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Mechanical properties of branch and stem wood for two Mediterranean cultivars of olive tree

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Abstract

There is currently a strong interest in wood and the demand for this material is expected to grow significantly worldwide. Consequently, market demand for wood from fruit orchards is growing as an additional source of supply. For these reasons, several studies were conducted to evaluate the properties of wood derived by orchard pruning or dismantling. Despite the abundance of raw materials from pruning, the mechanical properties of olive wood have not been studied completely by the scientific community, so the woody material obtained is usually considered waste or firewood. In fact, there is still a lack of knowledge about olive wood characteristics and considering the valuable role of olive species in the Mediterranean area, the current study aimed to determine and compare the physical and mechanical properties of branches and stem wood of two olive tree cultivars, "Sinopolese" and "Ottobratica", to provide information on this wood species. These two olive cultivars are commonly cultivated in the Calabria region (Southern Italy) for the extraction of oil from drupes, but large masses of wood are derived from their pruning. For the choice of parts, the stem was considered to become a branch when, above each branch intersection, it changed in diameter and direction of growth. The branches with a diameter lower than 20 cm were excluded. The tests conducted for this purpose were: Roughness profile; Impact wave; Vibrational analysis; Static modulus of elasticity; Bending strength; Abrasion resistance; Static hardness; Footprints; Compression strength; Screw withdrawal resistance parallel to grain; Screw withdrawal resistance perpendicular to grain. A MANOVA analysis was conducted between the Cultivar-Tree part and the physical and mechanical properties. The results showed some differences between the two cultivars principally related to mechanical properties such as moduli of elasticity and rupture, footprint, compression strength, and screw withdrawal resistances, where in general, the "Sinopolese" cultivar showed higher values than the "Ottobratica". Between the tree parts (stem and branches) within the same cultivars, branches demonstrated higher results in the majority of the tests, but highlighting statistical differences only in terms of static modulus of elasticity, bending strength, static hardness and screw withdrawal resistances depending on the cultivar. This result suggests that the branch wood, with its characteristics, could be valorized in the commercial utilization representing a valid opportunity for the local rural economy, even considering the conspicuous amount of wood obtained from olive pruning activity. Expanding knowledge about olive wood in terms of physical and mechanical characteristics could increase its use in multiple sectors and ensure a more aware use of the application of the wood resources by supporting the decision on its best end use.

Keywords MOE, Footprints, Static hardness, Screw withdrawal, Acoustic tests

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Introduction

Wood is the renewable natural material par excellence and as a renewable resource plays a fundamental role in social and economic development in rural contexts. Nowadays, wood is considered a technologically complex material [1] and has become even more highly valued and used for fine and intelligent furniture, textiles, biofuels, bioplastics, high-value chemicals and materials [2]. For this reason, there is currently a strong interest in wood, and the demand for this material is expected to grow significantly worldwide [3]. Consequently, market demand for wood from fruit orchard is growing as an additional source of supply, not only for energy use but for fine woodwork, tool handles, mosaics, veneers, flooring, and marquetry, too. McKendry [4] quantified large quantities of fruit tree wood obtained from the pruning operations carried out in Mediterranean fruit plantations as a source of energy and also for other industrial uses [5]. In addition, Kiaei et al. [6] suggested that fruit trees can help solve the problem of the lack of raw materials for the wood industry. In fact, only in the EU, a total of 11,301,345 hectares are dedicated to the cultivation of fruit trees and regarding the distribution of the fruit growing area in the EU member countries, Spain stands out with 43% of the total surface, followed by Italy with 21%, Greece with 10%, France with 8%, and Portugal with 6% [7]. Therefore, evaluating the total area of fruit tree cultivation in Europe, the enormous quantity of wood produced during annual pruning or from replacement or rejuvenation interventions is evident. For these reasons, in the last decades, several studies were conducted to evaluate the properties of wood derived by orchard pruning or dismantling. For example, Berti et al. [8] studied *Citrus×sinensis* (L.) wood to determine specific properties in South Italy while Sahin et al. [9] determined some wood properties of *Citrus×limon* (L.) wood grown in Mezitli-Mersin, Turkey. The results found that the wood from *Citrus* trees is fine-grained, and is characterized by a high density, average dimensional stability, and high surface hardness. Therefore, the results of the tests suggest the possibility of using citrus wood as a renewable raw material for the production of high quality products. Danihelová et al. [10] tested physical-acoustical characteristics of different fruit wood species (i.e., *Cerasus avium* (L. Moench), *Prunus cerasus* (L), *Pyrus communis* (L), *Juglans regia* (L), etc.), typically used in making musical instruments. In Greece, Passialis and Grigoriou [11] studied the technical properties of branch wood obtained by pruning of *Malus domestica*, *Pyrus communis* (L.), and *Prunus armeniaca* (L.) fruit-tree plantations.

Regarding olive species, in Spain, Requejo et al. [12] evaluated *Olea europaea* (L.) tree pruning for paper production evaluating as an important and very abundant wood resource in the Mediterranean areas of southwest Europe. Cara et al. [13] tested the production of fuel ethanol from steam-explosion pretreated olive tree pruning. Rencoret et al. [14] studied the structural characteristics of lignin in pruning residues of olive trees while Alshammari et al. [15] characterized natural fibres obtained from olive wood. Serìn and Penezoğlu [16] studied the morphological and physical properties of olive trees in Aydın and Kahramanmaraş regions in Turkey. Lo Giudice et al. [17] investigated the olive tree's chemical composition considering the potential uses of raw material derived from annual olive tree pruning. In fact, in Italy as in the world, olive tree is the most popular member of the *Oleaceae* family, and it is among the most extensively cultivated fruit crops [18]. Only in the EU, olive orchards cover the largest area, with more than 5 million hectares [7] and for this reason, olive wood represents a largely unexplored raw material considering the estimation of the large quantity of wood residues derived from periodical pruning of mature olive trees. Nevertheless, the knowledge about the wood quality of olive trees is not wide enough. Despite the abundance of raw materials from pruning, the mechanical properties of olive wood have not been studied completely by the scientific community, often due to the small size of the branches stem and from which to obtain the wood specimens for testing activities. In southern Italy (Calabria Region) there is the "Plain of Gioia Tauro", located in the province of Reggio Calabria, where, differently to other olive growing areas, two olive cultivars ("Sinopolese" and "Ottobratica") are characterized by a remarkable growth, perhaps unique in the world, with trees reaching and often exceeding 25 m in height: a real "forest of olive trees". From a structural anatomical point of view, olive trees have:

- The stem which constitutes the skeletal structure of the tree. It is the main part that rises from the ground and supports all the other parts (branches and crown). The stem is robust and woody, and its circumference can vary considerably depending on the age and variety of the olive tree.
- The branches, inserted on the stem, which vary in number, height and diameter depending on how the tree is agronomically managed, forming the tree crown. The main branches connect directly to the stem, while the secondary and tertiary branches develop from these. The shoots deriving from the year's vegetation grow on the tertiary branches [19–22].

