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Sawing yield estimation of defective logs in *Olea europaea* L., *Robinia pseudoacacia* L., and *Castanea sativa* Mill. species growing in Southern Italy

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Abstract

Key message This study assessed sawmill efficiency for olive (*Olea europaea* L.), black locust (*Robinia pseudoacacia* L.), and chestnut (*Castanea sativa* Mill.) logs in Southern Italy evaluating the impacts of taper, ovality, sweep, and fluting defects on sawing yield. Taper was the most significant defect, especially for olive and chestnut logs. Black locust showed stable yields (70%), highlighting its commercial potential. The results of this study demonstrate that the quality and defectiveness of logs—particularly taper and ovality—significantly influence the sawing yield of the investigated species and emphasize the importance of selecting high-quality raw materials to reduce waste and enhance the economic value of Mediterranean hardwoods.

Context The hardwood sawmilling sector plays a crucial role in the wood supply chain, where the efficiency of the sawing process is directly influenced by the quality of raw material and the presence of inherent log defects. Accurate evaluations of sawing productivity and yield potential are therefore essential to minimize wood waste, enhance value recovery, and support sustainable forest resource utilization.

Aims This study aimed to evaluate the sawing yield of hardwood sawn timber from olive (*Olea europaea* L.), black locust (*Robinia pseudoacacia* L.), and chestnut (*Castanea sativa* Mill.) logs sourced from Southern Italy, investigating the impact of four log defects: taper, ovality, sweep, and fluting defects across different diameter classes.

Methods Over 200 logs were analyzed for sawing yield using a vertical band saw and adopting a live-sawing pattern. Defects were measured and statistically assessed. Yield was calculated as the ratio of sawn product weight to raw log weight.

Results Taper significantly reduced yield, particularly in olive and chestnut logs, and, to a lesser extent, ovality was found to be a defect affecting yield only for olive trees and for the smaller diameter class. Black locust and chestnut maintained stable yields (70%), demonstrating strong commercial potential. Olive logs showed competitive yields in larger diameter classes, despite their irregular shapes.

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Conclusion The results of this study demonstrate that the quality and defectiveness of logs—particularly taper and ovality—significantly influence the sawing yield of Mediterranean hardwoods. Despite these challenges, species such as olive, black locust, and chestnut have shown yield values comparable to other widely used hardwoods, confirming their suitability for commercial applications. These findings support the potential for more sustainable and efficient use of locally available hardwood resources in Mediterranean forestry contexts.

Keywords Sawmill efficiency, Wood defects, Timber boards, Taper, Ovality, Live sawing

1 Introduction

1.1 The importance of sawmills in the valorization of wood products

Wood products are a cornerstone of social and economic development in many rural areas. In recent years, however, there has been growing attention to their ecological and environmental importance. As a result, increasing emphasis is being placed on valorizing all wood products and minimizing waste generated during their production. Sawmills produce and market products with a small carbon footprint from raw materials sourced from forests. In Europe, there is a huge demand for logs to be used for sawing, veneer, and other solid wood applications, and recent data from the European Sawmill Organisation (EOS 2024) indicate that sawnwood consumption in Europe in 2022 reached slightly over 110 million m³ (90% softwood and 10% hardwood), increasing the value compared to the previous 6 years (WHO 2022). Modern sawmills tend to prioritize the speed and production of sawnwood production rather than volume and value yield, i.e., the ratio between the total log volume and the volume of produced boards. It is interesting to note that the categorization of European sawmills into small, medium, and large-scale mills does not imply market differentiation. In fact, both medium and large sawmills and small sawmills process wood products for both domestic needs and export markets. The only difference is that medium and large mills have sufficient capital to invest in more sophisticated production processes and can utilize scarce resources efficiently (Faruwa et al. 2017).

1.2 Sawing yield and linked parameters

In this context, several studies have highlighted the relevance of production efficiency in sawmill operations, particularly in relation to the optimization of sawn timber yield. To maximize the value of a renewable yet limited resource such as wood, it is essential to understand the relationship between log quality and the resulting sawing yield, especially for hardwood species. Most sawmill operators therefore rely on their knowledge of log dimensions—such as length, diameter, and taper—to guide processing decisions and enhance performance.

The characteristics of logs vary widely within species, harvest sites, and even within the same tree. However, in small and medium sawmills, lumber may be of random length and width and contain randomly distributed defects of varying severity (Buehlmann and Thomas 2001). Yield is defined as the ratio of the amount of primary product output to the amount of raw material input, expressed as a percentage (Stragliotto et al. 2023; Garcia et al. 2012; Mitchell et al. 2005). A large number of factors affect the volume of sawn timber produced from a given log by the sawing process (Hallock et al. 1976).

Studies of sawmill productivity have a long tradition. Freese (1974) defined and compared different log rules for estimating the net yield of logs of a given diameter and length. Hallock and Lewis (1971) employed the Best Open Face (BOF) program to compare the potential yields of five different sawing methods and to obtain an increasing percentage of cuts from sawn logs. Several studies have investigated the main factors influencing sawing yield, often linking them to log characteristics, processing parameters, and species-specific traits. Steele (1984) identified seven interacting variables affecting lumber recovery, highlighting that improvements in kerf width, sawing accuracy, and log orientation can enhance yield by up to 25% in small logs. Feuillat and Keller (1997) emphasized that site conditions, soil, and tree form affect wood anatomy and technological quality, particularly in applications such as cooperage. Doussot et al. (2002) confirmed that similar environmental and anatomical variables influence final product quality. More recently, Melo et al. (2019) found that *Erismia uncinatum* (Warm.) showed the highest volumetric yield among four native Amazonian species, while larger diameters tended to reduce yield in three out of four species due to internal defects. Stragliotto et al. (2023) reported that only two of five Amazonian species assessed exceeded the Brazilian legal yield threshold for export, reinforcing the importance of internal log quality and species selection in maximizing recovery.

The importance of optimizing the sawing yield is justified by the desire to reduce waste in sawmills and improve the profitability of the sawing process by increasing conversion efficiency. In fact, several studies have estimated that total production costs could be

reduced by approximately 2% for each additional 1% increase in sawing yield (Buehlmann and Thomas 2001; Kline et al. 1998; Wengert 1994). Although this estimate mainly refers to temperate hardwood species commonly processed in North American sawmills, the underlying principle—higher efficiency leading to lower unit costs—applies broadly across species and processing contexts, including tropical and Mediterranean hardwoods.

