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STUDY OF TECHNOLOGICAL SUITABILITY OF *QUERCUS* SPP. TIMBER WITH SMALL TEST TUBES

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ABSTRACT

The results are reported of the physical characterization of oak timber, carried out by examining a series of physical parameters such as the shrinkage of the wood fibre, specific weight, hardness and moisture content of the green wood, in different species of the genus *Quercus* spp. growing in northwest Spain, i.e. *Quercus petraea*, *Q. robur* and *Q. pyrenaica*. Small defect-free samples were used, applying the methodology established by UNE-AENOR (1978) for testing wood samples. Conclusions were reached about the different behaviour of the three species after comparison of each of the parameters studied in relation to the position on the stem.

KEY WORDS: xylology, technological suitability, UNE regulations, *Quercus* spp., northwest Spain

INTRODUCTION

The abundance of information about physical parameters of wood, obtained in studies carried out at both a local (NW Iberian Peninsula) and at an international level (Bengtsson et al. 1999, Coro et al. 2002, Fernández-Parajes et al. 2005, Vila-Lameiro and Díaz-Maroto 2005) contrasts with the scarcity of xylological studies of species of the genus *Quercus* in the study area. The studies of Coro et al. (2002), Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005, Vila-Lameiro (2003), amongst others, provide background information and demonstrate the effect of silvicultural treatments on both physical and mechanical properties and the technological suitability of the wood of the above-mentioned genus for its use as e.g. a structural or decorative element. Data corresponding to these properties are combined in order to define the quality of timber produced in a forest (Arriaga et al. 1994).

Andersson (1996) established a mathematical model for estimating the quality of the wood of standing trees using different variables such as normal diameter, bark thickness, height (relative or crown), the number and height of branches, which are very important for classifying both timber and panels, especially with regard to the resistance and structural behaviour of the wood (Kollmann 1959). After studying the intensity of thinning in a *Pinus* *sylvestris* stand, Gómez et al. (1996) reached the conclusion that this factor had a significant effect on ring width, but not on the density or shrinkage of the wood fibres. Fernández-Golfín et al. (2001) analysed diverse species (*Populus* spp., *Pinus* spp. and *Eucalyptus globulus*) and stated that it was possible to vary the thickness of the rings through the use of different silvicultural methods, without any loss of timber quality. Furthermore, Lindström (1996) concluded that timber from thinned plots of *Picea abies* was less dense than timber from unthinned plots; likewise the density of certain timbers decreased slightly due to the effects of thinning (Kollmann 1959). Bergsted et al. (1997) - reported in Klang (2000) - also examined the relationship between wood density and stand density, quantified as the number of trees per hectare, and found a reduction in the wood density of 7% in cleared areas, although in another study (Pape 1999) the reduction in density was calculated as only 3.5% following thinning, with a positive correlation between the intensity of thinning and the diameter of the branches also being detected.

In the investigation of the uses of timber, study of the relationships between the moisture content and technological suitability is probably the most important, as these affect most transformation processes and the behaviour of the wood, and are particularly important during processes such as sawing, unrolling, brushing, varnishing, etc, (Arriaga et al. 1994).

If by "wood quality" we mean the calibre of each log, piece of wood or wood fibre in relation to specific uses (Savidge 2003), it is important from the point of view of industrial transformation to underline the importance of the homogeneity of the material. The more heterogeneous the properties of the wood obtained from one stem, the more difficult its industrial transformation will be and therefore the lower its value. Analysis of aspects such as the density of the wood, the content of cellulose, lignin or different components (Savidge 2003) is fundamental in establishing wood quality.

The suitability of wood for different uses is therefore determined by the analysis of its physical and mechanical properties, using samples of either large or small dimensions (Fernández-Golfín et al. 2001). This suitability is known as the "technological suitability of the wood" or in other words its capacity for a particular function or use under certain defined conditions (Kollmann 1959).

