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Review paper

# Gaps and perspectives for the improvement of the sweet chestnut forest-wood chain in Italy

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**ABSTRACT** The paper provides a summary regarding the current state of silviculture and the use of sweet chestnut wood (*Castanea sativa* Mill.) in Italy. Existing opportunities for chestnut silviculture are very promising because sweet chestnut covers nearly 800,000 hectares in Italy, representing almost 2.6% of the total area of the country, including 7.5% of national forest areas. In some geographic areas, especially in central-southern Italy, sweet chestnut is the only driver of the sawmill economy. In Italy, this species is typically harvested to produce solid beams and poles. In the field of load-bearing structures, research and innovation in silviculture have provided solutions to the growing use of industrial technologies, and sweet chestnut has become integrated into European standards with the same relevanceas the most commonly most used wood species, such as Norway spruce. However, diversification in wood products is lacking in regions that produce sweet chestnut, as the sawmills tend to be very chestnut-centric, and in terms of the types of final products sweet chestnut is applied to. The typical end uses for sweet chestnut represents a major weakness associated with the massive exploitation of chestnut wood. In addition, the production of sawmills in Italy has decreased recently due to the crisis-driven reductions inactivity. This transition has affected the traditional building sector. The most common wood quality defects associated with sweet chestnut, which limit the use of this species for other wood products, are well known by producers. To boost the demand for this wood, efforts must be made to identify more versatile uses for this wood, promoting differential forest management systems to obtain stems that can be utilised in other types of final products. A list of possible actions is considered to increase the applications for this species, which represents one of the best opportunities to develop a short supply chain.

**KEYWORDS**: coppice, short supply chain, bioeconomy, wood products, wood quality, tannins.

## Introduction

Sweet chestnut (*Castanea sativa* Mill.) plays an important role in the Italian forestry industry, both due to its extensive coverage throughout the country (800,000 hectares), covering nearly 2.6% of the total area in Italy, including 7.5% of the national forest area (Tabacchi et al. 2005, RRN 2014-2020). In Italy, sweet chestnut coppices include 589,362 ha, 15,506 ha sweet chestnut high forests intended for fruit production, and 147,568 ha grown for timber production (Manetti et al. 2017). This species grows along a geographical gradient, from the southern to northern regions, with a high production value. In some central-southern regions, sweet chestnut is the only driver of the sawmill economy. Despite the remarkable wood quality characteristics associated with this species, including beneficial mechanical properties relative to its weight, aesthetic appeal, and durability, for technical and economic reasons, in Italy the sweet chestnut have failed to reach the full potential for use.

Recently, the need to implement a short supply chain has been increased; currently, this principle is applied to the production of biomass for energy purposes (Becagli et al. 2010, Delfanti et al. 2014, Paletto et al. 2019, Pieratti et al. 2020, Maesano et al. 2014). Achieving a short supply chain for woodworking is more difficult because the chain is much more branched (Mirabella et al. 2014), and certain technical requirements must be met, particularly for wood used in structural applications. These technical requirements cannot always be fulfilled by sweet chestnut. Companies must sustain certain costs to obtain European Technical Approval (ETA). Although sweet chestnut wood has been successfully incorporated into the European criteria that must be satisfied for structural purposes, the process for sweet chestnut started later than that for Norway spruce. The chestnut industry has had to recover lost time because some traditional methods of woodworking (i.e. Uso Fiume) were not considered in the European standards because they are traditions associated with specific regions of Italy. Furthermore, chestnut has attracted less economic interest because it currently occupies a relatively restricted market niche.

In Italy, the areas potentially devoted to timber production often display weaknesses in the socio-economic structure, that partially compromise the effectiveness of the forest management. These problems include the high amount and the fragmentation of private ownerships, the lack of coordination and corporate association among operators, the high processing and personnel costs with respect

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to the produced value, the lack of clear silvicultural objectives and management strategies, the lack of information among professionals about positive characteristics and opportunities related to the coppice management (Manetti et al. 2020). All this leads to an insufficient and inconsistent supply of quality assortments of local origin; consequently most companies, especially medium and large ones, use imported timber.