1.3 Wood defects and their influence on sawing yield

The present study focuses on three hardwood species—olive (*Olea europaea* L.), black locust (*Robinia pseudoacacia* L.), and chestnut (*Castanea sativa* Mill.)—which are widely distributed in the Mediterranean region. These species play a central role in local timber production chains, particularly in small and medium-scale sawmills, where they generate both economic and social value. Their importance in regional contexts, combined with the frequent occurrence of natural defects in their logs, makes them ideal for investigating the effects of geometric irregularities on sawing yield.

Factors affecting sawing yield are sometimes recognized as defects that are common to several tree species. For example, among the defects, eccentric pith can be included, which occurs when the pith is not located in the center of the stem but is displaced laterally. This can occur due to uneven growth, often caused by environmental factors such as constant wind, soil slope, obstacles, or poor light distribution. The presence of mechanical stress induces uneven growth of cambial tissue, resulting in a deviation of the pith from the geometric center of the trunk. This phenomenon has been widely observed and documented in the literature and reflects the ability of the tree to modify its anatomical structure to improve mechanical stability and respond to environmental stresses (Kojs et al. 2012; Tomczak et al. 2012). Wood cracks, on the other hand, are splits or fissures that form in the wood, either during the life of the standing tree or during or after felling and seasoning. They can be caused by various factors (uneven shrinkage during drying; mechanical or environmental stresses; sudden changes in humidity or temperature; internal defects such as stresses due to abnormal growth (Kang and Lee 2004). A particular case of wood cracks is ring shake, which is characterized by a circular or semicircular failure on the tangential plane in the ligneous tissue along the annual growth ring (Proto et al. 2020). Taper is a natural phenomenon but can become a defect if it is excessively pronounced. The main causes recognized by Larson (1963) to explain the taper of trees derive from several factors such as nutritional, water conduction, mechanistic, and hormonal factors. The fluting is formed by irregular growth or by trauma suffered by the

tree, such as frost, impacts, or animal attacks. Sweep is another very common defect, especially in trees grown in windy areas, on slopes, or in search of light. Ovality is induced by the presence of dominant wind, growth on sloping terrain, or the uneven distribution of growth in the proximity of a displaced heartwood.

Whilst the presence of defects is to be expected in a physiological context, the qualitative classification of sawn timber permits a certain degree of tolerance with regard to defects, or their complete rejection, depending on the class of the timber. Consequently, the quality of logs entering the production line is important because it determines the quality and sawing yield that can be obtained (Papandrea et al. 2022; Borz et al. 2021; Musat et al. 2017; Wiedenbeck et al. 2003). As Wang et al. (2018) have demonstrated, the early detection of defects in hardwood logs is of paramount importance in order to ensure the expeditious removal of logs from the processing stream that exhibit minimal or negligible profitability. This concept is commonly known as the “break-even log,” which refers to the processing of a log with a quality that is lower than the break-even log, which inevitably results in a loss for the company. Carpenter et al. (1989) determined that holes, knots, wounds, and other growth defects have a negative effect on the strength and appearance of the wood, thus reducing the value of the log and its by-products. Buehlmann and Thomas (2001) proposed the necessity of distinguishing between lumber types of lower quality (boards with many and/or large defects) and higher quality (i.e., boards with few or no defects), starting from sawn log grades. In fact, quality classes can be applied, starting from the raw material, to assess the impacts of individual defects on the quality of produced assortments. The sawing yield of hardwood logs is strongly influenced by the presence of defects, which vary in type, location, and severity. Several studies have highlighted that both internal and external defects significantly affect not only the volume of usable timber but also the grade and value of the final products (Silva et al. 2014; Afrifah and Frimpong-Mensah 2014; Wang et al. 2018). Internal defects such as cracks, knots, and pith eccentricity are often difficult to detect prior to processing, especially when logs are stacked (Wang et al. 2018). In contrast, external geometric defects—such as taper, sweep, and ovality—can be assessed more easily using basic measurement tools like tape measures and calipers, making them critical parameters for pre-sawing evaluations (Silva et al. 2014). Among these, taper has been identified as one of the most impactful defects on yield. Nassur et al. (2013) found that a high taper coefficient leads to lower volumetric recovery, since the conical shape of the log results in greater waste and requires more trimming to obtain regular boards. This not only

decreases yield but also increases processing time, ultimately reducing sawmill efficiency. Similarly, the influence of log sweep has been investigated by Vital (2008) and (da Silva et al. 2021), who concluded that curved logs reduce yield by producing shorter and lower-quality boards, generating more waste, and complicating the sawing process. These findings emphasize how external defects can compromise the efficiency and profitability of hardwood processing, especially when present in combination.

Based on this context, our study focuses on evaluating the relationship between visible external defects—particularly taper, sweep, ovality, fluting, and pith eccentricity—and sawing yield in three Mediterranean hardwood species. This is especially relevant in view of the growing interest in maximizing resource efficiency from locally available timber, even when log quality is variable or sub-optimal. Riesco Muñoz et al. (2013) undertook a study in which they evaluated 46 oak trees, assigning them four quality grades. This assessment was based on the log dimensions and visible defects to determine the prediction of sawing yield. Ištvančić et al. (2011) researched the sawing yield of European walnut and European wild cherry logs in Croatia by measuring internal defects, and Karaszewski et al. (2013) scrutinized wood defects impacting the quality of beech logs, taking into consideration eleven defects. Rozas et al. (2023) estimated the yield of *Eucalyptus regnans* (F.Muell.) logs for lumber production, measuring the length and the width of radial cracks. Since the presence of some defects is intrinsic in the physiology of trees (such as a certain degree of taper, or the presence of knots related to the natural insertion of branches into the stem), they can influence the sawing yield.

Therefore, it is necessary to gather technical information regarding the yield, such as that on wood waste generation, to maximize the volume of lumber produced. For these reasons, the aims of the present work have been (i) to analyze the distribution of defects such as taper, fluting, sweep, and ovality on logs of three different wood species and different diameter classes, (ii) to evaluate the impacts of these defects on the sawing yield, and (iii) to predict sawing yield through the development of a regression model from defective logs of different diameter classes of three different wood species. In particular, this study investigates how the occurrence and intensity of geometric defects vary among olive, black locust, and chestnut logs across different diameter classes; it also examines whether and to what extent each defect contributes to the reduction of sawing yield, and whether these effects differ depending on the species. Finally, it explores the possibility of predicting sawing yield from

measurable log characteristics through a statistical modeling approach.

