Annals of Silvicultural Research
46(1), 2021: 1-7
https://journals-crea.4science.it/index.php/asr

Research paper

Anatomical, physical and mechanical characterization of sessile oak *(Quercus petraea Liebl.)* wood from central Italy aged coppices

Michele Brunetti[1], Nicola Macchioni[1*], Francesco Grifoni[2], Simona Lazzeri[1], Lorena Sozzi[1] , Andrea Cutini[3]

Received: 21/08/2018 *Accepted: 23/10/2019* *Available online: 16/12/2020*

ABSTRACT The present paper aims to implement the knowledge on sessile oak (*Quercus petraea* (Matt.) Liebl.) in the Mediterranean area where, although present, the species is rare both for natural and anthropogenic reasons. The focus is on two sessile oak aged coppice stands in Tuscany (Central Italy), classified as worthy of protection for their value at local to European level. In addition to environmental and stand structure characteristics, the technological properties of sessile oak wood at the surveyed sites are provided and compared with data in literature. Wood features consist of the anatomical parameters (growth ring thickness, earlywood and latewood thickness, fiber length, earlywood and latewood vessel diameter, amount of earlywood and latewood vessel) and the physical and mechanical parameters (density, modulus of elasticity, strength, hardness). No appreciable technological differences resulted between wood properties in the stands analysed and those from other Italian and French provenances reported in literature. Results highlighted that, even if already managed as coppice, the timber produced by both the stands is basically qualified as source of reproductive material for re-afforestation and to favour again the diffusion of this endangered species in suitable areas. All of this, taking into account that wood quality is determined by technological properties, but also by growing conditions (i.e. site quality), and by the quality of silvicultural management.

KEYWORDS: *Quercus petraea*, sessile oak, wood properties, coppice, silviculture.

Introduction

The species of subgenus *Quercus*, such as sessile oak (*Quercus petraea* (Matt.) Liebl.) and pedunculate oak (*Quercus robur* L.), are of strategic importance for the European silviculture and the forestry context. Basic knowledge on ecology, ecophysiology, genetics, silvicultural and management systems of these species, both under natural/semi-natural and artificial conditions, is largely available, especially for Central and Northern European Countries (Bary-Lenger and Nebout 1993, Timbal and Aussenac 1996). On the other hand, the information is scarce in the Mediterranean countries where both species, although present, rarely build up pure woods or woods where they are dominant, either for natural or anthropogenic causes . Even in this case, the covered area is often negligible with respect to the total forested area. More often, both species can be found into mixed woods dominated by other tree species.

This is especially the case of sessile oak in Italy, where it can be considered as a rather common species in the Alps and pre-Alps (Viciani and Moggi 1997, Andreis and Sartori 2011) but it becomes sporadic proceeding southwards where the influence of the Mediterranean climate is progressively and significantly higher (Viciani et al. 2016). Other reasons of this scattered distribution, deals with the ecology of sessile oak, a mesophilous oak which build fragile ecosystems, with a narrower distribution than its potential (Thomas et al. 2002, Kasprowicz 2010) as a consequence of the conversion of more fertile lands to agricultural uses, of coppicing as prevailing management system and of the artificial diffusion of *Castanea sativa* Mill. (Bernetti 1987, Cutini and Mercurio 1999, Arrigoni and Viciani 2001). In Northern-Central Italy and Tuscany, sessile oak still shows a relatively wide distribution and is present in the typical mesic and dry-mesic communities which, although scattered and localized, are often well-characterised (Viciani et al. 2016).

Recently, the synergism of different factors such as the increasing attention to biodiversity, the attempts for defining more ecologically-based management systems, the efforts for supporting and promoting the evolution of degraded forest stands towards more complex and better functioning forest ecosystems, led to dedicate a special attention to these communities. Several Authors (Cutini et al. 1993, Cutini et al. 1995, Barsacchi et al. 1997, Viciani and Moggi 1997, Bruschi et al. 2000, Grifoni 2003, Cutini and Giulietti 2006) highlighted and described the presence of interesting small populations, stressing the gap of knowledge about ecology and distribution of the species with respect to Central and Northern Europe and their potential importance as a source of genetic variability.