This cultivation of olive trees is extended over more than 20,000 hectares and contributes considerably to the characterization of the physiognomy of the region's agroecosystems. In fact, in this area, the typical olive plantation is recognizable by medium to large trees that periodically are subject to pruning operations to permit to allow them to restore a vegetative and productive balance. In particular, every 15–20 years, an extraordinary reform pruning activity is conducted, and each olive tree is reduced not only in branches but also in the stem (partially or completely). Thanks to these operations, medium and large portions of olive wood are processed in several sawmills located in this area aimed to produce flooring, paneling, veneer, and indoor furniture. Therefore, branch wood and stem wood are used for sawmilling operations without distinction based on their different wood properties. To the best of the authors' knowledge, studies on the characteristics of olive wood are not numerous and, even more, they are completely non-existent regarding the comparison between branch and stem wood of the same species. In general, branch wood has been poorly investigated compared to stem wood, and currently, there is a lack of data which could support any potential added value of the branches for any production path [23]. Regarding the physical aspects, some studies reported that the mechanical characteristics of branches' wood are usually lowered compared to those of the stems of *Fagus sylvatica* (L.), *Acer* (spp.), *Pinus sylvestris* (L.). The mechanical tests showed that the MOE_S and compression strength of maple branch wood were slightly lower than those of stem wood, maple MOR was slightly higher for branch wood, and beech compression strength was similar for branch and stem wood [24]; several authors [6, 25] investigated on wood density and anatomical characteristics of branches in different species (*Terminalia superba* (Engl. & Diels) and *Pterygota macrocarpa* (K. Schum), while Cieszewski et al. [26] evaluated wood quality assessment of stem wood from the tree branch sample of different *Betula* (L.) species. Okai et al. [27] assessed the mechanical strengths properties of branch and stem wood of some tropical hardwood species (*Aningeria robusta* (A. Chev.) Aubrév. & Pellegr, *and Terminalia ivorensis* (A. Chev.). Their results showed that the overall compression and shear strengths parallel to the grain of the branch wood of *A. robusta* and *T. ivorensis* were higher than that of their corresponding stem wood. Dong et al. [28] focused their research on the physical and morphological properties of branch and stem wood of *Crataegus azarolus* (L.): the results of hawthorn wood in southwest Iran, indicated that different altitude levels had a significant effect on physical and fiber biometry of both stem and branch woods. There are significant statistical differences of the studied parameters between stem and branch woods. The highest average values of the physical properties of wood were found in the trunk, as regards the length of the fibers of the woody tissue, and in the branches as regards the diameter of the fibers and the thickness of the cell wall.

Considering the precious role of olive wood in Southern Italy, as in the Mediterranean areas, the current study aimed to determine and compare the physical and mechanical properties of branches and stem wood of two olive tree cultivars ("Sinopolese" and "Ottobratica") to provide information on *Olea europaea* (L.), since they are autochthonous olive cultivars from Southwestern Calabria, commonly cultivated in the Calabria Region for oil extraction and whose pruning activity involves the removal of large masses of wood. In detail, specific objectives have been: (i) to determine the physical properties; (ii) to test the mechanical properties of small clear wood specimens; and (iii) to compare the results between the two cultivars and between branches and stem wood in the same cultivars.

Materials and methods

Materials and samplings

The woody material was gathered from a local orchard of olive trees after fruit harvesting operations in the municipality of Oppido Mamertina, in the "Plain of Gioia Tauro" (South Italy). Regarding temperatures and the climatic regime of the area, in Oppido Mamertina, the summers are short, with clear sky, and characterized by hot, muggy and dry weather, the winters, instead, are long, cold, wet, windy, and partly cloudy sky. During the year, the temperature generally ranges from 7 to 28 °C and is rarely below 4 °C or above 30 °C. Basic information about the trees and the growing site are reported in Table 1.

The two cultivars were distinguished by botanical morphological characteristics (size and shape of the drupes, difference in leaf colour, size and shape of the leaves, ripening times of the fruit). Both cultivars presented majestic habits, with large branches reaching more than 50 cm in diameter, From the pruning of the olive tree, for each cultivar ("Sinopolese" and "Ottobratica"), 3 trees were selected to obtain logs from branches and stems for the experimental specimens' production (Fig. 1A). For the choice of parts, the stem was considered to become branch when, above each branch intersection, it changed in diameter and direction of growth. During pruning operation branches were cut from the stem, excluding the branches with a diameter lower than 20 cm. The logs carefully selected and separated by cultivar and tree parts, were sawn into disks with transversal cuts and boards through tangential cuts (Fig. 1C). Among them, the defect-free were selected to prepare the specimens (Fig. 1D) for the experimental material. The specimens were obtained from portions of wood far from the areas where tension wood was present. The sawn wood collected in the field was transported to the laboratory

Table 1 Wood tested collection site, timber harvested, and wood characteristics information

Cultivar	**Sinopolese**		**Ottobratica**	
Latitude (°)	38°16′48″		38°16′52″	
Longitude (°)	15°59′06″		15°58′58″	
Altitude (m a.s.l.)	340		340	
Age	70		70	
Mean height (m)	15.5		17.6	
Tree part	**Stem**	**Branches**	**Stem**	**Branches**
Mean log diameter (cm)	67 (± 13)	38 (± 9)	70 (± 15)	41 (± 9)
Max. log diameter (cm)	92	52	93	55
Min. log diameter (cm)	42	24	47	27
Wood density (kg/m^3, 12% MC)	1023 (± 39)	1070 (± 60)	994 (± 44)	1020 (± 49)
Max. wood density (kg/m^3, 12% MC)	981	985	922	936
Min. wood density (kg/m^3, 12% MC)	1102	1176	1075	1113