2 Material and methods

2.1 Study site and log sampling

This study was conducted on logs of three different hardwood species from forests and agricultural sites located in the Calabrian region (South Italy).

In order to avoid possible variations due to the use of different milling machines, as well as the operator's skill and experience, the tests were conducted in only one sawmill (Riesco Muñoz et al. 2013), considered a representative medium-sized sawmill in Southern Italy, as the average processed volume of a general sawmill is estimated to be $5000 \text{ m}^3\text{year}^{-1}$ (Giametta 2008; Proto et al. 2012). This industrial sawmill is located in the municipality of Molochio ($38^\circ 19' 5.423'' \text{ N } -16^\circ 1' 26.526'' \text{ E}$, Reggio Calabria, Italy) and produces mainly flooring strips and laths.

This study has focused on the first step of the sawmill process, wherein a vertical log band saw (SNT 1300 model, Bongioanni company, 75 kW) with 1.38 mm blade thickness converts logs into boards. Furthermore, to eliminate the possibility of yield variance in the sawing process, the sawing pattern was here predefined, and all logs were sawn into boards using the live sawing method, adapted in terms of thickness to the log dimension and the sawmill production objective. Live sawing is a fast method of breaking down the log that involves longitudinal cuts parallel to the axis of the log and parallel to each other (Ištvančić et al. 2011; Pinto et al. 2006; Ferreira et al. 2004; Popadić et al. 2014; Stängle et al. 2015; Steele et al. 1993).

Considering the availability of logs in the sawmill during this study, for each species, a minimum of 30 sample logs was selected: 30 chestnut logs, 120 olive tree logs, and 60 black locust logs. In the specific case of olive logs, the samples were obtained from the largest branches derived from extraordinary pruning activities (Mammoliti et al. 2024) and from stem logs (excluding logs that presented with holes inside). In traditional olive groves intended for oil production, trees in the study area are often not subjected to regular pruning, which results in very large and tall specimens. When pruning is eventually carried out, basal branches can reach dimensions comparable to those of stem logs and are routinely processed by sawmills. These branches, therefore, are considered log material for sawn timber production. This practice is consistent with the findings of Mammoliti et al. (2024), who investigated the wood quality differences between branches and stems in olive trees, suggesting the possibility of using branch wood to obtain products similar to those obtained with trunk wood. The

decision not to distinguish the origin of the olive logs (from stems or large branches) arises from the choice to follow the actual supply of wood from the sawmill. The logs were measured in terms of length and outside bark diameter, and then sorted into four main diameter classes: A (20–30 cm), B (30.1–40 cm), C (40.1–50 cm), and D (50.1–90 cm). At the end of the phase of sawing into boards, the moisture content of each sawn sample was determined using a digital moisture meter with two electrodes (Schaller, WLW). Diameter, length, volume, moisture content, and weight measurements were carried out on the logs selected for this study, and these data are summarized in Table 1, classifying olive, black locust, and chestnut logs into different diameter classes considering the average diameter of each log. In the case of the conspicuous number of olive logs, these were further divided into nine diameter subclasses (Table 1).

2.2 Data collection and statistical analysis

Usually, the sawing yield is calculated as the relationship between the volume of products and the volume of logs (Ištvančić et al. 2019; Li et al. 2015; Melo et al. 2019). Taking into account the possibility of having logs characterized by irregular shapes that do not favor a precise volume measure, and to guarantee a single objective measurement that is not affected by operators (Guttenberg 1960), in this study, the determination of the yield of sawed wood was based on the weights of logs and products, considering the following relationship:

$$\text{Sawing yield} = \frac{W_p}{W_l} * 100$$

Here, the following pertains:

Sawing yield = Percent yield of sawn log (%);

W_p = Weight of products (kg);

W_l = Weight of log (kg).

Operatively, the logs were first weighted using a digital floor weighing scale (model SPF, range 6000 kg × 2 kg). Then, each log was individually processed into boards during the primary sawmill process. The sawn boards were grouped by log, and each one was weighed using a portable digital floor weighing scale (model Radwag, range 60 kg × 0.02 kg). For olive species, the average board thickness was 33 mm (between 15 and 85 mm), with the greatest number of boards (almost 310 boards) being 22 mm thick. Black locust boards were on average 27 mm (between 17 and 32 mm) thick, and chestnut boards were always 27 mm thick. The lengths of the boards were set at 2.50 m, and since the boards were not edged, width oversize was not calculated. All boards obtained from each log were considered in the yield calculation, with the exception of woody material with a thickness of less than 15 mm, which was considered waste and excluded from the useful volume obtained. The European standards EN 844 (2019) and EN 1309 (EN 2018) were employed for the terminology. Four wood defects were monitored in the logs: taper, ovality, sweep, and fluting. Table 2 shows the criteria for measuring the log defects analyzed. Taper was measured

Table 1 Sawn logs’ characteristics and their distribution in diametral classes (wood logs). The table reports data collected on logs from three species (Olive, Black locust, and Chestnut), classified into diameter classes (10 cm intervals) and subclasses (5 cm intervals) and subclasses (identified by specific alphanumeric codes)

Species	Diameter class code	Subclass code	Diameter subclass (cm)	Number logs	Length (m)	Volume (m ³)	Moisture content (%)	Weight (kg)
Olive	A (20–30 cm)	A1	20–25	14	2.50	0.07 (±0.02)	30	85 (±20)
		A2	25.1–30	16	2.50	0.12 (±0.03)	30	135 (±35)
	B (30.1–40 cm)	B1	30.1–35	12	2.50	0.16 (±0.04)	40	186 (±48)
		B2	35.1–40	19	2.50	0.24 (±0.06)	40	274 (±64)
	C (40.1–50 cm)	C1	41–45	16	2.50	0.30 (±0.09)	40	340 (±106)
		C2	45.1–50	13	2.50	0.37 (±0.10)	40	420 (±116)
		D (50.1–90 cm)	D1	50.1–60	19	2.50	0.48 (±0.14)	40
	D2		60.1–70	5	2.50	0.54 (±0.08)	40	616 (±96)
	D3		70.1–90	6	2.50	0.80 (±0.29)	40	919 (±335)
Black locust	A (20–30 cm)	-	-	30	2.50	0.13 (±0.23)	35	104 (±42)
	B (30.1–40 cm)	-	-	30	2.50	0.23 (±0.04)	40	184 (±59)
Chestnut	A (20–30 cm)	-	-	30	2.50	0.14 (±0.03)	40	93 (±22)

as the difference between large-end diameter (D_1) and small-end diameter (D_2), divided by log length. Sweep was measured, identifying the maximum deviation of the center line of the log from a straight line between the two ends, divided by the log length (L). Fluting, defined as the longitudinal depression on the log, was calculated as a percentage of the length of the deeper groove (d) divided by the log diameter (D). Ovality was calculated based on both the lengths of the major (D_1) and minor (D_2) axes at the end of the log with the largest diameter. The difference, as a percentage, was divided by the thick-end diameter.