The present paper aims to contribute with the research activities carried out on two sessile oak aged coppice stands in Tuscany (Central Italy), classified as worthy of protection for their importance both at the local up to European level (Cutini et al.

---

1 - CNR – IBE Sesto Fiorentino – Italy

2 - Viale Matteotti Giacomo 19/D, Arezzo - Italy

3 - CREA , Research Centre for Forestry and Wood – Italy

*Corresponding author: nicola.macchioni@ibe.cnr.it

http://dx.doi.org/10.12899/asr-1672

1993, Viciani and Moggi 1997, Viciani et al. 2016). In order to enhance an often too narrow approach in highlighting and describing these populations and to give the deserving attention to wood properties issue, this paper provides the analysis of technological characteristics of wood grown there, comparing results to data in literature. Specifically, the following properties were examined: growth ring thickness, earlywood and latewood thickness, fiber length, diameter of earlywood and latewood vessels, amount of earlywood and latewood vessels, density at 12% moisture content, modulus of elasticity, bending-compression-shear strength, Brinell hardness, on small, clear specimens.

The aim of this paper is to evaluate the suitability of these stands, coming from agamic regeneration, as source of reproductive material for re-afforestation and to favour the re-diffusion of this strategic oak species. A more accurate definition of stand structure and wood technological properties could help to discriminate these stands from others, to evaluate their potential re-diffusion, the suitability of wood for traditional processing (sawing, slicing, splitting and staving) to produce common and high added value assortments and use at best their inherent potential ecological and economic role.

Material and methods

Both sessile oak stands are located close to Arezzo, Tuscany. One study site is located in Sargiano (43’ 26 N, 11’ 52 E), the other one in Pieve a Quarto (43’ 25 N, 11’ 51 E). The first stand is situated on a gentle slope facing North North East, at 330-395 m a.s.l.; the second one is located at 350-410 m a.s.l, same aspect, but, on a steep slope.

Mean annual rainfall in the area is 835 mm with a maximum in autumn (November) and spring (March) and a minimum in summer months (135 mm); dry period ranges from half June to August. Mean annual temperature is 14°C, the coldest and the warmest monthly mean temperatures are 4.8°C and 23.5°C, respectively. According to Thornthwaite classification, both sites are included in the sub-humid climate zone with moderate summer water deficit. Bedrock material is ‘Macigno’, i.e. blocks of sandstone alternated with schist, (Oligocene Lower Miocene). Both sites present deep, acid and well-drained soils.

The first stand covers about 13 ha and was managed in the past as coppice with standards, with a rotation of 14 years (Cutini et al. 1993). From the 1980s, no regular exploitations were carried out. Stand structure is therefore typical of an aged coppice. Stand structure and mensurational parameters were surveyed by four 314 m² circular plots. Stand age ranges from 50 to 60 yrs; number of stools per hectare (mean ± standard deviation) is 2,650±446, number of shoots is 3,786±1,516 and basal area is 25.91±2.14m². Mean shoot diameter at 1.30m (dbh)) is 9.7±1.9 cm while tree (standards and shoots) dominant height is 16.1±2.7m. Sessile oak, mainly living in the upper storey where an average of 154±12 ha^{-1} standards were observed, is the dominant species representing the 86.5±9.0% of total basal area. Other tree species, mainly living in the middle and lower storeys, are *Quercus ilex* L., *Fraxinus ornus* L., *Ostrya carpinifolia* Scop. and *Arbustus unedo* L.