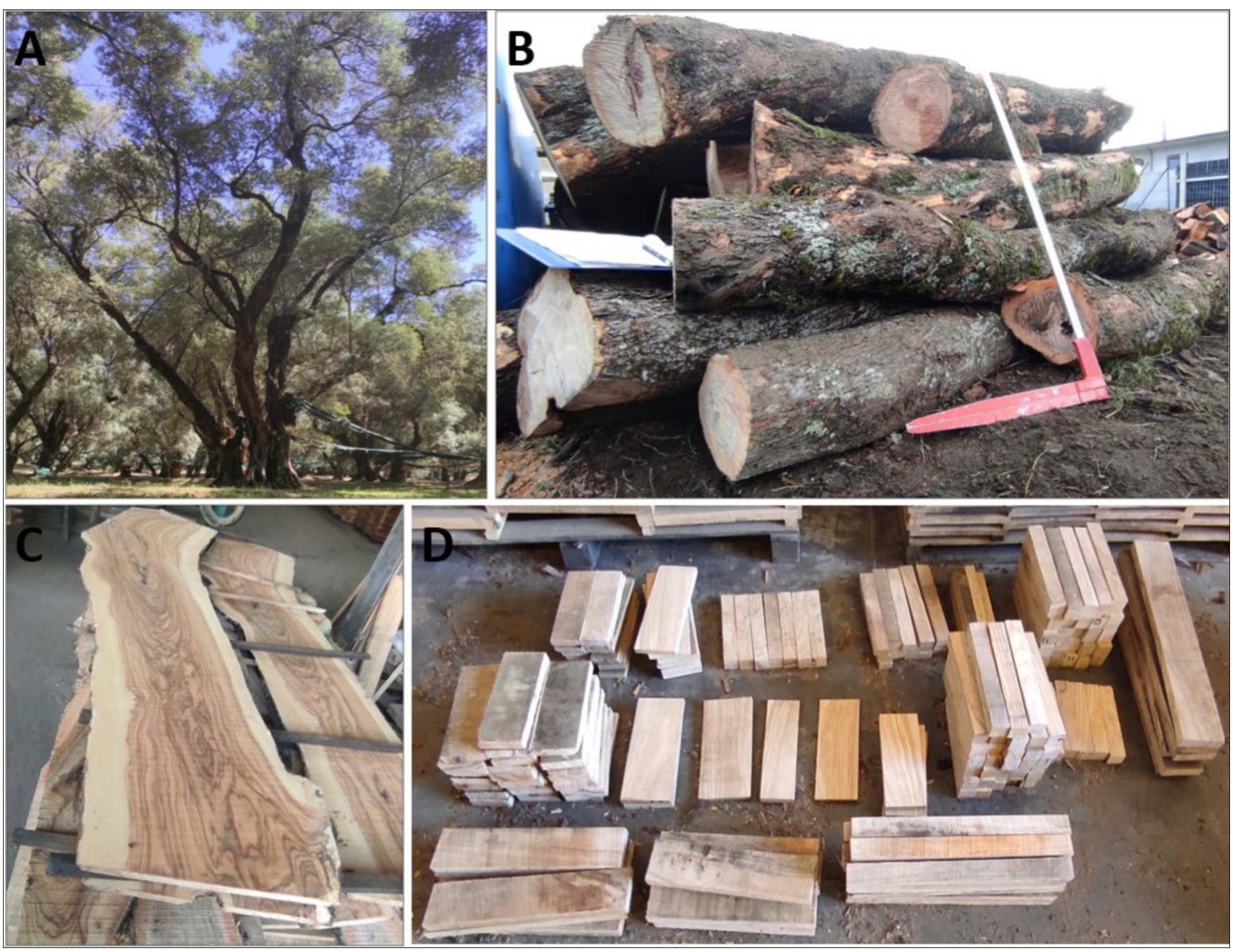

Fig. 1 "Sinopolese" olive trees (**A**), branches logs (**B**), branches sawn wood (**C**) and branches wood specimens for laboratory tests (**D**)

of Wood Technology and Forest Mechanization of the AGRARIA Department of Reggio Calabria for the production of specimens, conditioning and, subsequently, for carrying out the tests. A total of 400 specimens were obtained for each cultivar, of which 20 specimens were prepared from branches and 20 specimens from stems for carrying out the eleven kinds of tests described in the next section. The dimension of each specimen shown in Table 2. Once the specimens were prepared, they were conditioned in a climatic chamber (*Memmert GmbH, Germany*) at 20 ± 2 °C and 65% (± 5%) relative humidity (RH) to reach an equilibrium moisture content (EMC) of 12%. Air-dried density of each sample was determined in accordance with the ISO standard 13061-2 [29], and moisture content was determined following the oven dry method [30, 31]. In the laboratory, ten prismatic samples with dimensions of 30R × 30T × 40L mm were obtained from each of the trunks and branches of each cultivar to be used to measure the density at 12% (EMC), in accordance with the ISO 13061-2 standard [29].

Methods

The laboratory tests consisted of non-destructive tests and destructive tests for the characterization of the "Sinopolese" and "Ottobratica" cultivars olive wood. Non-destructive techniques were applied for the estimation of dynamic modulus of elasticity (MOEd), and for the surface roughness profile measurements. Destructive tests concerned static modulus of elasticity, bending strength, abrasion resistance, static hardness, footprints, compression strength, and screw withdrawal resistance.

Surface roughness

For the surface roughness profile measurements, the specimens were sanded sequentially with 100 and 200 grit sandpaper on the tangential surfaces, according to the UNI EN ISO 21920-3 [32]. The roughness profile was recorded with a Mitutoyo Surftest SJ-301 (Mitutoyo Corporation, Japan) surface roughness measuring system. Measurements were made with the profile method using a skid type diamond stylus with 5 µm tip radius and a 90-tip angle. The measuring speed was 0.5 mm/min with a cut-off of 8 mm on six plots of 10 × 10 mm distributed randomly on the surface of each specimen for a total of 240 measurements for each olive tree cultivar (120 measurements per each part of tree of each cultivar analysed). The R_a parameter (µm), the arithmetical mean of the absolute values of the profile deviations from the mean line of the roughness profile, was recorded and used to evaluate the surface roughness of the specimens. The average value of R_a was obtained by averaging six records on different positions on each sample.

Dynamic modulus of elasticity

The estimation of dynamic modulus of elasticity (MOEd) was determined with two different non-destructive tools, both based on acoustic wood property: the Microsecond Timer (Fakopp Enterprise, Agfalva, Hungary) used to conduct the impact wave test (MOEd_MST), and the Portable Lumber Grader (Fakopp Enterprise, Agfalva, Hungary) for the vibrational analysis (MOEd_PLG).

Both tests were replicated several times deriving the average data from at least three recordings for each sample measurement with each tool.