The collected data were statistically analyzed, performing descriptive statistics and Linear regression analysis with a stepwise method to investigate whether the parameters of taper, fluting, sweep, and ovality were significantly responsible for the sawing yield, applying a significance level of 0.05 ($p < 0.05$). Also included were the log volume and the mean diameter to evaluate whether the dimensional parameters could influence the yield, excluding the length since it was fixed at 2.5 m. The validity of the linear regression model was preliminarily assessed by normality tests (Shapiro-Wilk and Kolmogorov-Smirnov) on the residuals of the regressions for each class and species. Furthermore, multicollinearity among predictors was controlled using the Variance Inflation Factor (VIF), excluding variables with $VIF > 10$ and non-significant p -values from the final model to ensure robustness and stability; all analyses were performed using SPSS version 20.0 software (IBM Corp., Armonk, NY, USA).

3 Results

The investigated defects were observed in the logs with varying percentages of occurrence across species and diameter classes (Table 3). Regarding olive logs, we found that a taper defect was always present in all classes and subclasses studied, except for the A1-diameter class (20–25 cm), where 29.6% of logs belonging to this

subclass were free of taper defects. The fluting defect was observed to increase with the increase in diameter, starting from about 10% of defect presence in the A class to 95% in the D class. An opposite trend was seen for the sweep defect, which tended to decrease with the increase in diameter class. The ovality defect did not appear to be influenced by the diameter. From the investigation of defects on the logs of black locust, we found that all the logs showed a taper defect. Each log of the diameter class A (20–30 cm) exhibited ovality, and none had a fluting defect. Only 20% of the logs had sweep defects. Concerning diameter class B (30.1–40 cm), about 30% presented fluting and/or sweep defects, and almost all logs showed ovality. For the study concerning chestnut sawing yield, unfortunately we only had one diameter class available (diameter class A). Taper and ovality were the defects that were most present on the 30 chestnut logs (about 100%), with 33% of logs showing sweep defects and no logs showing a fluting defect. The distribution of the defects for the olive logs is shown in Table 4; in detail, we can see how many types of defects simultaneously affected the logs, distinguished by diameter classification. A1 was the only diameter subclass free of defects, representing 7.1% of the logs. The higher concentrations of defects detected at the same time on the same log were identified in the D3 and C1 subclasses, with 80% of logs examined in the D3 subclass having three types of defects, and about 31% of the logs investigated in the C1 subclass having four types of defects. Concerning the simultaneous presence of more than one singular defect in black locust logs, both diameter classes (A and B) showed that no log was without defects or had only one defect; 80% of logs in diameter class A were affected by two defects, and 20% were affected by three defects at the same time, while no log showed four defects. The diameter class B contained 63%, 20%, and 17% of logs with two, three, and four defects simultaneously. All the chestnut logs were affected by at least one defect (one log), two defects (19 logs) or three defects (10 logs) at the same time (Table 4).

Table 2 Defects evaluated in the sawing yield calculation, indicating for each the measuring instruments used and the parameters recorded, along with the calculation formula

Defects	Equipment	Parameters	Unit	Formulas
Taper	Measurement tape, caliper	Length (L) Thick-end diameter (D_1) Thin-end diameter (D_2)	cm/m	$T = \frac{(D_1 - D_2)}{L}$
Fluting	Measurement tape, caliper	Diameter (D) Depth (d)	%	$F = \frac{d}{D} * 100$
Sweep	Measurement tape, caliper	Length (L) Arrow deflection (a)	cm/m	$S = \frac{a}{L}$
Ovality	Caliper	Thick-end diameter (D_1) Thin-end diameter (D_2)	%	$O = \frac{(D_1 - D_2)}{D_1} * 100$

Table 3 Frequency (%) of four evaluated defects (taper, fluting, sweep, and ovality) observed in logs, distinguished by tree species and diameter classes

	Logs				Taper defect	Fluting defect	Sweep defect	Ovality defect
	Diameter class code	Subclass code	Diameter (cm)	Tot. logs	Logs (%)	Logs (%)	Logs (%)	Logs (%)
Olive	A (20–30 cm)	A1	20–25	14	71.4	14.3	50.0	71.4
		A2	25.1–30	16	100	6.30	68.8	93.8
	B (30.1–40 cm)	B1	30.1–35	12	100	25.0	75.0	91.7
		B2	35.1–40	19	100	36.8	57.9	89.5
	C (40.1–50 cm)	C1	40.1–45	16	100	75.0	43.8	68.8
		C2	45.1–50	13	100	84.6	30.8	84.6
	D (50.1–90 cm)	D1	50.1–60	19	100	84.2	31.6	94.7
		D2	60.1–70	5	100	100	20.0	80.0
		D3	70.1–90	6	100	100	17.0	83.0
Black locust	A (20–30 cm)	-	20–30	30	100	0.00	20.0	100.0
	B (30.1–40 cm)	-	30.1–40	30	100	30.0	33.0	90.0
Chestnut	A (20–30 cm)	-	20–30	30	100	0.00	33.0	97.0

Table 4 Percentage of logs that simultaneously exhibit one, two, three, or all four of the evaluated defects (taper, fluting, sweep, ovality) in the three examined wood species and for each diameter class