The second stand is a mixed sessile oak and chestnut (*Castanea sativa* Mill.) coppice with *Quercus ilex*, *Ostrya carpinifolia*, *Fraxinus ornus* and *Arbustus unedo*. Stand structure and mensurational parameters were surveyed by means of six 400 m² plots (Grifoni 2003). The stand structure is less homogenous with respect to the first stand: standards, aged from 30 up to 135 yrs, are mainly represented by sessile oak, while the number of shoots per hectare is here 773±486 and the (standards and shoots) tree dominant height is 21.81±0.7 m.

Five shoots of average characteristics were sampled from both stands. From each tree a bolt was cut at a stem height of 1 to 2 m . From each bolt, a diametric board 3 cm thick was sawn.

Samples were extracted from the board for the anatomical characterization sampling the following growth rings from the pith: *(i)* vessel measurements: each 3 rings up to the 15th ring, then each 5 yrs up to the 45th ring; *(ii)* fiber length measurements, all the rings from the 2nd to the 15th.

Fiber length measurements were performed through the disruption of the tissues from longitudinal radial sections through immersion into a solution of 10% chromic acid and 10% nitric acid for 24 hours. Mash obtained was rinsed with distilled water and mounted on glasses by means of Arabic gum (20 g in 100 cm^3 of distilled water). Glasses obtained were directly measured through fibrescope, measuring at least 100 fibers per growth ring.

Measurements on vessels were performed by an image analysis software (AnaliSys©) from pictures obtained by SEM on gold coated samples. For each ring the radial and tangential diameters were measured on at least 15 earlywood and 15 latewood vessels. Vessels amount was calculated from the average of three ring porous area and three final wood pictures.

The analysis was performed on the mean values per growth ring.

The physical and mechanical characterization was made on small clear specimens according to the ISO 3129/2012 standard (“Wood - Sampling methods and general requirements for physical and mechanical testing of small clear wood specimens”).

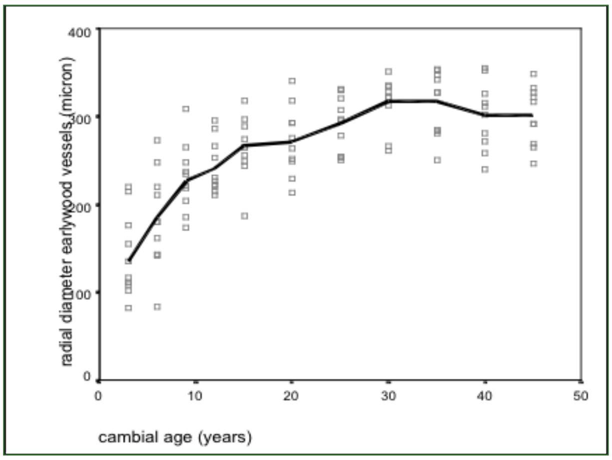
The tests showed in Table 1 were performed after climatic chamber conditioning (T = 20±2°C e U = 65±5%) up to constant weight. Mechanical values were referred to the conventional value of 12% moisture content, according to the reference standards.

The statistical difference in mean between provenances Sargiano and Pieve a Quarto has been tested by student t test.

Table 1 - Properties measured and standard references.

Property	Standard reference
Density (12%)	ISO 3131
MOE	ISO 3349
MOR	ISO 3133
Compression	ISO 3787
Shear	ISO 3347
Hardness Brinell	EN 1534

Figure 1 - Variation of the radial diameter of earlywood vessels according to cambial age.



Results

Table 2 shows the mean values and the variability indexes of main anatomical characteristics for site A and site B.

The number of latewood vessels per square millimeter excluded, the *t* test for mean values considered the two stands as a unique population, the relative differences being not significant.

The standard deviation of earlywood vessels is quite high. This is due not only to the large dimension of these anatomical elements, but also to the high variation showed by the earlywood vessels at increased cambial ages (Fig. 1).

The tangential diameter of earlywood vessels and the number of earlywood and latewood vessels per mm^2 showed a similar pattern at increasing cambial ages (Fig. 2). The average values showed larger earlywood vessels compared to similar measurements published by Bergès et al. (2008), these coming from Central France oak forests, and by Gričǎr et al. (2013) from Slovenia. Apparently, according to the results from Fonti and Garcia-Gonzalez (2008), the anatomical parameters of growth correspond to a *Q. petraea* grown on sites characterized by high precipitations over the spring time.