A short wood-supply chain has several advantages, including the reactivation of silviculture practices to produce wood for different end uses (Romagnoli et al. 2019). Short supply chains can also be used to bolster regional economies. Species used in short supply chains sometimes show better characteristics than would typically be expected (De Angelis et al. 2018, Romagnoli et al. 2015) due to advances in wood modifications (Romagnoli et al. 2015). The present study evaluates and briefly discusses the real strengths and weaknesses of the sweet chestnut timber chain in Italy, suggesting possible improvements to achieve ecological and economic sustainability goals for the whole sector, including the efficient application of the concept of the short-supply chain, based on the most recent trends.

## Chestnut forest management

The majority of Italian sweet chestnut stands (91%) are concentrated in eight regions (Tab. 1) of the 21 italian regions (Tabacchi et al. 2005, RRN 2014-2020). The most prevalent management strategy for timber production is the use of coppice (75.2%), with a clear-cutting at the end of rotation and standards released. The rotation length and number of standards to be released are determined by regional regulations; the minimum allowable rotation length ranges from 8 to 15 (Tab. 1). The Regional Forest Regulations typically specify the minimum number of standards to be released, which can range from 30 to 80 units per hectare. The size of a regulated forest compartment ranges from 5 ha to 20 ha on average. Thinning is not prescribed by regional laws. Tab. 1 illustrates the basic characteristics of the selected management regulations that are currently promoted by regional authorities in Italy. These examples typify the lack of national alignment regarding the regulation of sweet chestnut forestry management systems.

Standards may have twice (2t) or three times (3t) the rotation age of shoots, although rotation ages of 3t have become increasingly rare in recent decades. According to regional rules, standards should be selected among the dominant trees, including those of gamic origin, although the gamic regeneration in a sweet chestnut coppice tends to be rare due to the dense canopy cover, which represents a powerful phenotypic structure (Manetti and Amorini 2012).

**Figure 1** - A) Shoot released in the stool B) Standard born from seed (gamic origin).


The ecological and functional roles of standards have been recently subject to inherent debate because the presence of standards has been proven to be unnecessary for the survival of the sweet chestnut coppice. Some authors (Manetti and Amorini 2012, Marcolin et al. 2020) indicated that standards might negatively affect the development of the coppice stand, increasing shoot mortality and limiting the diameter growth, socially disqualifying the shoots and depressing the sprouting by the stools. The only dimension that was shown to be positively influenced by the presence of standards was the average height of the shoots. Based on these findings, new experiments examining the effects of grouped standards can be performed (for extensive references, Tab. 2).

**Table 1** - Rotation lenght of sweet chestnut coppices in Italy according to the Forestry regulations of the regions with greater chestnut area (from Manetti et al. 2017, modified).

| Region | Chestnut area(ha) | Min. rotation age (year) | Max. rotation age (year) | Standards to release (N° ha−1) | Max extension of cutting area (ha) | Regional forest prescription |
|---|---|---|---|---|---|---|
| Piedmont | 169,075 | 10 | N.A. | grouped | 5 | R.L. 2011 |
| Tuscany | 156,869 | 8 | 50 | 30 | 20 | R.L. 2003 |
| Liguria | 110,278 | 12 | N.A. | 60 (optional) | N.D. | R.L. 22/01/1999 |
| Lombardy | 82,782 | 15 | N.A. | 50 | 10 | R.L. 2007 |
| Lazio | 35,003 | 14 | 35 | 30 | 20 | R.L. 7/2005 |
| Campania | 53,200 | 12 | N.A. | 30 | N.D. | R.L. 11/96 updated in 2017 |
| Calabria | 69,370 | 14 | 35 | 30 | 10 | R.L. 2011 |

In contrast, some forest owners and logging companies consider standards to represent an important component of sweet chestnut management, necessary to obtain beams and boards of larger sizes at the end of the coppice rotation, and to diversify the wood products for which sweet chestnut is used, which can include poles and lumber. One of the problems associated with the use of timber obtained from standards is a defect known as ring shake, which is a predisposition for the wood to cracking along the ring when internal growth-induced tensions are released, such as when the tree falls or during the subsequent drying process (Fonti et al. 2002, Mutabaruka et al. 2005, Becagli et al. 2006, Spina and Romagnoli 2010, Romagnoli and Spina 2013, Romagnoli et al. 2014).