	Logs				Defect free	1 defect	2 defects	3 defects	4 defects
	Diameter class code	Subclass code	Diameter (cm)	Tot. logs	Logs (%)	Logs (%)	Logs (%)	Logs (%)	Logs (%)
Olive	A (20–30 cm)	A1	20–25	14	7.1	14.3	42.9	35.7	0.00
		A2	25.1–30	16	0.00	6.30	18.8	75.0	0.00
	B (30.1–40 cm)	B1	30.1–35	12	0.00	0.00	33.3	41.7	25.0
		B2	35.1–40	19	0.00	0.00	31.6	52.6	15.8
	C (40.1–50 cm)	C1	40.1–45	16	0.00	6.30	31.3	31.3	31.3
		C2	45.1–50	13	0.00	0.00	15.4	69.2	15.4
	D (50.1–90 cm)	D1	50.1–60	19	0.00	0.00	5.30	78.9	15.8
		D2	60.1–70	5	0.00	0.00	20.0	60.0	20.0
		D3	70.1–90	6	0.00	0.00	20.0	80.0	20.0
Black locust	A (20–30 cm)	-	20–30	30	0.00	0.00	80.0	20.0	0.00
	B (30.1–40 cm)	-	30.1–40	30	0.00	0.00	63.3	20.0	16.7
Chestnut	A (20–30 cm)	-	20–30	30	0.00	3.30	63.3	33.3	0.00

Descriptive statistics of logs for defects and sawing yield, distinguished by species and diameter classes, are reported in Table 5. Two different trends emerged for olive logs. For taper and fluting, the distribution among the diameter classes of the logs was found to increase as the diameters increased, while an opposite trend was observed for the sweep and ovality defects.

In black locust, all defects increased as the diameter increased, affecting the sawing yield and maintaining it at around 70% in the two diameter classes.

Compared to the other species, chestnut logs presented ovality as the predominant defect, with the highest average value (12 cm). Despite this, with the same diameter class, ovality did not appear to reduce sawing yield, which was approximately 69.5%, similar to that for black locust.

Table 5 Descriptive statistics for logs from the three tree species investigated (Olive, Black locust and Chestnut) categorized by diameter class. The analyzed parameters include taper, fluting, sweep, ovality, and sawing yield

Species	Diameter class code	Parameter	Minimum	Maximum	Mean	Std. Deviation
Olive	A (20–30 cm)	Taper (cm/m)	0.00	6.00	1.53	1.38
		Fluting (%)	0.00	26.1	1.88	6.29
		Sweep (cm/m)	0.00	12.9	3.44	3.61
		Ovality (%)	0.00	21.0	9.29	6.70
		Sawing yield (%)	50.7	71.6	64.8	5.25
	B (30.1–40 cm)	Taper (cm/m)	0.00	6.00	2.32	1.70
		Fluting (%)	0.00	46.2	7.03	12.3
		Sweep (cm/m)	0.00	11.3	4.14	3.54
		Ovality (%)	0.00	3.85	2.81	0.99
		Sawing yield (%)	60.6	77.3	66.8	3.60
	C (40.1–50 cm)	Taper (cm/m)	0.00	11.0	3.79	3.19
		Fluting (%)	0.00	50.3	15.1	13.2
		Sweep (cm/m)	0.00	7.74	2.11	2.87
		Ovality (%)	0.00	3.13	1.95	1.16
		Sawing yield (%)	55.3	71.2	65.4	4.37
	D (50.1–90 cm)	Taper (cm/m)	0.00	19.0	5.93	4.59
		Fluting (%)	0.00	51.7	20.3	11.3
		Sweep (cm/m)	0.00	14.6	2.08	3.88
		Ovality (%)	0.00	2.94	1.73	0.69
		Sawing yield (%)	50.8	71.5	64.9	5.08
Black locust	A (20–30 cm)	Taper (cm/m)	0.00	1.90	0.97	0.39
		Fluting (%)	0.00	0.00	0.00	0.00
		Sweep (cm/m)	0.00	4.55	0.63	1.38
		Ovality (%)	2.03	13.5	6.41	2.99
		Sawing yield (%)	65.6	74.4	69.8	2.27
	B (30.1–40 cm)	Taper (cm/m)	0.20	4.20	1.82	1.05
		Fluting (%)	0.00	6.00	0.90	1.77
		Sweep (cm/m)	0.00	5.20	1.29	1.95
		Ovality (%)	0.00	26.5	11.02	8.09
		Sawing yield (%)	65.6	73.6	70.2	2.05
Chestnut	A (20–30 cm)	Taper (cm/m)	0.00	3.70	1.58	1.14
		Fluting (%)	0.00	0.00	0.00	0.00
		Sweep (cm/m)	0.00	1.85	0.38	0.61
		Ovality (%)	3.45	21.4	12.8	4.58
		Sawing yield (%)	57.6	76.0	69.5	4.32

A statistical analysis of the olive wood data highlighted that the sawing yield was not significantly affected by the diameter class ($p > 0.05$), divided into nine subclasses. From the analysis of the data collected during the sawmill surveys aggregated into the four classes of diameter (A—20–30 cm, B—30.1–40 cm, C—40.1–50 cm, and

D—50.1–90 cm), the yield of sawn olive logs increases with the increase in the volume and diameter classes of the logs.

From the stepwise regression analysis of data not distinguished into diameter classes (Table 6), in which the sawing yield was assumed as the dependent variable,

Table 6 Results of linear regression analysis performed separately for each wood species, using sawing yield as the dependent variable. The selected predictors include mean diameter (D_mean), log volume (V_log), taper, fluting, sweep, and ovality defects

Species		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Olive	(Constant)	63.680	1.498		42.523	0.000
	D_mean (cm)	0.212	0.050	0.645	4.227	0.000
	V_log (m ³)	-7.990	2.973	-0.362	-2.687	0.008
	Taper (cm/m)	-1.198	0.093	-0.879	-12.916	0.000
	Fluting (%)	0.011	0.024	0.031	0.455	0.650
	Sweep (cm/m)	-0.007	0.079	-0.006	-0.094	0.925
	Ovality (%)	-0.169	0.068	-0.169	-2.473	0.015
Black locust	(Constant)	71.866	4.547		15.804	0.000
	D_mean (cm)	-0.067	0.284	-0.160	-0.237	0.813
	V_log (m ³)	8.789	23.714	0.252	0.371	0.712
	Taper (cm/m)	-1.057	0.439	-0.443	-2.411	0.019
	Fluting (%)	0.109	0.238	0.068	0.459	0.648
	Sweep (cm/m)	0.118	0.236	0.094	0.498	0.621
	Ovality (%)	-0.021	0.072	-0.065	-0.293	0.771
Chestnut	(Constant)	51.044	36.823		1.386	0.178
	D_mean (cm/m)	1.923	2.868	1.069	0.670	0.509
	V_log (m ³)	-209.400	280.737	-1.188	-0.746	0.463
	Taper (cm/m)	-2.530	0.564	-0.668	-4.484	0.000
	Sweep (cm/m)	-1.893	0.964	-0.265	-1.964	0.061
	Ovality (%)	0.115	0.106	0.122	1.082	0.290

D_mean = mean diameter of log; V_log = volume of log. Unstandardized coefficients (B) indicate the expected change in the dependent variable for a one-unit change in the predictor. Standardized coefficients (Beta) express this relationship in terms of standard deviations, allowing comparison of the relative importance of predictors

we found that among the independent variables (taper, fluting, sweep, ovality, volume of log (V_log_m³) and mean diameter of log (D_mean)), the dimensional variables, and most notably the average diameter, generally positively affect the yield, while the volume of log significantly decreases the sawing yield. Among the defects, the results of the analysis highlight that the taper, and, to a small extent, the ovality, can reduce the sawing yield significantly and can slightly reduce the ovality defect.

