of heartwood and the presence of defects significantly affected the physical and mechanical performance of Spanish juniper wood, which should be considered when assigning potential uses.

— While clear Spanish juniper heartwood was classified as heavyweight with statistical support; clear sapwood was ranked lightweight. The high presence of knots within heartwood drove it even heavier and harder.

— Shrinkage in volume, and the relationship between tangential and radial shrinkages, resulted comparatively lower than those reported for other regional commercial wood species, conferring Spanish juniper wood (heartwood particularly) a great rare stability, which is very appreciated in outdoor wooden carpentry. A very great durability in the open and resistance to adverse weather conditions further support its suitability for this purpose.

— Spanish juniper wood resulted even harder than other commercial conifers, heartwood particularly, which points out its consideration as very precious for luxury wooden flooring; together with its stability, unique grain pattern, colour contrast between sapwood and heartwood, and scarcity in the market.

— Sustainable forest management plans for Spanish juniper stands may include the potential commercial use of this rare precious wood, which may furthermore contribute to the preservation of these forests.

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