Earlywood vessels in dry sites show smaller sizes, also affected by the amount of precipitation of the previous year.

As for the evolutive course across the cambial age increase, most of the measured characteristics show a first abrupt change (and a higher variability) among 6 and 11 years; afterwards, a slope variation becomes evident that, maintaining the same trend, shows a less important change of the measured feature. The describing curve normally becomes more and more flat up to the cambial age of 30-40 yrs.

Table 2 - Values of anatomical variables measured at the sites.

Provenance		1 (μm)	2 (μm)	3 (μm)	4 (μm)	5 (mm/10)	6 (mm/10)	7 (mm/10)	8	9
A Sargiano	Mean	249.1	25.6	197.3	24.3	6.5	23.5	29.9	12.1	71.0
	N°	54	54	54	54	55	55	55	54	54
	SD	65.55	4.53	46.53	4.24	2.96	11.86	13.65	7.07	21.99
	CV	0.26	0.18	0.24	0.17	0.45	0.51	0.46	0.58	0.31
B Pieve a Quarto	Mean	269.3	24.5	207.3	22.7	7.1	27.2	34.3	8.8	91.4
	N°	55	55	55	55	55	55	55	55	55
	SD	63.94	5.39	48.96	4.61	3.87	12.88	13.65	5.53	26.50
	CV	0.24	0.22	0.24	0.20	0.54	0.47	0.40	0.62	0.29
A+B	Mean	259.3	25.1	202.3	23.5	6.7	25.4	32.1	10.4	81.3
	N°	109	109	109	109	110	110	110	109	109
	SD	65.23	4.99	47.82	4.49	3.45	12.46	13.76	6.52	26.33
	CV	0.25	0.20	0.24	0.19	0.52	0.49	0.43	0.63	0.32

Legenda: 1 = Radial diameter of earlywood vessels; 2= Radial diameter of latewood vessels; 3 = Tangential diameter of earlywood vessels; 4 = Tangential diameter of latewood vessels; 5 = earlywood width; 6 = latewood width; 7 = Ring width; 8 = Earlywood vessels number/mm^2; 9 = Latewood vessels number/mm^2.

Figure 2 - Number of earlywood (left) and latewood (right) vessels per mm^2.