More specifically, to identify the variables that manifest significant differences at $p < 0.05$ in sawing yield, the linear regression analysis conducted by sorting the data into four diameter classes (A, B, C, D) exhibited that the sawing yield of olive log can be predicted with a precision ranging from 53 to 97% for diameter classes A, C, and D, while for class B, the predictive model of sawing yield is not applicable ($p > 0.05$) (Table 7).

Table 7 Linear regression models used to predict the sawing yield as the dependent variable, developed separately for each wood species and divided by diameter classes. Each model includes the regression equation, the statistical significance (Sig.), and the coefficient of determination (R²)

Species	Diameter class code	Linear regression model	Sig	R ²	Eq
Olive	A (20–30 cm)	Sawing yield (%) = 59.62 – 2.03 * T – 0.27 * O	0.005	0.530	(1)
	B (30.1–40 cm)	Sawing yield (%) = 54.01 – 0.87 * T	0.072	0.361	(2)
	C (40.1–50 cm)	Sawing yield (%) = 62.52 + 0.29 * D_mean – 14.58 * V_log – 1.36 * T	0.000	0.968	(3)
	D (50.1–90 cm)	Sawing yield (%) = 59.01 + 0.26 * D_mean – 6.83 * V_log – 1.04 * T	0.000	0.903	(4)
Black locust	A (20–30 cm)	Sawing yield (%) = 92.69 – 4.63 * T	0.009	0.453	(5)
	B (20–30 cm)	Sawing yield (%) = 94.55 – 0.73 * D_mean – 1.93 * T	0.000	0.679	(6)
Chestnut	A (20–30 cm)	Sawing yield (%) = – 2.53 * T	0.000	0.775	(7)

Note: T (cm/m), Taper defect; O (%), Ovality defect; D_mean (cm), mean diameter of log; V_log (m³), volume of log

From the stepwise regression analysis of black locust logs not distinguished into diameter classes, the sawing yield exhibited significant differences in terms of taper defect ($p < 0.05$) (Table 6). Linear regression analyses conducted by sorting the data into two diameter classes (A, B) showed that the sawing yield can be predicted with 45% and 68% precision for diameter classes A and B, respectively (Table 7), when knowing the taper value for diameter class A and the taper and mean diameter values

for diameter class B. The predictive model for calculating the yield of sawn chestnut logs through regression analysis is expressed in Eq. (7), where, by inserting the value of the taper, it is possible to achieve a model accuracy of 78%.

Figures 1, 2, and 3 represent the influence of taper defects on the sawing yield for the olive, black locust, and chestnut logs, respectively. Although the taper was found to be a significant statistical factor affecting the sawing

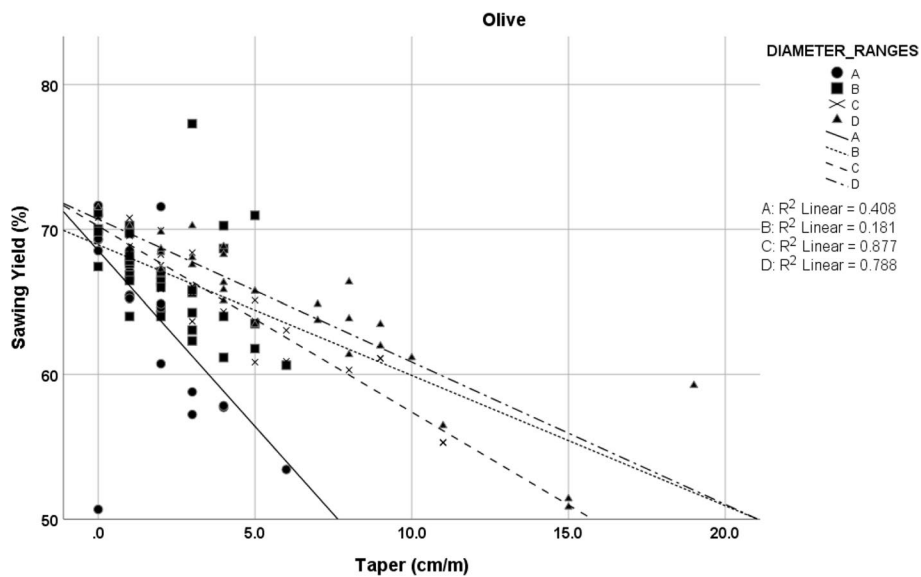


Fig. 1 Linear correlation between taper defect and sawing yield for olive logs divided into four diameter classes: A (20–30 cm), B (30.1–40 cm), C (40.1–50 cm), and D (50.1–90 cm)