Alternative forestry techniques can be applied in place of short rotation to diversify and improve wood products, enhance the protective function, contribute to environmental and biodiversity conservation, and maintain the social component and cultural heritage of rural areas. They are characterised by an extension of the rotation time (up to 30–50 years vs 8–15 for traditional coppice with standard) and the early (8–12 years) and frequent thinning (every 7–10 years) of stands to allow the regular growth of released shoots (Manetti et al. 2009, Manetti et al. 2017). In particular, single tree-oriented silviculture can maximise the potential of both the growing location and the individual trees, due to the early selection of a low number of future trees (80–150 per hectare) whose crown is completely free from the primary competitors on the dominant layer, whereas no treatment is performed for the remaining stand. Subsequent thinning is performed to permit free grown growth.

Longer rotation can be applied also through stand silviculture characterised by gradual from below thinning throughout the stand. The guidelines regarding the latter forestry techniques recommend the early and frequent thinning to allow sun-driven and fast-growing species such as the sweet chestnut to constantly produce a well-developed dominant canopy layer (Manetti et al. 2009).

## Forest owners and wood processing companies

As it was introduced, most sweet chestnut forests are privately owned (80%), resulting in forests that are overly fragmented and organised into relatively small parcels, approximately 1.5 ha on average. Association are relatively scarce, making it difficult to plan the management and adopt common interest policies and resulting in the production of an insufficient and inconsistent supply of local, quality materials (Gajo and Marone 2000). These conditions are highly limiting for the adoption of sweet chestnut by industries that require abundant and well regulated wood supply: however, small- and medium-sized processing companies have survived over time, especially when they produce wood for use in structural building applications.

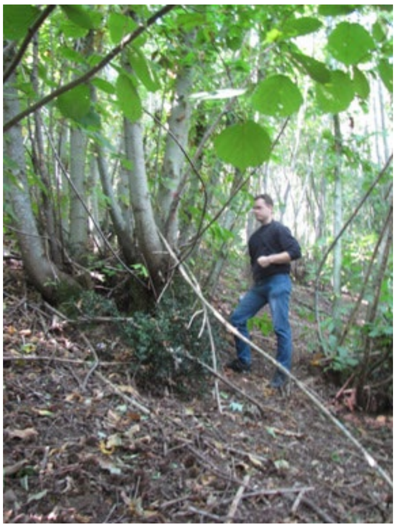
Traditionally, standing forests are sold at the end of the rotation period, for both private and public owners. Because of the negative stumpage price, owners rarely perform thinning. One potential solution