For the impact wave test, the specimens were tested by Microsecond Timer (Fakopp Enterprise, Agfalva, Hungary) device to measure the Time of Flight of an acoustic wave generated mechanically by tapping the start sensor with a hammer which travels through the wood tissue

Table 2 Tests conducted, and specimens used in the study

Properties	Code	Standard	Specimens' dimension ($R \times T \times L$) (mm)
Surface roughness	R_a	UNI EN ISO 21920-3 [31]	100 × 100 × 170
Dynamic modulus of elasticity (impact wave)	MOEd_MST	–	30 × 20 × 300
Dynamic modulus of elasticity (vibrational analysis)	MOEd_PLG	–	30 × 50 × 300
Static modulus of elasticity	MOEs	EN 408 [32]	20 × 20 × 500
Bending strength	MOR	EN 408 [32]	20 × 20 × 500
Abrasion resistance	WL	UNI EN 15185 [33]	120 × 120 × 20
Static hardness	SH	ISO 13061-12 [36]	60 × 60 × 100
Footprints	F	UNI 4712 [37]	60 × 60 × 100
Compression strength	C	ISO 13061-17 [38]	20 × 20 × 30
Screw withdrawal resistance parallel to grain	SW_Par	EN 1382 [39]	60 × 60 × 100
Screw withdrawal resistance perpendicular to grain	SW_Per	EN 1382 [39]	60 × 60 × 200

reaching the opposite sensor. The dynamic modulus of elasticity was calculated using Eq. (1):

$$\text{MOEd\_MST} = \rho \cdot v^2 \quad (1)$$

where MOEd_MST = dynamic modulus of elasticity (10^{-6} N/mm^2); ρ = density (kg/m^3); v = wave transmission velocity (m/s^1).

Portable Lumber Grader (Fakopp Enterprise, Agfalva, Hungary) tool was used to determine the natural longitudinal vibration frequency of the tested lumber. Specimen vibration has been generated with a hammer on the transversal face of the specimen and the signal is captured by a microphone placed at the opposite transversal face. The acoustic signal is analysed by a computer with the Fourier vibration analyser (Fakopp Enterprise, Agfalva, Hungary) to detect the natural frequency of each specimen. This equipment includes a balance to determine the weight of the specimen [31]. Using the specimen's mass (m, in kg), width (w, in m), length (l, in mm), height (h, in mm), and the longitudinal vibration × frequency (f, in Hz), MOEd_PLG (in 10^{-6} N/mm^2) is calculated with the following Eq. (2):

$$\text{MOEd\_PLG} = \frac{m}{lwh}(2fl)^2 \quad (2)$$

Static modulus of elasticity and bending strength tests

Static modulus of elasticity (MOEs) and bending strength or modulus of rupture (MOR) were determined perpendicular to grain. For these tests, the specimens were tested adopting the four-point bending test, performed using a 300 kN universal testing machine (METRO COM, Italy—10402030 model), applying to the load a speed of 3.6 mm/s. The distance between the two points of the load was 120 mm, while that between the supports is 380 mm, in accordance with European Standard 408:2010 + A1 [33] (Table 2). Data were recorded by the dedicated METRO COM software.

Abrasion resistance tests

The abrasion resistance measurements were conducted according to the UNI EN 15185 [34]. The specimens were abraded using a Taber Rotary Abraser 5135 (Taber Industries, USA) applying loads of 1000 g, with 500 cycles at the controlled speed of 60 revolutions per minute (RPM). S-42 sandpaper strips (Taber Industries, USA) were used as the abrasive. Sandpaper was changed after each 250 test cycles to guarantee the same abrasive performance. The specimens were weighed before the abrasion test, after 250 cycles, and after 500 cycles [35]. The weight loss in percentage was determined by Eq. (3):

$$\text{WL} = \frac{(W_1 - W_E)}{W_1} \bullet 100 \quad (3)$$

where WL = weight loss (%); W_1 = weight of test specimen before abrasion (g); W_E = weight of test specimen after abrasion (g).

Static hardness tests

The static hardness tests were carried out tangentially on wood specimens and the measurements were performed by applying a force necessary to embed an 11.28-mm-diameter steel ball indenter halfway into a sample according to the ISO standard 13061-12 [36] using the same universal testing machine used for bending strength tests. The surface hardness test measures the resistance of a sample of wood to denting and wear and it was calculated using the following Eq. (4):

$$\text{SH} = K \bullet F \quad (4)$$

where SH = surface hardness at moisture content W (kN); K = coefficient equal to 4/3 in the case of penetration of the plunger to a depth of 2.82 mm; F = maximum load during the penetration of the plunger into the test sample to the specified depth (kN).

Footprints tests

For the footprints measurements the specimens were tested on 5 points of replication for each sample according to UNI 4712 [37] and using the same universal testing machine used for bending strength tests. The peak load of 1575 N was applied with a cylindrical indenter (10 mm diameter) steel force punch during the test, corresponding to a unit stress of 2000 N/mm^2. For each sample, the deformation was measured at 5 points at three different moments: during the test at the peak load, immediately after the test, and two days after the test (48 h after), by using a digital comparator (1 µ sensitivity). The results were compared to the measurements of the original size of specimens obtained in the same five points.

Compression strength tests

About the compression strength tests parallel to the grain, the olive wood specimens were tested by the same METRO COM universal testing machine applying a load at a constant loading-head movement settled (in this case at a speed of 5 mm/s) to reach the maximum load within 300 s from the start of the test, in accordance with the standard in force for compression tests (ISO 13061-17 [36, 38]). The compressive strength was measured using (Eq. 5)

$$C = \frac{F_{max}}{A} \quad (5)$$

where C = compressive strength parallel to the grain (N/mm^2); F_{max} = maximum load (N); A = cross-sectional area (mm^2).

Screw withdrawal resistance

Screw withdrawal resistance was measured parallel to the wood grain (SW_par), and perpendicular to them (SW_per), and was assessed according to EN 1382 [39]. The tests were conducted with the commercial Screw Withdrawal Force Meter device (Fakopp Enterprise Bt., Sopron, Hungary). The screw applied without predrilling was a standard SPAX (PZD) type head screw 45 mm long, with size of diameter 3 mm.

The withdrawal parameter of the screw SW (N/mm^2) was calculated according to the following expression (Eq. 6),

$$SW = \frac{F_{max}}{d \bullet l_p} \tag{6}$$

where F_{max} is the maximum withdrawal load (N), d is the diameter of the screw (mm), and l_p is the depth of the penetration of the screw into the wood (mm) [35, 39, 40].