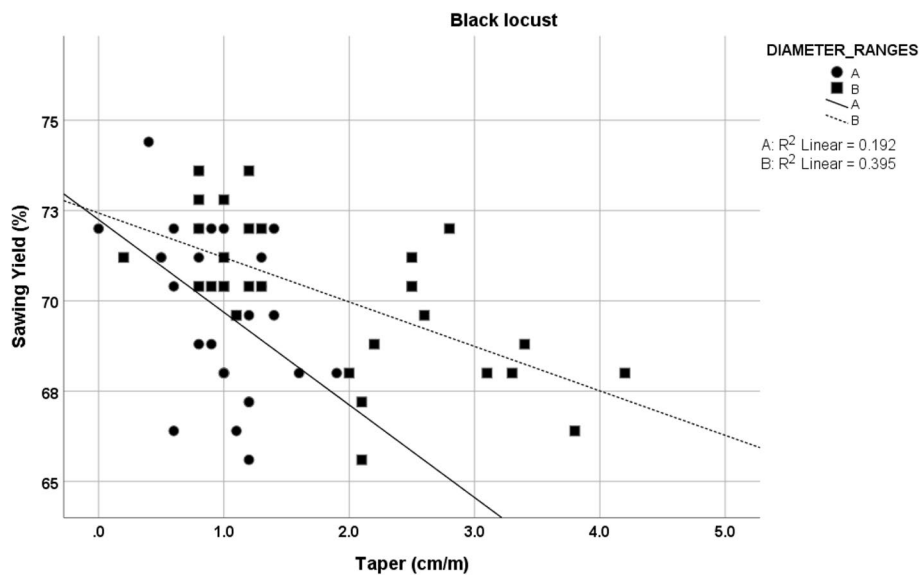


Fig. 2 Linear correlation between taper defect and sawing yield for black locust logs, divided into two diameter classes: A (20–30 cm), B (30.1–40 cm)

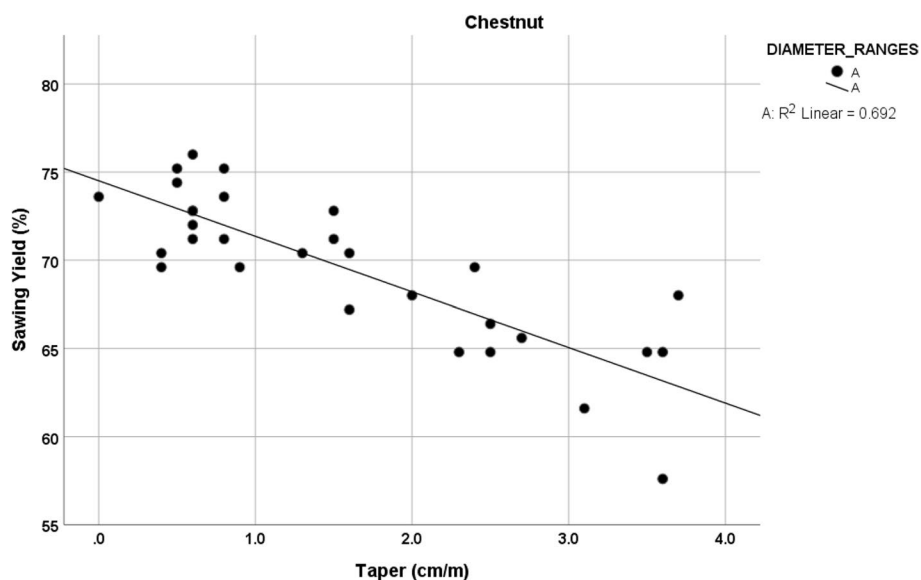


Fig. 3 Linear correlation between taper defect and sawing yield for chestnut logs belonging to diameter class A (20–30 cm)

yield for all species investigated, regarding the olive logs, it was found to be an excellent parameter for predicting sawing yield in the largest diameter classes (C and D) and a good predictor in the case of chestnut, while for the smallest olive diameter classes (A and B) and for the black locust logs, the R^2 between sawing yield and taper defect was less than 0.5.

Normality tests (Shapiro-Wilk and Kolmogorov-Smirnov) on the regression residuals for each class and species showed acceptable significance values ($p > 0.05$) in most cases, supporting the normality of the residuals and therefore the validity of the basic assumption of the model.

4 Discussion

The findings that the dimensional variables such as mean diameter and log volume generally affect the sawing yield align with the observations of Melo et al. (2019), who noted that higher yields associated with larger diameters are not always guaranteed in cases where the diameter cannot be fully utilized or where logs present significant defects. Although mean diameter and volume are mathematically correlated due to the fixed log length, their effects may reflect different aspects of log morphology—particularly in the presence of shape irregularities such as taper or fluting—that can influence sawing efficiency. This exception was also evident in the present study, emphasizing the critical role of log quality in optimizing yield. The results suggest that the sweep and ovality defects tend to be less marked in logs with large diameters. Logs with smaller diameters instead show more pronounced taper and fluting defects. Compared to olive and

chestnut logs, black locust has been found to be less sensitive to defect variability, maintaining stable yield across logs with minor structural irregularities. Among the observed defects, taper was the most impactful, although less so than for olive logs. Among the defects, taper had the most important effect on sawing yield among the four types of defect. This result could be linked to the fact that taper is the most widespread type of defect among the examined logs. The other defects, generating considerable waste but only for a small number of logs, resulted in limited impact on the sawing yield. Furthermore, in many cases, the concomitant presence of multiple defects on the same log may have led to a compounded negative effect on sawing yield, making it difficult to isolate the impact of individual defects and potentially underestimating their specific influence. Moreover, olive tree logs often do not have regular cylindrical shapes, so high volumes do not always correspond to high levels of sawing yield. In order to obtain commercially marketable assortments, the logs must undergo several cuts that will inevitably produce a quantity of waste wood that is greater the further the log moves away from the ideal cylindrical shape, suggesting that yield could be improved by selecting logs with fewer shape deformities. The inverse relationship between taper and yield was particularly evident, demonstrating that taper limits the number of boards obtainable, especially in smaller-diameter classes.

The choice of the type of cut could also have determined the influence of different defects on the sawing yield. In fact, by proceeding with cuts parallel to the longitudinal axis of the logs—live sawing—at higher values of average diameter, higher sawing yields are obtained.

The tapering defect significantly reduces the yield, which reduces one of the two extreme diameters of the log, resulting in a reduction in the number of obtainable boards. Concerning the type of cutting, Vilkovský et al. (2023) compared three log-sawing patterns for beech logs (*Fagus sylvatica* L.) through-and-through sawing, cant sawing, and quarter sawing, and they found that the through-and-through sawing generates a sawing yield slightly lower than cant sawing (72.3% and 78.5%, respectively). Moreover, the sawing yield obtained by Smajić et al. (2021) adopting the live sawing pattern for pedunculate oak (*Quercus robur* L.) logs (around 57.3%) is in line with the results of this research, Vilkovský et al. (2023) assuming that the cause could be linked to the greater tapering of the logs cut using the through-and-through sawing pattern. Overall, live sawing in this study provided stable yields, though it generated more waste in logs with pronounced taper.