MATERIAL AND METHODS

Study area, origin and composition of the stands under study

The samples were extracted from trees in inventoried stands in Galicia, Asturias and León (NW Spain). *Quercus petraea*, *Q. robur* and *Q. pyrenaica* are not commonly used for privately reforestations in the study region because of silvicultural and management considerations and fragmentation of property. In fact in recent years, only the Forest Services have used these species in forest reforestations for protective and conservation purposes. The stands under study therefore originate from natural regeneration, either by seeding, or shoots arising from stumps or roots, usually with a monospecific cover of oak, with some specimens of chestnut, birch, maple, hazelnut or holly (Díaz-Maroto 1997, Vila-Lameiro 2003, Díaz-Maroto et al. 2005, Díaz-Maroto et al. 2006). The oaks under study are mainly located in forests in eastern Galicia and on the border between Asturias and Leon (*Quercus petraea*), in the south of the province of Lugo and in Ourense (*Q. pyrenaica*) or are located throughout Galicia (*Q. robur*).

Collection of samples and analytical techniques used

Two factors were taken into account in locating the sampling sites within the forest stands; on one hand areas next to forest perimeters were excluded in order to avoid creating an edge effect, which would distort the results (Gómez et al. 1996, Fernández-Golfín et al. 2001) and on the other hand, relatively homogeneous stands, representative of the forests under study, and in good conditions of health and where possible without any pollard trees, were chosen (Fernández-Parajes et al. 2005). Initially minimum extensions of between 0.5 and 1 ha were considered as this size of stand allows mitigation of possible problems of ecotone associated with smaller areas (Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005) and also allows consideration of sample plots with a minimum of 50 trees (Hummel 1969, Díaz-Maroto et al. 2005, Díaz-Maroto et al. 2006). Furthermore, largely monospecific oaks stands were chosen, in which the presence of other inventory species, i.e. of normal diameter equal to or greater than 5 cm, was less than 20% of the total (Fernández-Parajes et al. 2005).

A single inventory of permanent plots was carried out, attempting to cover all possible combinations of age classes, site qualities and densities existing for each of the species under study; rectangular plots of surface areas between 130 and 2120 m^2 were finally considered, in which the normal diameter in cross section and the total height of all inventory trees were measured (Tab. 1). In addition, in each plot, two dominant-type trees were selected, felled and cut into sections (Vila-Lameiro 2003), extracting discs of wood at different heights on the stem of each tree (stump height, normal height and each metre on the stem). Samples were obtained from each disc in accordance with the criteria established under UNE regulation 56-526-78 for carrying out tests with samples of small dimensions and free of defects (Klang 2000, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005).

Tab. 1: Summary of field data collected in monospecific stands of Quercus spp.

Species	Inventoried Plots	Felling plots	Nº of trees felled	Nº of samples analysed
Quercus robur	178	94	188	504
Quercus petraea	53	51	96	542
Quercus pyrenaica	41	28	56	774

Statistical analysis

In addition to the initial descriptive analysis of each of the properties studied, bivariate correlation analysis was applied to elucidate the interdependence or the covariance of the variables, and analysis of variation (ANOVA) was used to compare the correlated variables, identifying the intervals of variation (Ferrán 1997). ANOVA was used to determine whether there were significant differences among groups and if so whether they were statistically significant. Finally, in those cases in which there was a particularly defined relationship between certain parameters, the data was fitted to a linear regression line (SasStat Institute Inc. SAS/STAT® 9.1 2004).

RESULTS

Description of the physical properties analysed

Information regarding the plots inventoried, trees felled and samples analysed corresponding to each species is summarised in Tab. 1. Some preliminary, basic physical parameters were obtained using this material: moisture content of green wood –M_{SAT}–; normal specific weight (corresponding to an internal wood moisture content of 12%) –rH_{12}–; total shrinkage –C_V–; coefficient of shrinkage –*v*– and Monning hardness –H_M, evaluated in mm^{-1} as the inverse of the footprint made in the test tube during the test– for each of the three species of *Quercus* analysed. Without considering the statistical significance of these results, the variability among the three species for the initial five parameters was evident, except for the specific weight, which varied very little.

Firstly, the values of M_{SAT} for *Quercus pyrenaica* and *Q. petraea* were very similar (approximately 63%) and much higher than that corresponding to *Q. robur*, which did not reach any higher than 44% (Tab. 2). The uniformity of this parameter within each species was high, which explains the small number of samples necessary for its estimation, according to the established regulations UNE 56-526-78 (UNE 56-526 1978, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005).