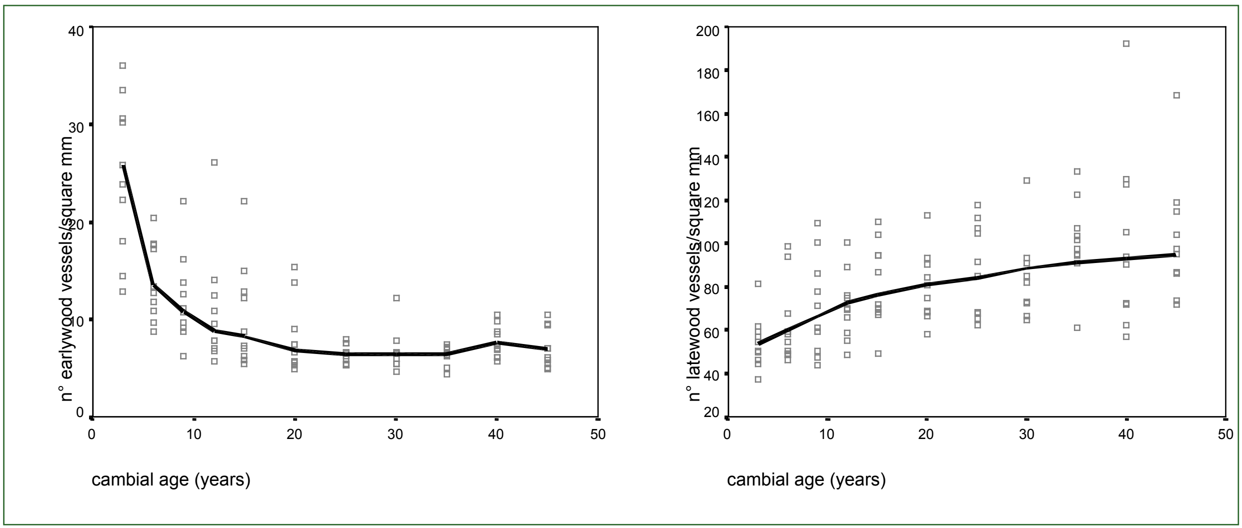


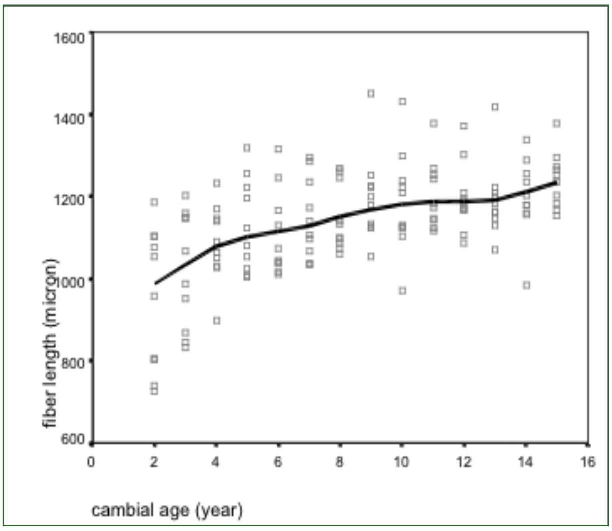
Table 3 - Table of correlation between parameters with reference to Pearson's coefficient. The first column and the first row are referred the to the number used in Table 2. N° 10 is the cambial age.

	10	1	2	3	4	5	7	6	8	9
10	1.000	.710	.494	.670	.387	.080	-.089	-.121	-.587	.555
1		1.000	.385	.823	.202	.298	.206	.144	-.775	.441
2			1.000	.361	.658	-.082	-.019	.001	-.247	.307
3				1.000	.187	.168	.109	.073	-.683	.454
4					1.000	-.143	-.175	-.153	-.008	.168
5						1.000	.485	.259	-.340	.039
7							1.000	.970	-.298	-.059
6								1.000	-.234	-.075
8									1.000	-.473
9										1.000

Taking into account the correlations between measured parameters (Tab. 3), we get quite good and very significant correlations among normally related parameters (e.g. radial/tangential diameter of earlywood vessels), while the correlations are poor or very poor among "different" parameters, e.g. anatomical parameters and annual ring width, except the highly significant negative correlation between the diameters of earlywood vessels and the number of earlywood vessels per square millimeter.

The measurements on fiber length values (Fig. 3) show a very high variability across the first 8-9 yrs. After that, a short plateau and the onset of a new fluctuation are evident, but it is difficult to state which is the parameter affecting this variability. In fact, even if literature (Helinska-Raczowska and Fabisiak 1991) reports about a dependency of fiber length on ring width, this is not at all demonstrable by means of the present dataset. The plot on Figure 4 shows that the traced curve describes very poorly the cloudy data distribution.

Figure 3 - Fiber length variation with cambial age.



The analysis of increments shows that, as expected, tree ring width variation is associated mostly to the latewood width variation (Fig. 5). The linear regression is very close to the experimental data, (r^2=0.94). The ratio ring width/earlywood width is vice versa not significant (r^2=0.23). Earlywood layer shows a quite stable width because less influenced by environmental growing conditions than latewood. This is confirmed also by Fonti and Garcia-Gonzalez

Figure 4 - Ratio ring width/ fiber length.