Statistical analysis

Data analysis

Descriptive statistics of the properties of the tree part (branch and stem) wood, distinct for "Sinopolese" and "Ottobratica" cultivars measured during the laboratory tests, were calculated. A multivariate analysis of variance was conducted between the Cultivar—Tree part and the parameters detected; a significance level of 0.05 was applied. The statistical analysis of the data was performed using the SPSS software version 20.0 (IBM Corp., Amonk, NY, USA).

Results and discussion

In this study, two different cultivars of olive wood, "Sinopolese" and "Ottobratica", were investigated about mechanical, physical, and surface properties (R_a, MOEd_MST, MOEd_PLG, MOEs, MOR, WL, SH, F, C, SW_Par and SW_Per) distinguishing between two tree parts (branches and stem).

The principal experimental results are summarized in Table 3 which provides the main descriptive statistics of the properties analysed distinct for the two "Sinopolese" and "Ottobratica" cultivars and between branches and stem wood.

Table 3 Main descriptive statistics of properties tested for olive wood, distinguished for the "Sinopolese" and "Ottobratica" cultivars, and between stem and branches wood

Properties	Units	Sinopolese				Ottobratica			
		Stem		Branches		Stem		Branches	
		Max (min)	Mean (st.dev.)	Max (min)	Mean (st.dev.)	Max (min)	Mean (st.dev.)	Max (min)	Mean (st.dev.)
R_a	µm	7922 (978)	3937 (± 1494)	7748 (1150)	3795 (± 1508)	6462 (1736)	3484 (± 1105)	7128 (1672)	3925 (± 1444)
MOEd_MST	N/mm^2	10,587 (2139)	7704 (± 2614)	11,156 (1413)	7053 (± 3524)	10,040 (2431)	8028 (± 1551)	10,230 (2700)	8235 (± 1632)
MOEd_PLG	N/mm^2	13,963 (7132)	10,397 (± 1717)	14,072 (6732)	10,604 (± 1949)	10,782 (7971)	9379 (± 939)	10,546 (5714)	9227 (± 1189)
MOEs	N/mm^2	11,872 (6257)	8526 (± 1659)	15,571 (6003)	10,476 (± 2429)	10,152 (5111)	7408 (± 1297)	13,737 (4834)	8963 (± 2339)
MOR	N/mm^2	104 (29)	71 (± 21)	117 (52)	85 (± 19)	55 (11)	38 (± 12)	90 (15)	48 (± 19)
WL	%	0.51 (0.22)	0.31 (± 0.06)	0.40 (0.27)	0.32 (± 0.04)	0.46 (0.18)	0.36 (± 0.08)	0.41 (0.21)	0.32 (± 0.07)
SH	kN	9.2 (5.2)	7.0 (± 1.1)	11.0 (6.8)	9.1 (± 1.1)	7.6 (4.4)	5.9 (± 0.9)	7.3 (5.0)	6.3 (± 0.7)
F	mm	− 0.01 (− 0.09)	− 0.04 (± 0.02)	− 0.01 (− 0.08)	− 0.03 (± 0.02)	− 0.03 (− 0.09)	− 0.06 (± 0.02)	− 0.02 (− 0.11)	− 0.06 (± 0.03)
C	N/mm^2	75 (52)	60 (± 7)	75 (43)	61 (± 7)	54 (28)	46 (± 6)	67 (36)	47 (± 8)
SW_Par	N/mm^2	52 (27)	39 (± 6)	50 (31)	42 (± 6)	42 (30)	36 (± 3)	49 (30)	39 (± 4)
SW_Per	N/mm^2	53 (38)	44 (± 4)	52 (39)	46 (± 4)	42 (32)	40 (± 3)	47 (38)	43 (± 3)

Comparing the two cultivars, regarding the stem tree part, similarities in some properties ($p > 0.05$) were observed for roughness profile (R_a), moduli of elasticity (MOEd_MST, MOEd_PLG), abrasion resistance (WL), and static hardness (SH), while significant differences were found in static modulus of elasticity (MOEs, $p < 0.05$), bending strength (MOR, $p < 0.01$), footprint (F, $p < 0.01$), compression strength (C, $p < 0.01$), and screw withdrawal resistances (SW_Par, $p < 0.05$, SW_Per, $p < 0.01$). Branches wood between the two cultivars demonstrated similarities ($p > 0.05$) concerned about roughness profile (R_a), moduli of static and dynamic elasticity (MOEs, MOEd_MST, MOEd_PLG), abrasion resistance (WL), static hardness (SH), and screw withdrawal resistance in parallel fiber direction (SW_Par), while significant differences ($p < 0.01$) emerged in MOR, F, C, SW_Per.

In regard to the "Sinopolese" cultivar, multivariate analysis of variance (Table 4) among the data of properties collected for the two tree parts, there were no significant differences emerged between branches and stems for most parameters analysed. There were significant differences between branch and stem wood for MOEs ($p < 0.01$) (Fig. 2), MOR ($p < 0.05$) (Fig. 3) and SH ($p < 0.01$) (Fig. 4).

The branches and stem of the "Ottobratica" cultivar highlighted very similar differences to those found for the "Sinopolese" cultivar, with significant differences between branches and stem in the values regarding MOEs, MOR ($p < 0.05$) and SH ($p < 0.01$) but also, for the parameters SW_Par and SW_Per ($p < 0.01$) (Figs. 5, 6).

The estimates of the elastic modulus, between the wood of stem and branches, with the two different acoustic methods (Microsecond Timer—MOEd_MST, and Portable Lumber Grader—MOEd_PLG) gave slightly different results. The difference could be because the Portable Lumber Grader is a tool designed to grade longitudinal vibration frequency of the tested sawn lumber, while the Microsecond Timer is designed to evaluate wood from standing trees and construction timber measuring the Time of Flight of an acoustic wave travels through the