**Table 2** - Basic comments on standard release in sweet chestnut coppice.

| Author/s | Results |
|---|---|
| Merendi 1942 | "… even if the standards are completely missing, there is no fear that thinning phenomena will be known, as it is well known the exceptional vitality of this wonderful plant that emits stool even when it is cutted in a state of extreme old age". La Rivista forestale Italiana 1-3: 33–36. |
| Corona et al. 1986 | "…too high number of standards damage coppice development". Annali Accademia Italiana Scienze Forestali 35: 123–158. |
| Zanzi Sulli et al. 1993 | "…until the end of 1800 the standards function was essentially linked to the production of lumber or fruit and branches for animal husbandry". Rivista di Storia dell'Agricoltura 1: 109–121. |
| Zanzi Sulli 1995 | "…the issue of excessive standards is not the result of refining research over the time, but rather the regulatory response to political, social and often also the emotional demand of public opinion". Sherwood 7: 7–11. |
| Bianchi et al. 2009 | "…30-50 aged standards can advertisely affect the growth of the future coppice". ARSIA, Tuscany Region, Florence. |
| Fiorucci 2009 | "…standards represent the emblematic case of how the scientific world has failed to adequately support to the political one and to have a consistent impact on sectorial legislation." Forest@ (6): 56–65. - doi: 10.3832/efor0572-006 |
| Manetti and Amorini 2012 | "…the coppice in the absence of standards is not only more productive but also shows greater efficiency, stability and soil coverage …" Forest@ 9: 281–292 |
| Marcolin et al. 2020 | "..... the presence of standards did not benefit regeneration. Rather, it displayed a marked depressive effect on the growth rate of young chestnut seedlings ........" Forest Ecology and Management 472: 118273 |

to make thinning an attractive option, is to grant chestnut coppice compartments to logging companies which would thus stimulated to perform pre-commercial thinnings in order to obtain higher quality timber at the end of rotation. Sweet chestnut forests are sometimes poorly tended because they are located within designated protected areas which may be subjected to stricter regulations, and there is evidence of the abandonment of sweet chestnut stands due to the lack of interest from private owners. The lack of good silvicultural techniques has frequently resulted in coppices with a high density of dead standing shoots which increases the risk of wildfire. The presence of many stumps too high above the ground is also a sign of a lack of good management practices, and, which make harvesting and thinning procedures much more difficult (Fig. 2).

**Figure 2 -** Chestnut stumps above the ground level.



## Stand productivity

Inventory data (Tabacchi et al. 2005) has indicated that sweet chestnut as a very high production potential in Italy, which is currently estimated at approximately 140 million $m^3$ (177 $m^3$ $ha^{-1}$), with a current increment of 6.3 $m^3$ $ha^{-1}year^{-1}$, on average (Tab. 3). Sweet chestnut is generally considered to be highly productive under optimal environmental conditions, comparable with fast-growing species. In the Cimini Mountains in Lazio region, on the most fertile locations, a mean increment of 20 $m^3$ $ha^{-1}$ can be achieved at ages of 15–16 years (Cantiani 1965). The distribution of wood volume in assortments attached to the yield table reflect the market of the time: 36% poles, 26% tannin, 18% saw timber, 12% other uses, and 8% barrel slates. The lack of data on how wood from chestnut coppice is currently used represents a major gap in the knowledge required to operationally improve the supply chain.

Despite the lack of a systematic investigation into the growth potential of chestnut coppices in the Italian regions, some basic differences in shoots diameter and height, stand basal area and volume, according to the sweet chestnut geographic provenance can be highlighted. These dendrometric parameters, are very dependent on stool and shoots density and site conditions (soil fertility, slope, and altitude). Additionally, several diseases can influence forest productivity, such as the most recent attack of *Dryocosmus kuriphilus* Yasumatsu on sweet chestnut, which often results in reduced wood production (Palmeri et al. 2014, Ugolini et al. 2014, Ferracini et al. 2019, Gehring et al. 2018, Gehring et al. 2020). On *Dryocomus kuriphilus* there are several studies related to nut production (Battisti et al. 2013, Sartor et al. 2015) but statistic on the impact on forest damage is lacking. Other examples include bark canker (*Cryphonectria parasitica*) and ink disease (*Phytophtora cambivora*). Most efforts at disease prevention have been addressed toward chestnuts cultivated for fruit, but disease can also affect forest vitality.

## Wood quality

The sweet chestnut forest-wood chain should pursue wood quality for all possible applications. Fine wood quality can support the versatility of final end-use products. General wood quality (no ring shake, remarkable dimension, straight grain) is the only good method for coping with rapid market changes, allowing the forest wood supply chain to survive.