Tab. 2: Summary of descriptive statistics of the properties of Quercus spp. in the study area

Statistics	M_{SAT}			rH_{12}			C_v			*v*			Hardness		
Species	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py
Mean	43.64	62.68	63.91	751.2	754.6	757.5	14.98	17.15	18.52	0.58	0.49	0.540	3.645	4.126	3.872
Standard Deviation	10.96	8.71	11.71	53.76	80.51	73.83	3.34	3.6	5.84	0.13	0.15	0.76	2.29	2.30	1.41
Kurtosis	0.063	0.35	0.82	0.42	0.37	0.04	0.25	2.78	117.66	0.56	72.81	307.9	9.20	9.38	11.25
Standard error of kurtosis	0.28	0.21	0.18	0.28	0.21	0.17	0.28	0.21	0.24	0.28	0.21	0.17	0.453	0.431	0.469
Skew	0.56	0.19	-0.10	0.12	0.32	0.17	0.15	0.89	8.70	0.38	5.2	16.09	2.97	2.83	2.80
Standard error of skew	0.14	0.10	0.09	0.14	0.10	0.08	0.14	0.10	0.12	0.14	0.10	0.089	0.228	0.217	0.237

Q r: *Quercus robur*; Q pt: *Quercus petraea*; Q py: *Quercus pyrenaica*

The value of rH_{12} is obtained from the specific weight under hygroscopic equilibrium, which is posteriorly corrected for a moisture content of 12%, according to the established method UNE 56-526-78 (UNE 56-526 1978, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005), given that equilibrium is reached within predictable limits, of between 10 and 14%. The mean value for the three species ranged between 750 and 760 kg/m^3, and it was the parameter that showed the least intra- and interspecific variations, particularly in the case of *Q. robur*, with a distribution very close to normal for all three species (Tab. 2).

Analysis of the shrinkage of the wood fibre of the three oak species revealed this parameter to show the higher inter- and intraspecific variability. This is taken into account in the different sampling regimes and in the Spanish regulations, 30 times more samples are required than for calculating the M_{SAT} UNE 56-526-78 (UNE 56-526 1978, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005). The range of values of C_V were similar for *Quercus pyrenaica* and *Q. petraea* (Tab. 2) and although only slightly higher than the mean value for *Q. robur* (14.98%) they were always higher than 15%, with mean values of 17.15 and 18.52% respectively. Although the variability in the latter species was lower, there was no doubt as to the normality of the distribution function (Tab. 2).

Study of the distribution function of the parameters analysed

For in-depth statistical analysis, knowledge of the distribution function of each of the parameters under study is required. For this, the null hypothesis considered was that the data sets were normally distributed. The coefficients of kurtosis and asymmetry, the distribution of estimators by quartiles were studied and the Kolmogorov-Smirnov and Cramer-von Mises tests were carried out (SasStat Institute Inc. SAS/STAT® 9.1 2004). These analyses revealed that all of the variables studied were normally distributed, except those related to fibre shrinkage, which were not normally distributed, but without justifying the need for analysis of non normal distributions.

Intra- and interspecific variation of the parameters analysed

As the results of the descriptive statistics of the parameters under study were not conclusive, analysis of the intra-tree, inter-tree and inter-species variability was carried out (Tab. 3). The analysis of variability within each species showed clearly defined behaviour; whereas in *Quercus petraea* and *Q. pyrenaica* the variability within each specimen (intra-tree) was greater than the variability among different specimens (inter-tree), this was not the case with *Q. robur*. More specifically, the inter-tree variability in M_{SAT}, C_V and v was significantly higher in this species, although the differences in the latter two parameters were low (almost imperceptible), and probably not statistically significant.

The hardness of the wood of each of the three species of *Quercus*, which was in descriptive terms very variable and generally low, was again very variable, except in *Quercus petraea*, in which the variation in the groups was higher, although not excessively so (Tab. 3). In the remaining cases the variation was not statistically significant.

The analysis of the variation in the properties described indicated that the intra-species (within species) variation was always greater than the inter-species (among species) variation. This was not totally clear for C_V and hardness as the statistical significance was borderline, and therefore another posterior analysis was required.