Table 4 Multivariate ANOVA tests of cultivar-tree part

Cultivar	Dependent variable	Tree part		Mean difference	Std. Error	Sig.[b]	95% Confidence interval for difference[b]	
							Lower bound	Upper bound
Sinopolese	R_a	Stem	Branches	141.700	474.654	0.767	– 819.187	1102.587
	MOEd_MST	Stem	Branches	228.200	202.949	0.268	– 182.650	639.050
	MOEd_PLG	Stem	Branches	42.377	88.812	0.636	– 137.414	222.169
	MOEs	Stem	Branches	– 1950.140*	657.800	0.005	– 3281.786	– 618.494
	MOR	Stem	Branches	– 13.595*	6.333	0.038	– 26.415	– 0.775
	WL	Stem	Branches	– 0.011	0.017	0.509	– 0.045	0.023
	SH	Stem	Branches	– 1.574*	0.358	0.000	– 2.299	– 0.849
	F	Stem	Branches	– 0.007	0.006	0.294	– 0.020	0.006
	C	Stem	Branches	– 0.829	2.120	0.698	– 5.121	3.463
	SW_Par	Stem	Branches	– 2.861	1.924	0.145	– 6.755	1.034
	SW_Per	Stem	Branches	– 1.388	1.144	0.232	– 3.704	0.927
Ottobratica	R_a	Stem	Branches	– 440.350	406.651	0.286	– 1263.572	382.872
	MOEd_MST	Stem	Branches	0.700	103.995	0.995	– 209.827	211.227
	MOEd_PLG	Stem	Branches	67.072	57.669	0.252	– 49.672	183.817
	MOEs	Stem	Branches	– 1555.282*	598.105	0.013	– 2766.083	– 344.481
	MOR	Stem	Branches	– 10.302*	4.922	0.043	– 20.267	– 0.338
	WL	Stem	Branches	0.040	0.024	0.103	– 0.008	0.089
	SH	Stem	Branches	– 1.049*	0.247	0.000	– 1.549	– 0.549
	F	Stem	Branches	– 0.004	0.008	0.642	– 0.019	0.012
	C	Stem	Branches	– 1.717	2.273	0.455	– 6.320	2.885
	SW_Par	Stem	Branches	– 3.263*	1.166	0.008	– 5.623	– 0.902
	SW_Per	Stem	Branches	– 3.018*	0.801	0.001	– 4.639	– 1.396

Based on estimated marginal means

*The mean difference is significant at the 0.05 level

[b] Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments)

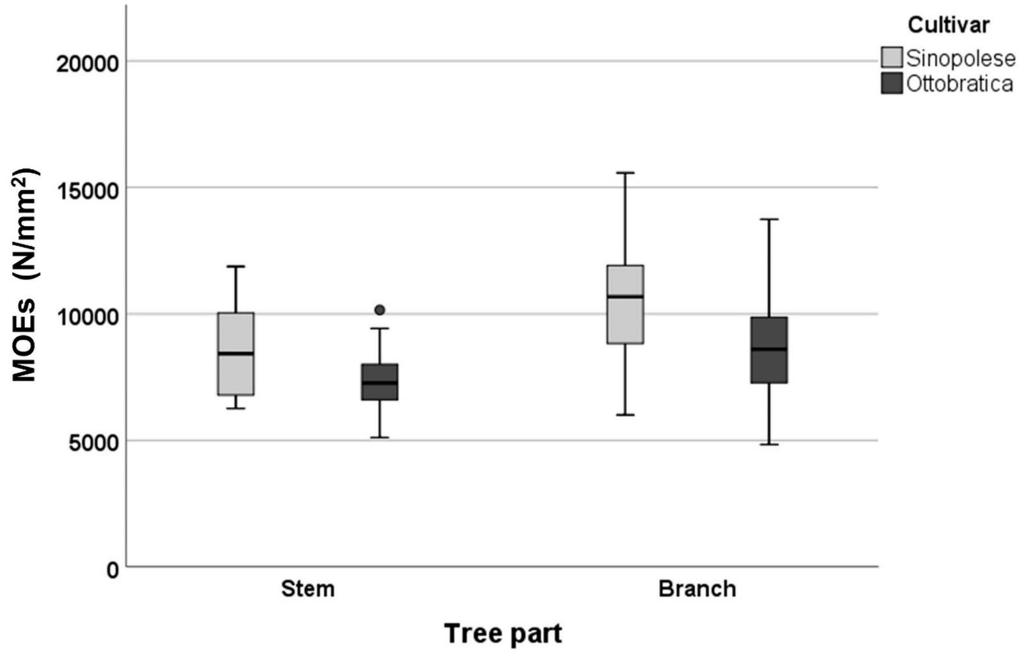

Fig. 2 Differences between the cultivar olive wood of "Sinopolese" and "Ottobratica", distinct into stems and branches, about static modulus of elasticity—MOEs

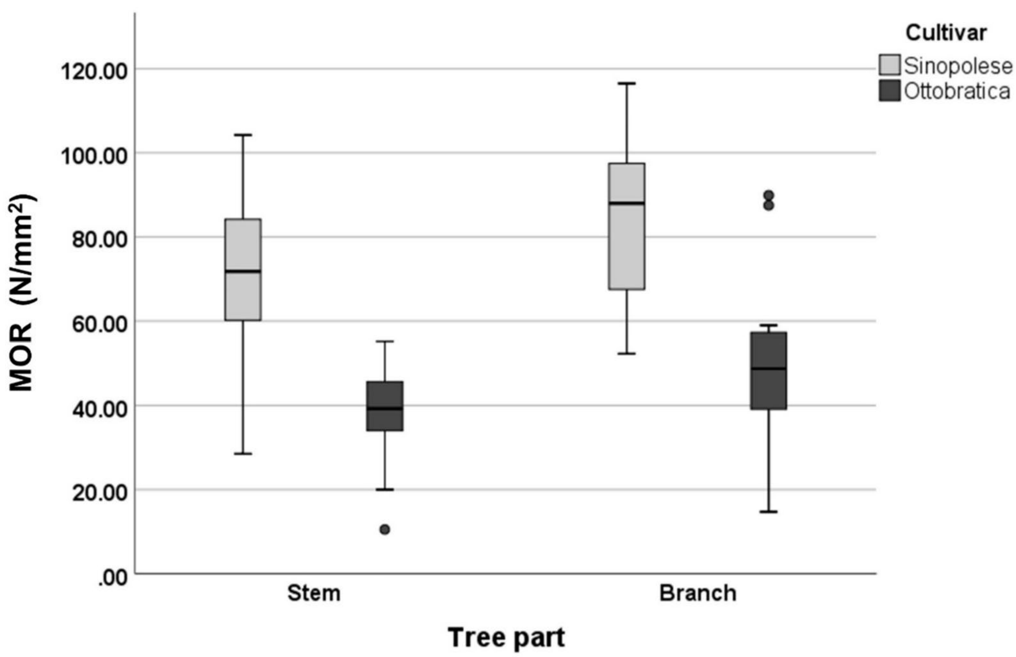

Fig. 3 Differences between the cultivar olive wood of "Sinopolese" and "Ottobratica", distinct into stems and branches, about bending strength—MOR

wood tissue, even if several authors use this tool on sawn lumbers [41, 42]. The results of MOEd_MST showed a slight underestimation of the static MOE, as also found in other studies [43] while, the opposite results, with high difference compared to the static MOE, were obtained with the Portable Lumber Grader, in accordance with other research [41].