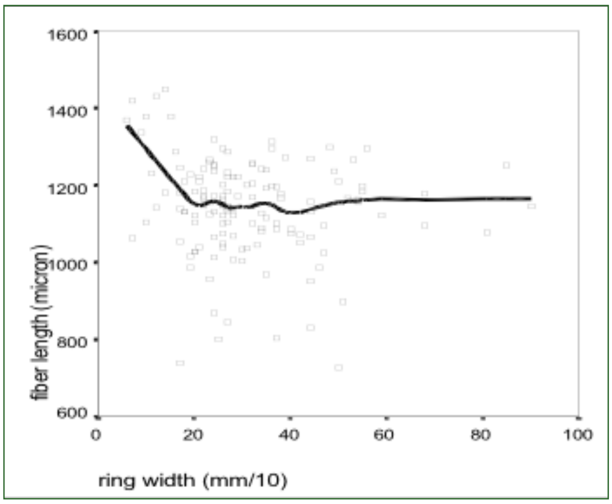


Figure 5 - Linear regression ring width/latewood width.

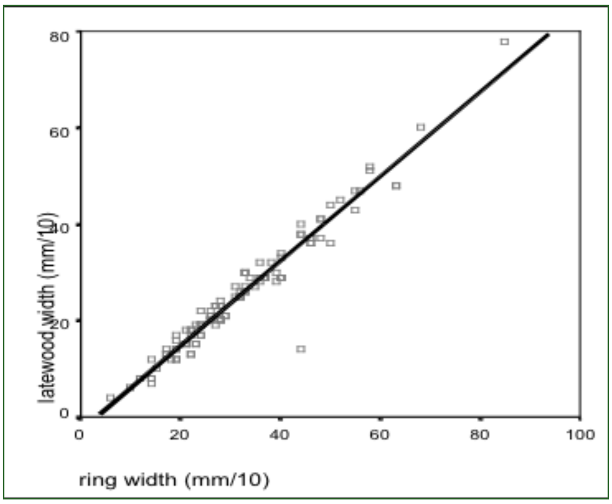


Table 4 - Wood properties of oak wood from Sargiano and Pieve a Quarto. (The number of samples varies according to the different size of sampled trees).

		A Sargiano				B Pieve a Quarto			
Property	Unit	Mean	N°	SD	CV	Mean	N°	SD	CV
Density 12%	g/cm^3	0.801	71	0.05	0.06	0.815	86	0.08	0.10
MOE	MPa	15,826	32	2,175	0.14	11,763	88	2,426	0.21
MOR	MPa	126	31	12.4	0.10	105	88	17.3	0.16
Compression	MPa	55	38	5.2	0.09	55	86	7.3	0.13
Shear	MPa	14	76	2.0	0.14	16	85	3.0	0.19
Hardness	kg/mm^2	3.00	24	0.34	0.11	4.30	48	0.83	0.19

(2008) and by Matisons and Dauškane (2009). Both demonstrate that earlywood layer width is less influenced by the seasonal weather variations, compared to latewood.

Values of physical and mechanical properties are shown in Table 4. Differences between the two stands are high significant ($p<0.001$) for MOE, MOR and Brinell hardness, significant ($p<0.01$) for shear strength and no significant for density and compression strength.

Data comparison with those available on technical bibliography for the Italian provenances (Giordano 1988), shows results among the mean references (in terms of density and strengths). In the case of French provenances (Sallenave 1964), the mechanical performances have similar values even if the measured density is higher than in the references.

Discussion

Both stands, not managed since a relatively long time, show mensurational characteristics typical of the aged mixed coppice forest, with an overall high tree density (shoots + standards) and a sustained height development as shown by shoots density, basal area and dominant height. Worthy of note is the difference in sessile oak density between the two stands with Sargiano having a number of shoots per hectare (3,786±1,516) remarkably higher than Pieve a Quarto (773±486), it depending on the relative abundance of tree species mixture and on the number and age classes of standards released over the past coppice cycles.