Tab. 3: Study of the intra and inter-tree variation in the properties of Quercus spp. in the study area

Statistics	M_{SAT}			rH_{12}			Cv			v			Hardness		
Species	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py
Intra-tree variability	44524	10101	12601	11006	7891	184685	4243	883	1252	697	121	476	71	113	51
Inter-tree variability	29255	25133	58919	17987	25756	237496	4145	6098	3339	683	624	2727	145	152	91
Significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.375	0.022	0.957

Q r: *Quercus robur*; Q pt: *Quercus petraea*; Q py: *Quercus pyrenaica*

Bivariate relationships between characteristic wood parameters

The previous analysis of means revealed the different behaviour of *Quercus robur* compared with the other species. For a more detailed examination of this behaviour, analysis of bivariate correlations between the variables described and others such as the moisture content at the moment of stabilization under controlled conditions (theoretically 12%), hygroscopicity, Koëller's coefficient and coefficient Bd, with the correlations between the latter two variables comparing the shrinkage until the saturation point of the fibre with the specific weight (Koëller) and the effective amount of fibre that can be transformed in a sample of wood (dry weight compared with the saturated volume) or, in other words, the saturated volumetric dry weight (coefficient Bd).

Apart from the expected correlations such as those between the saturated moisture content with other levels of moisture and specific weights or hygroscopicity, different specific weights with each other or C_V with v, some significant correlations (P>99%) were detected.

The correlation between M_{SAT} and rH_{12} was particularly notable, and was high in all cases, especially for *Quercus petraea* and *Q. pyrenaica*, with the values of Pearson's coefficient of correlation (ρ) ranging between 0.4 and 0.7 (Tab. 4). There were also significant correlations between the former and other variables, although less significant than with rH_{12}. In *Q. robur* the correlation between M_{SAT} and Köeller's coefficient was also high (ρ=0.6).

Tab. 4: Bivariate correlations between different descriptors of the properties of Quercus spp.

Parameters		M_{SAT}			rH_{12}			Cv			Koëller			Bd			Hardness		
	Sp.	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py	Q r	Q pt	Q py
M_{SAT}	Q. r.	1,00																	
	Q. pt.	---	1,00																
	Q. py.	---	---	1,00															
rH_{12}	Q. r.	-0,38	---	---	1,00														
	Q. pt.	---	-0,68	---	---	1,00													
	Q. py.	---	---	-0,41	---	---	1,00												
C_v	Q. r.	0,50	---	---	n.s.	---	---	1,00											
	Q. pt.	---	n.s.	---	---	0,42	---	---	1,00										
	Q. py.	---	---	n.s.	---	---	0,37	---	---	1,00									
Koëller	Q. r.	0,58	---	---	-0,36	---	---	0,94	---	---	1,00								
	Q. pt.	---	n.s.	---	---	n.s.	---	---	0,84	---	---	1,00							
	Q. py.	---	---	n.s.	---	---	n.s.	---	---	0,92	---	---	1,00						
Bd	Q. r.	-0,44	---	---	0,94	---	---	n.s.	---	---	-0,56	---	---	1,00					
	Q. pt.	---	-0,70	---	---	0,97	---	---	n.s.	---	---	-0,32	---	---	1,00				
	Q. py.	---	---	-0,32	---	---	0,96	---	---	n.s.	---	---	n.s.	---	---	1,00			
Hardness	Q. r.	n.s.	---	---	n.s.	---	---	0,25	---	---	0,31	---	---	n.s.	---	---	1,00		
	Q. pt.	---	-0,25	---	---	0,47	---	---	n.s.	---	---	n.s.	---	---	0,43	---	---	1,00	
	Q. py.	---	---	n.s.	---	---	n.s.	---	---	n.s.	---	---	n.s.	---	---	n.s.	---	---	1,00

Q r: *Quercus robur*; Q pt: *Quercus petraea*; Q py: *Quercus pyrenaica*; n.s.: not significant

Among the specific weight correlations, those with Bd were particularly notable, especially in *Quercus petraea* and *Q. pyrenaica*, with ρ > 0.89. The specific dry weight rH_{ANH} showed a certain degree of correlation with C_V, with the value of ρ close to 0.5 and a significance of 99 %; the corresponding value for *Q. robur*, was lower (Tab. 4). At the level of fibre shrinkage, only C_V correlated with Köeller's coefficient, with ρ > 0.85, although (for *Q. pyrenaica* and the genus *Quercus* in general) C_V and v were sometimes highly correlated (ρ between 0.6 and 0.7).