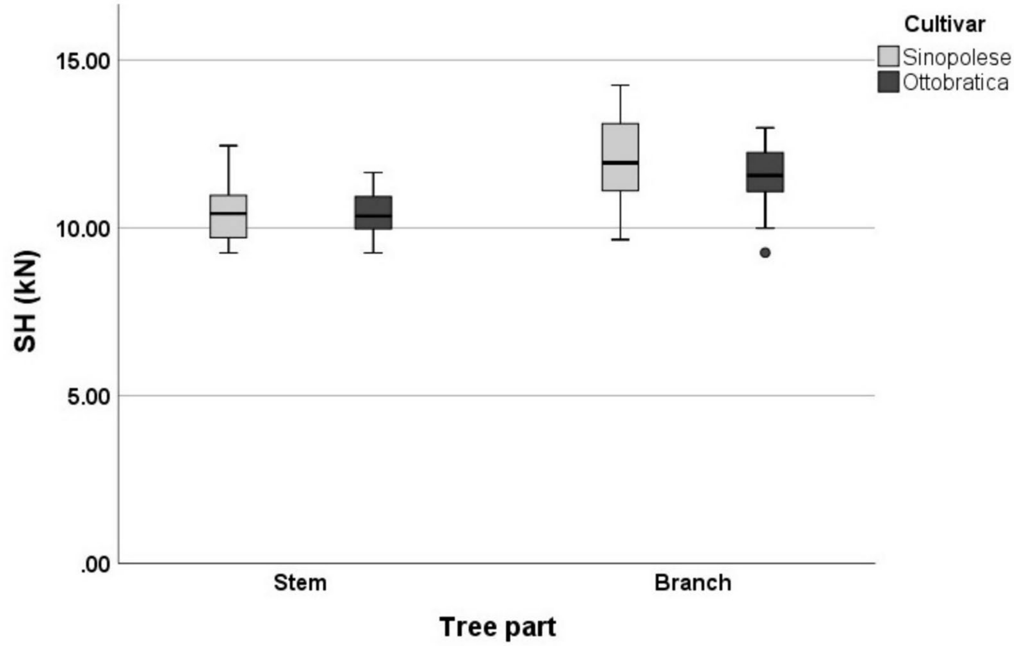

Fig. 4 Differences between the cultivar olive wood of "Sinopolese" and "Ottobratica", distinct into stems and branches, about static hardness—SH

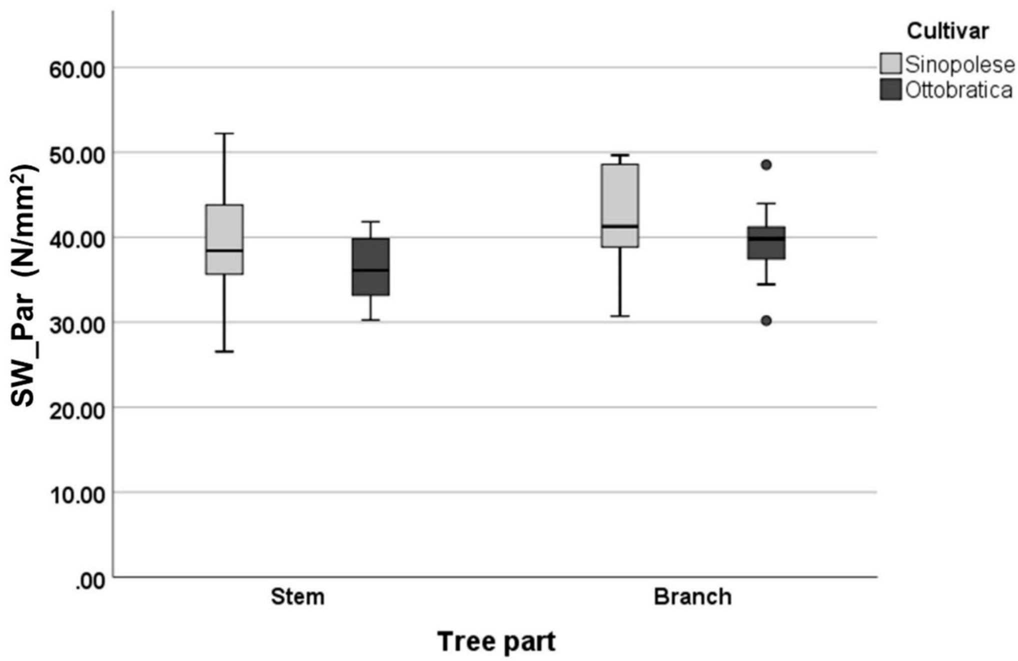

Fig. 5 Differences between the cultivar olive wood of "Sinopolese" and "Ottobratica", distinct into stems and branches, about screw withdrawal resistance parallel to grain—SW_Par

Collecting the available information and taking under investigation only the parameters which were determined statistically different between the cultivars or among the tree parts of them, emerged that the values of both the MOEs and the MOR were lower than those reported in the literature for olive wood [44–46]—MOE 17770 N/mm^2, MOR 155 N/mm^2. However, the static elastic modulus found by Düzkale et al. [47] on *Olea europaea* (L.)