Another important principle is the cascading use of wood, especially under the assumption of a circular economy, ensuring a necessary link between quality/versatility and forest management. The main limitations to improved sweet chestnut wood quality include size, ring shake, and the curvature of logs, which are defects that can be reduced by suitable silvicultural approaches. Forest management affect also wood mechanical properties (Marini et al. 2021).

Details regarding size are provided in Table 4, according to the most used products. Depending on the final intended product, a longer rotation was demonstrated to be the most important objective for the sweet chestnut industry. Ring shake remains a limiting factor and is likely the most studied defect observed in sweet chestnut (Spina and Romagnoli 2010, Romagnoli and Spina 2013, Becagli et al. 2006). Most studies examining ring shake and the effects of forest management have indicated that regular, early (8–10 years) and intense thinning represents an important forest management technique for reducing ring shake; however, genetic issues and provenance also play important roles (Fonti et al. 2002, Vinciguerra et al. 2011). Ring shake in sweet chestnut makes wood suitable for use as poles, as roundwood for bioengineering, and for energy purposes, which would prevent more valuable wood products from being used for such purposes. Other authors (Fonti

**Table 3** - Growth potential of sweet chestnut coppice stands in Italy.

| Author/s | Geographic Area | Dendrometric and dendroauxometric parameters |
|---|---|---|
| Caldart 1931 | Cimini Mountains (Lazio) | MAI among 9 and 20 m³ ha⁻¹ year⁻¹, depending on site fertility |
| Cantiani 1965 | Cimini Mountains (Lazio) | Maximum MAI: 20 m³ ha⁻¹year⁻¹ |
| La Marca 1981 | Irno's Valley (Campany) | Maximum MAI: 19 m³ ha⁻¹ year⁻¹. Maximum MAI: 13 m³ ha⁻¹year-1 (12 years in the third fertility class) |
| Eccher and Piccini 1985 | Lombardy | MAI: 6.3 m3 ha⁻¹ year⁻¹ (20–25 years) |
| SAF 1985 | Lazio | Mean amount of biomass: 110 m³ ha⁻¹. Mean increment: 8 m³ ha⁻¹year⁻¹ (13 mean years) |
| Bernetti 1987 | Tuscany | MAI in best site conditions variable between 4 to 8 m³ ha⁻¹ year⁻¹. |
| Hofmann et al. 1998 | Tuscany | Stand volume: 170 m³ ha⁻¹ |
| Cutini 2001 | Amiata Mountain (Tuscany) | MAI: 17.6 and 12.8 m³ ha⁻¹ year⁻¹, respectively, for 15 and 38 years. |
| Amorini and Manetti 2002 | Monte Amiata (Tuscany) | MAI: 10.9 m³ ha⁻¹ year⁻¹ (23 years) |
| Ciancio et al. 2004 | Calabria | MAI: 16.3 m³ ha⁻¹ year⁻¹ (13–15 years); MAI: 14.2 m³ ha⁻¹ year⁻¹ (-30 years); MAI: 12.0 m³ ha⁻¹ year⁻¹ (43–45 years) |
| Nosenzo et al. 2006 | Monte Tovo (VC) | MAI: 8.3 m³ ha⁻¹ year⁻¹ (50 years) |
| Nosenzo 2008 | Torino, Biella, Vercelli, Novara Cuneo (Piemonte) | Mean basal area: 30-35 m²ha⁻¹. Mean diameter: between 13 cm and 30 cm. Mean height between 13 m and 20 m. Biomass: 300 m³ ha⁻¹ |
| Tabacchi et al. 2011 | Italy | Mean volume of stools and bigger branches: 180.4 m³ ha⁻¹. (Annual increment: 6.8 m³ ha⁻¹ year⁻¹; Phytomass aboveground: 118.1 Mg ha⁻¹) |
| Angelini et al. 2013 | Viterbo (Lazio) | MAI: culmination between 18 and 22 years, with values between 7.2 and 13 m³ ha⁻¹ |
| Maziliano et al. 2013 | Presila di Catanzaro (Calabria) | Stand volume: between 90 and 630 m³ ha⁻¹, respectively, for 9- and 50-year coppices. Culmination of MAI at 25 years: 16 m³ ha⁻¹ year⁻¹. CAI culmination apparently at 15 years (21 m³ ha⁻¹) |
| Mattioli et al. 2016 | Bracciano, Oriolo Romano, Sutri (Lazio) | Number of shoots: between 1.942 and 11.445 ha⁻¹; Mean diameter: between 4 and 16 cm. Basal area: between 17.54 m² ha⁻¹ and 41.86 m² ha⁻¹. Number of standards: variable between 36 and 91. Mean diameter: between 24 and 46 cm. Mean age: 6 to 22 years. |
| Travaglini et al. 2015 | Chianti (Toscana) | CAI: between 6.7 and 4.7 m³ ha⁻¹ year–1, respectively, at 20 and 30 years. |
| Manetti et al. 2016 | Amiata Mountain (Tuscany) | Number of shoots: between 736 and 968 ha⁻¹. Mean diameter: 7.2 cm. Basal area: between 23.43 m² ha⁻¹ and 25.61 m² ha⁻¹ (11 years) |
| Manetti et al. 2016 | Colline Metallifere (Tuscany) | Numbers of shoots: between 888 and 1324 ha⁻¹. Mean diameter: between 9.7 and 10.4 cm. Basal area: between 18.23 m² ha⁻¹ and 29.55 m² ha⁻¹ at 17 years |