As regards the hardness, only correlations of low significance were observed in *Quercus petraea* and *Q. pyrenaica* for some values of specific weight and Bd - in the former species with the hardness itself and in the latter species with the standard hardness (C_D, in $mm^{-1} \cdot kg^{-2}$) (Tab. 4).

Finally the analysis was completed by different regression analyses, in order to explain the mathematical relationships mentioned above. Specifically, the previously mentioned relationships between hardness, specific weight, M_{SAT}, C_V and the coefficients of Koëller and Bd were studied either by linear regression or curvilinear estimation. Different analyses were carried out on the combined data for all three species of *Quercus* as well as individually for each species.

the corresponding value of the coefficient of volumetric contraction was 0.6, may even be defined as sinuous. The same is also true for *Q. petraea*, although the corresponding value was lower, 0.49. These values are consistent with those obtained in previous studies (Guindeo et al. 1997, Vila-Lameiro 2003), in which the values for *Quercus robur* were closer to those for *Q. pyrenaica* than to those for *Q. petraea,* which are always lower (Le Moguédec et al. 2002).

The sinuousity is consistent with certain problems associated with drying and the possible appearance of fissures that prevent its use as a structural element, as already indicated by the C_V, this being the reason why the wood should be sawn before being dried UNE 56-526-78 (UNE 56-526 1978, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005). The level of total shrinkage is lower in *Q. robur*, 14.98%, UNE 56-526-78 (UNE 56-526 1978, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005). Values of 17 and 18 % are commonly reported in the European literature (Guindeo et al. 1997), suggesting that prior, gradual drying is required before sectioning the trunk. Different methods of classification may even determine the destination of the wood depending on the values of C_V and v.

Thus, although according to the values of C_V, only *Quercus robur* may be used as a structural material, the analysis should also include quantification of v, as it is with this parameter that the sinuousity of the wood fibre is assessed. According to this analysis, it is *Q. robur* that is classified as more sinuous, with $v = 0.59$, which is higher than the critical value of 0.55 established as the limit between moderately sinuous and sinuous UNE 56-526-78 (Guindeo et al. 1997). However, the associated variability, which was greater than that corresponding to the previous parameters, and the similarity of the values for the other two species to the critical value, i.e. 0.54 for *Quercus pyrenaica* and 0.49 for *Quercus petraea*, indicates that overall the wood of the three species may be defined as moderately sinuous, making it unlikely that the wood could be used for purposes with high added value, such as in cabinetmaking, and its use in carpentry is only recommended (CTBA 1985). These values are often related to the specific weight and the rate of growth so the lower growth gives rise to specific weight values no greater than 700 kg/m^3, which would allow use of the wood in cabinetmaking, and in the opposite case, it would be more appropriate for carpentry (CTBA 1985). In the specific case of the oaks under study, growth is fairly rapid, with a mean ring width of more than 2.5 mm (Vila-Lameiro and Diaz-Maroto 2005), which further corroborates the previous statements.

The lower sinuousity of *Quercus pyrenaica* is closely related to the lower possibility of storing moisture within the wood because of its greater density, given that this leads to lower variation in dimensions due to loss or gain of moisture (Barnett and Jeronimidis 2003).

The hardness parameters, with values between 3.5 and 4.2 mm^{-1} (Tab. 2) was, apparently fairly high for species of the genus *Quercus*, compared with those reported by other authors (Guindeo et al. 1997). However, if hardness is interpreted on the basis of the level of specific weight (approximately 750 kg/m^3) it is estimated in different European regulations, such as the French (NF B 51002), that for this density the Monnin Hardness, used in this case should range between between 3.5 and 4.5 mm^{-1} in the genus *Quercus* (CTBA 1985).