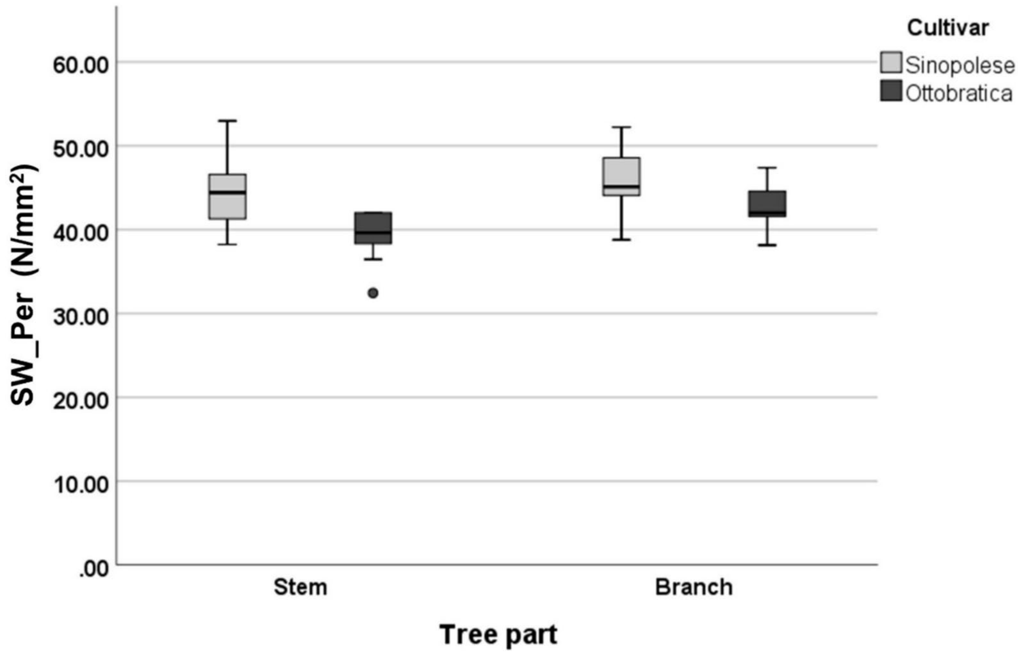

Fig. 6 Differences between the cultivar olive wood of "Sinopolese" and "Ottobratica", distinct into stems and branches, about screw withdrawal resistance perpendicular to grain—SW_Per

in Turkey, is about 50% lower (4444 N/mm^2) when compared to those obtained from the present study ("Sinopolese" branches 10,476 N/mm^2—"Sinopolese" stem 8526 N/mm^2; "Ottobratica" branches 8963 N/mm^2—"Ottobratica" stem 7408 N/mm^2). Continuing the comparison with the study by Düzkale et al. [47], it can be noted that the modulus of rupture (64.82 N/mm^2) and the compressive strength in the direction parallel to the fibers (C) (53.17 N/mm^2) obtained for the olive in Turkey, are placed between the average values obtained for the two cultivars tested in this research ("Sinopolese" 78 N/mm^2—"Ottobratica" 43 N/mm^2; "Sinopolese" 61 N/mm^2—"Ottobratica" 47 N/mm^2, for MOR and compression strength average values between branches and stem, of each cultivar, respectively).

Static hardness ("Sinopolese" branches 9.1 kN—"Sinopolese" stem 7.0 kN—Ottobratica" branches 6.3 kN—Ottobratica" stem 6.0 kN) was found to be consistent with Green et al. [48] who ranged Janka hardness between 1.60 and 10.90 kN for hardwoods, and between 1.50 and 5.33 kN for softwoods since the hardness found with the Janka test is approximately proportional to the density of the wood in general, but above all by the variation in density within an annual ring. Of the two olive tree cultivars analysed, the "Sinopolese" is the one that presented the highest static hardness values, and in both cultivars the hardness was always higher in the branches than in the stems. However, specifically comparing these values with the SH of the olive tree reported by the Ruffinatto et al. [45] (14.1 kN) they were lower by 35–50% in the case of "Sinopolese", and by 55–60% in the case of the "Ottobratica" cultivar.

The study of the physical–mechanical properties of olive wood is slightly diffused. No studies were found on the performance of resistance to imprinting and extraction of the screw for olive wood, as well as the evaluation of the hardness of the wood, so the comparison with the results resulting from this research cannot be carried out. However, considering the results obtained from studies carried out on other types of hardwood such as *Quercus cerris* (L.) wood (density 0.834 ± 0.058 g/cm^3), for indentation resistance, Todaro [49] obtained values of permanent deformation (or residual) equal to − 17.12 μ, values not very discordant from those found in this study. Considering the beech wood to compare the olive compression strength, Kapidani et al. [50] measured 71.96 N/mm^2, which was, even for this parameter, higher than that of the olive wood (mean of 60.7 and 46.50 N/mm^2 for "Sinopolese" and "Ottobratica" cultivars, respectively). In regard to the screw withdrawal resistance parallel to grain the values were higher than some other hardwood species present in scientific literature [9, 51–53], (*Carpinus Betulus* (L.)—22.78 N/mm^2, *Fraxinus excelsior* (L.)—16.00 N/mm^2, *Fagus sylvatica* (L.)—12.60 N/mm^2), and perpendicular (*Carpinus Betulus* (L.)—25.31 N/mm^2—*Fagus sylvatica* L.—15.80 N/mm^2, *Fraxinus excelsior*

(L.)—19.00 N/mm^2), but lower compared to lemon wood that presents screw withdrawal resistance 44 and 51 N/mm^2 (parallel and perpendicular to grain, respectively) for both cultivars independently of the tree parts tested. Rahmanto et al. [54] focused on the comparison of the properties between branches and stems by analysing anatomically seven different commercial wood species and from their study, it emerged that although there are anatomical differences such as fibre length and vessel diameter between the wood of the two parts of the tree, the fiber derivative resulted in the same quality class for stem and branch, concluding that the main stem and branch have similar wood properties. So, the study of the properties of the wood could be carried out using the branch effectively, especially since stem wood is sometimes not suitable due to the presence of cavities or decays that defect wood quality, while branches wood, is often less involved in wood deterioration.

This first examination suggests the possibility of using the branches wood to obtain similar products produced with stem wood.

Conclusion

Nowadays, in the agroforestry contexts, there is a growing interest in the use of wood species from alternative sources, especially fruit-tree woods, for multiple purposes. This study took inspiration from this trend, aiming to expand the notions connected to the wood obtainable from the extraordinary pruning of olive trees. In fact, considering the lack of information on this woody species, the results gathered from this study can enrich the interest in the wood olive. The investigation focused on determining and comparing the physical and mechanical properties of branches and stem wood of two olive tree cultivars ("Sinopolese" and "Ottobratica") to provide information on this species by considering the differences found in intraspecific terms and in the distribution of the wood in the tree. In this study, differences were found on several properties, between the two cultivars when compared to each other for part of the tree, where in general, the "Sinopolese" cultivar showed higher values than the "Ottobratica". Between the branches and stem wood within the same cultivar, statistical analysis highlighted significant differences only for some properties (static modulus of elasticity, bending strength, static hardness and screw withdrawal resistances depending on the cultivar) with higher results for wood of branches. These results could be motivated by the differences obtained in wood density between the cultivars or by some intrinsic characteristics of each cultivar not yet recognised, but no studies were found about the characterization of the wood olive cultivars, although very widespread is the topic related to olive oil. That suggests the possibility of using the branches wood to obtain similar products produced with stem wood. The commercial utilization of wood branches can represent a valid opportunity for the local rural economy when stems are not adequate (defected, decayed, etc.). In conclusion, the knowledge about olive wood on its performances concerning physical and mechanical characteristics can increase its use in multiple sectors and ensure a more aware use of the application of the wood resources.

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