The distribution of anatomical parameters measured along the radius partially reflects what reported in literature. Hamilton (1961) quotes the presence of rings with a higher percentage of latewood for the first-formed rings around the core for southern red oak (*Quercus falcata* Michx.). It may be due to the physiological reduction of increments in the last-formed rings; such a trend is not detectable from our data coming from stands originated and structured differently.

The measured anatomical variation more similar to literature reports is the distribution of vessels diameters and number of vessels/mm^2 (Hamilton 1961, Helinska-Raczowska and Fabisiak 1991, Helinska-Raczowska 1994).

On previous works (Helinska-Raczowska and Fabisiak 1991, Helinska-Raczowska 1994) the juvenile age of *Q. petraea* is indicated being around 35-40 years of cambial age taking into account the continuous variations of several anatomical parameters during that period, fiber length included. They support this statement also by means of the evaluation of sexual maturation of the tree that normally reaches the reproductive phase at 25-30 yrs. Other authors were probably more influenced by the abrupt variation occurring during the first decade and stated that the juvenile wood in most of the *Quercus caducifoliae* species occurs within the first 10 years.

From the viewpoint of wood technology, results of the anatomical measurements show that the juvenile wood phase should include the period of rapid variation of the parameters: i.e., the first decade. This is also clearly visible through the analysis of fiber length distribution along the radius.

Moreover, measurements made on the growth ring, divided per porous zone (earlywood) and latewood allowed to highlight that the ring porous zone is clearly visible from the 6th-7th cambial year, having, before that age, very small pores and, in some cases, distributed almost as a semi-ring porous wood.

Even if the analyzed wood comes from forests formerly managed as coppice and made at now by outgrown shoots under natural evolution, the physical and mechanical properties of the Sargiano and Pieve a Quarto stands are similar to those of other provenances grown under the high forest system. This outcome means that the reproductive material provided by these stands will be suitable for the typical uses of the sessile oak wood, such as furniture, parquets, barrels.

The real consistency for higher value-added uses is given by wood defectiveness impact. Suited silvicultural practices applied throughout the life cycle may be the technical means acting more effectively to get the awaited quality timber.

Conclusions

Results achieved so far implemented the knowledge on two basic issues about sessile oak: the role of silviculture, and of coppicing in the case, and of Mediterranean environmental conditions, generally unfavorable for the species, on wood properties.

In spite of the origin from agamic regeneration and the lack of management following the suspension of coppice system, no appreciable technological differences were found between wood quality in the examined stands and the one from other Italian and French provenances in literature.

The genetic material from these stands will be therefore qualified for the reforestation of this endangered species in suitable areas, always taking into account that wood quality is made by its technological properties, by the growth environment, but may be improved as well by well-grounded silvicultural management all over the stand life cycle.

Acknowledgments

The study was financed by Ente Cassa di Risparmio di Firenze by the project “Indagine per la protezione e la valorizzazione dei boschi di rovere in Toscana”.

References

Andreis C., Sartori F. 2011 - *Vegetazione Forestale della Lombardia. Inquadramento fitosociologico*. Archivio Geobotanico 12–13: 1–215.

Arrigoni P.V., Viciani D. 2001 - *Caratteri fisionomici e fitosociologici dei castagneti toscani*. Parlatorea 5: 55–99.

Barsacchi M., Bettini D., Bussotti F., Selvi F. 1997 - *I popolamenti di* Quercus petraea *(Matt.) Liebl. del bosco di Tatti*. Monti e Boschi 4: 22-28.

Bary-Lenger A., Nebout J.P. 1993 - *Le chêne*. Editions du Perron, Alleur-Liege. 604 p.

Bergès L., Nepveu G., Franc A. 2008 - *Effects of ecological factors on radial growth and wood density components of sessile oak (*Quercus petraea *Liebl.) in Northern France*. Forest Ecology and Management 255(3-4): 567-579.

Bernetti G. 1987 - *I boschi della Toscana*. Edagricole, Bologna: Giunta Regionale Toscana.