To the best of the authors' knowledge, there are no scientific studies evaluating sawing yields for the species considered in this study, but the values obtained reflect what has been found in research carried out over the last 20 years on hardwoods. In general, sawing yields for hardwood species range between 63 and 69% (Johansson and Sandberg 2010). Specifically, yields of about 60–62% have been reported for oak wood (Nylinder and Woxblom 2005; Popadić et al. 2014; Riesco Muñoz et al. 2013; Selver et al. 2023), while teak wood has shown yields around 68% (Bouaphavong et al. 2023). An interesting comparison emerges, in particular, with the results obtained by Riesco Muñoz et al. where both studies identified the diameter of the logs as a key variable for predicting the sawing yield, suggesting that large logs allow for a higher volumetric recovery. However, the comparison between the two studies highlights that the type of sawn product also influences the final yield. In the oak study, the final products were quartersawn planks, which require specific dimensions and quality, while in our case the focus on boards contributed to a higher average yield (about 70%).

The results were intermediate when compared to eucalyptus wood for which Batista et al. (2015) found in their research a saying yield of about 53–54%. It should be considered that the authors had only monitored small-diameter logs (25–30 cm), and the cuts were performed with a circular saw, which, being equipped with a toothed disc that determines a greater cutting thickness than a band blade, causes a greater production of sawdust, with a consequent reduction in yield. The use of suitable cutting technology, such as the band saw used in this study, also facilitates greater yield efficiency, especially for larger

diameters. This research suggests that, despite the olive, black locust, and chestnut species being less commonly studied, they offer a competitive yield potential that reinforces their suitability for use in commercial sawing applications. Other studies have also observed that the presence of defects negatively affects yield (Carpenter et al. 1989; Ištvančić et al. 2011; Missanjo and Magodi 2015).

Riesco Muñoz et al. (2013) observed that defects other than taper, such as an increase in the amount of bark and heartwood, especially in lower quality logs, had a greater impact on overall yield, reducing the quality of timber intended for structural uses, such as quartersawn planks. This difference reflects not only species-specific properties but also product requirements: our study focuses on boards, which tolerate a greater variety of defects, while in the study by Riesco Muñoz et al. (2013), which focused on quartersawn planks, the defects, as well as the cutting method, must be more rigorously controlled, since they directly affect the structural use of the wood. Some scientific works have observed how the cutting patterns influence the sawing yield (Wang SJ 1988; Popadić and Todorović 2009; Popadić et al. 2014; Missanjo and Magodi 2015). In several cases, the decision regarding the cut is random, leading to a low yield of sawn wood (Biasi and Rocha 2007; Buehlmann and Thomas 2002). The choice of an appropriate log breakdown method for each species is necessary to valorize timber and optimize the production at the sawmill (Bonato 2017; Popadić et al. 2014; Santos et al. 2019). Popadić and Todorović (2009) and Popadić et al. (2014) observed that live sawing has a negative impact on the yield, but the results obtained by Riesco Muñoz et al. (2013) confirm its effectiveness in maximizing yield, giving in the case of oak, the best results for large logs, with a maximum yield of 55.3%. In this work, live sawing proved to be especially useful for species such as chestnut and black locust, ensuring greater stability in yield, helping optimize the production of boards, a product with less stringent requirements in terms of size and quality than those analyzed by Riesco Muñoz et al. (2013). A live sawing performed parallel to the trunk axis, as was used in the present work, could lead to an increase in the sawing yield for the raw product (sawn boards), as was also observed by Klement et al. (2023) for hardwood.

5 Conclusion

This study emphasizes the critical role of intrinsic log characteristics, including dimensions and defect presence, in influencing sawing yield for three Mediterranean hardwood species. The identification of taper as the most impactful defect—particularly for olive and chestnut logs—provides valuable practical guidance for sawmills aiming to improve processing efficiency by selecting logs

with fewer shape deformities. The stable and relatively high yields observed in black locust and chestnut, comparable to those of more traditionally exploited hardwoods, highlight their significant potential for expanding local timber supply chains and reducing dependence on imported wood. The findings contribute to a better understanding of how defect types variably affect yield, suggesting the need for refined quality assessment protocols that could be integrated into log grading and sorting processes. Moreover, these results encourage the adoption of advanced technologies such as computer vision and AI-driven predictive models, which have the potential to revolutionize log evaluation and optimize sawing operations, ultimately reducing waste and enhancing the sustainability of hardwood production in Mediterranean forestry.

Looking ahead, future research should investigate the influence of branch-related defects in addition to those occurring on the main stem, especially for olive logs where the distinction between stem and branch wood may significantly affect defect development and yield outcomes. Addressing this gap could provide deeper insights into the variability of wood quality in olive and improve selection criteria tailored to this species. Expanding this research to include a wider range of defects—such as knots, cracks, and insect damage—and incorporating other Mediterranean hardwood species will further support the development of region-specific processing guidelines. By maximizing the commercial value of local wood resources through informed log selection and advanced processing methods, this work contributes to fostering a more circular, efficient, and environmentally sustainable forestry economy in the Mediterranean basin, aligned with increasing market demands and climate change challenges.

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Authors' contributions

Conceptualization: Maria Francesca Cataldo, Andrea Rosario Proto, Salvatore Francesco Papandrea; methodology: Maria Francesca Cataldo, Angelo Mammoliti, Andrea Rosario Proto, Salvatore Francesco Papandrea; validation: Andrea Rosario Proto; formal analysis: Maria Francesca Cataldo, Andrea Rosario Proto, Salvatore Francesco Papandrea; investigation: Angelo Mammoliti, Andrea Rosario Proto; resources: Andrea Rosario Proto; data curation: Maria Francesca Cataldo, Angelo Mammoliti, Andrea Rosario Proto, Salvatore Francesco Papandrea; writing—original draft preparation: Maria Francesca Cataldo, Andrea Rosario Proto, Salvatore Francesco Papandrea; writing—review and editing: Maria Francesca Cataldo, Andrea Rosario Proto, Salvatore Francesco Papandrea; visualization: Maria Francesca Cataldo, Andrea Rosario Proto; supervision: Angelo Mammoliti, Andrea Rosario Proto; project administration: Andrea Rosario Proto; funding acquisition: Andrea Rosario Proto. All authors have read and agreed to the published version of the manuscript.

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Data availability

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Code availability

No custom code or software was developed for this study.

Declarations

Ethics approval

Not applicable.

Consent for publication

Not applicable.

Competing interests

No potential conflict of interest was reported by the author(s).

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