The difference among *Quercus robur*, *Q. petraea* and *Q. pyrenaica* as regards the intra and interspecific variability has been commented on by other authors (Zhang et al. 1994, Barnett and Jeronimidis 2003, Guilley and Nepveu 2003, Fernández-Parajes et al. 2005, Díaz-Maroto et al. 2005, Vila-Lameiro and Diaz-Maroto 2005, Díaz-Maroto et al. 2006). In this case the greatest variability in the parameters studied for *Quercus petraea* and *Q. pyrenaica* was registered at the level of the tree, as already pointed out by Zhang and other authors in different studies of this species (Zhang et al. 1994, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005), but *Q. robur* behaved differently, which may be related to age or origin (Guilley 2000, Le Moguédec et al. 2002).

According to various studies, the specific weight and the fibre shrinkage depend particularly on age, so that at more advanced ages the variability among trees is greater and the intra-tree variability more uniform (Zhang et al. 1994, Fernández-Parajes et al. 2005, Vila-Lameiro and Diaz-Maroto 2005). This is the situation found in the population sampled, in which the *Quercus robur* trees were generally more mature than those of the other two species.

However, Guilley and Nepveu (Guilley and Nepveu 2003, Díaz-Maroto et al. 2005, Díaz-Maroto et al. 2006) state that the specific weight and other oak wood parameters depend on the anatomical structure and anatomical variations of each tree, which are closely related to the process of duraminization. Therefore trees originating from low-lying forest plantations (common in stands of *Quercus petraea* and *Q. pyrenaica* in Galicia) will show greater intra-tree variability, given that the genetic input of the stand is more uniform than in *Q. robur* (Guilley 2000).

These statements become clear on establishing the relationships with the Koëller and Bd coefficients, and it is easy to correlate the two coefficients according to the following expression:

$$C_{Koëller} = \frac{1}{B_d} - \frac{1}{rH_a}$$

This explains why the analysis of the results centre on Bd, as it is the parameter that correlates most closely and also provides the most useful information in practical terms, which is an assessment of the amount of effective wood fibre, known as the saturated volumetric dry weight (Kollmann 1959), i.e. in which the weight of water occupying the pores of the wood is subtracted. Thus, after analyzing different correlations of little interest and poorly justified in statistical terms, the relationship between the saturated specific weight and the coefficient Bd is of great interest. The relationship established was a linear regression, because although other fits were tried, the latter provided the best fit, as often found in studies of wood properties (Le Moguédec et al. 2002, Pang 2002, Guilley et al. 2004).

The correlation obtained for *Quercus robur* was poor, because of the great variability in stands of this species, all of which were located in highland forests, suggesting the need for a zoned study, differentiating the origin, which is not required with the other two species (Díaz-Maroto 1997, Vila-Lameiro 2003, Barnett and Jeronimidis 2003, Díaz-Maroto et al. 2005, Díaz-Maroto et al. 2006). Therefore, considering the study for the other two species, the result was highly positive, given that it is possible to estimate the coefficient Bd and the saturated volume from a small sample of green wood, with approximately 80 % certainty, and that this can be easily carried out at the time of cutting, along with determination of the dry weight. In other words, the amount of fibre or the effective amount of wood that will be available at the moment of transformation and future sale of the product (Guilley 2000, Le Moguédec et al. 2002, Guilley and Nepveu 2003, Díaz-Maroto et al. 2005, Díaz-Maroto et al. 2006).

CONCLUSIONS

From the results of the present study, the following overall conclusions can be reached:

- The wood of the genus *Quercus* can be classified as moderately sinuous, although in some cases it may even be classified as sinuous, which determine the drying process and the future use of the wood.
- *Quercus pyrenaica* has the densest wood of the three species, followed by *Quercus petraea* and then *Quercus robur*, which may be explained by the presence of less cavities filled by water or air.
- The wood of the three species in the area of study was very hard compared with wood from other areas, which is linked to the high density of the wood under study.
- Although all three species belong to the same family and genus, they are significantly different in terms of their internal constitution and their behaviour, which along with factors such as different harvesting methods or age, explains the greater similarity between *Quercus pyrenaica* and *Q. petraea*.
- The study of the amount of effective fibre, although not possible in the samples of *Quercus robur* available, allowed accurate relationships to be established between the actual amount of fibre or the dry weight of the wood and the saturated specific weight obtained in green or recently felled wood.

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