Bruschi P, Vendramin G.G., Bussotti F., Grossoni P. 2000 – *Morphological and molecular differentiation between* Quercus petraea *(Matt.) Liebl. and* Quercus pubescens *Willd. (*Fagaceae*) in Northern and Central Italy*. Annals of Botany 85: 325–333.

Cutini A., Giulietti V. 2006 – *La rovere: una specie da valorizzare nei boschi cedui della Toscana*. Annali dell’ Istituto Sperimentale di Selvicoltura 33 (2002-2004): 159-168.

Cutini A., Mercurio R. 1999 - *La rovere: criteri per la conservazione e la ridiffusione*. Monti e Boschi 40(1): 31-34.

Cutini A., Mercurio R., Moggi G., Viciani D. 1993 - *Osservazioni su una nuova stazione di rovere (*Quercus petraea *(Matt.) Liebl.) in Toscana*. Atti e memorie dell’Accademia di lettere, arti e scienze “F. Petrarca”, Arezzo LIV: 319-341.

Cutini A., Mercurio R., Nocentini L. 1995 - *Ulteriori stazioni di rovere (*Quercus petraea *(Matt) Liebl) in Valdichiana*. Giornale Botanico Italiano 129: 178.

Fonti P., García-González I. 2008 - *Earlywood vessel size of oak as a potential proxy for spring precipitation in mesic sites*. Journal of Biogeography 35(12): 2249-2257.

Giordano G. 1988 - *Tecnologia del legno*, Vol. III, Utet, Torino 1988.

Gricăr, J., De Luis M., Hafner P. Levani T. 2013 - *Anatomi-cal characteristics and hydrologic signals in tree-rings of oaks (*Quercus robur *L.)*. Trees 27(6): 1669-1680.

Grifoni F. 2003 - *Altre stazioni con rovere (*Quercus petraea *(Matt.) Liebl.) nell’Italia centrale: prima caratterizzazione ecologico-forestale*. In: Proceeding of III Congresso Nazionale S.IS.E.F, Atti 3: 47-53.

Hamilton J.R. 1961 - *Variation of wood properties in Southern red oak.* Forest Products Journal XI: 267-271.

Helinska-Raczowska L., Fabisiak E. 1991 - *Radial variation and growth rate in the length of the axial elements of sessile oak wood.* IAWA Bullettin 12: 257-262.

Helinska-Raczowska L. 1994 - *Variation of vessel lumen diameter in radial direction as an indication of the juvenile wood growth in oak (*Quercus petraea *Liebl.)*. Annals of Forest Science 51: 283-290.

Kasprowicz M. 2010 - *Acidophilous oak forests of the Wielkopolska region (West Poland) against the background of Central Europe.* Biodiversity: Research and Conservation. 20. 1-212. 10.2478/v10119-010-0012-4.

Matisons R., Dauškane I. 2009 - *Influence of climate on earlywood vessel formation of* Quercus robur *at its northern distribution range in central regions of Latvia*. Latvijas Universitates Raksti 49.

Sallenave P. 1964 - *Propriétés physiques et mécaniques des bois tropicaux.* Centre Technique Forestier Tropical, France,1964.

Thomas F.M., Blank R., Hartmann G. 2002 - *Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe.* Forest Pathology 32: 277 - 307.

Timbal J., Aussenac G. 1996 - *An overview of ecology and silviculture of indigenous oaks in France.* Annals of Forest Science 53: 649-661.

Viciani D., Gennai M., Lastrucci L., Gabellini A., Armiraglio S., Caccianiga M., Andreis C., Foggi B. 2016 - *The* Quercus petraea*-dominated communities in Italy: Floristic, coenological and chorological diversity in an European perspective.* Plant Biosystems 150: 1376-1394. DOI: 10.1080/11263504.2016.1165754

Viciani D., Moggi G. 1997 - *Ricerche su alcuni popolamenti di rovere* Quercus petraea *(Matt.) Liebl. in Toscana.* Webbia 51: 237-249.