et al. 2002, Romagnoli and Spina 2013, Spina and Romagnoli 2010) have suggested some preventative measures for avoiding ring shake, such as maintaining the regularity of annual shoot growth (through active forest management) and the application of slow trunk drying processes. Log curvature is affected by the number of shoots and the height of the stools relative to the ground level. Curvature in the logs requires operators to shorten the logs. The irregular shapes of the shoots, especially when associated with the presence of large knots or sweet chestnut canker, can further limit the lengths of the logs (Fig. 3).

## Wood technology, processing, and marketing

The relaunch of a production industry must consider the processing costs, from harvesting to the final product. Logging costs are dependent on infrastructure viability, such as the road network, which is cru-

**Figure 3 -** a) curvature of the lumber, b) trimmer machine, c) chestnut cancer where the bole is eliminated, d) chestnut lumber

cial in Italy. Greater than 75% of the national sweet chestnut supply territories are accessed by inadequate road networks (Baldini et al. 2003). Harvesting operations can also be affected by slope and accidentality, especially for abandoned sweet chestnut sites. Additionally, the lack of viability increases the risk of trunk damage during thinning operations.

The machines used for forest operations are often outdated, despite the recent trend towards the production of more efficient systems (such as yarders), innovation in this field is not so exploited in Central and Southern Italy. Most forest harvesting systems are "tree length systems", although sometimes wood can also be cut into shorter assortments, such as small poles used for agriculture. Woody production first goes to the sawmills, which are interested in minimising wood processing and primary transport of full plants (Manetti et al. 2017).

Sawmills produce load-bearing structures or poles, which are one of the most important end-use products for sweet chestnut. The most advanced sawmill structure has a trimming-selecting machine; however, determining the lengths of the assortments continues to require a significant amount of operator expertise (Fig. 3) to reduce machining losses and to obtain the best products demanded by the market. Innovation in this field includes the recent development of end trimming machines that can be used in sweet chestnut sawmills to enable cross-cutting among short assortments. These machines are not new developments, and newer models that are currently available on the market can achieve increased productivity with higher safety standards. The competitiveness of an enterprise strongly depends on its innovation capacity, the development of new products and services, and the improvement of the overall process quality (Massa and Gessa 2011).

The prevailing private ownership of forest managers, mostly family-run (Borri et al. 2016), determines an insufficient and discontinuous production in the local and national market, forcing over time to use import timber of sweet chestnut, especially in medium and large companies (Manetti et al. 2017). For instance, only one-third of the timber used in Lombardy comes from this region, even though there is likely enough wood to satisfy local needs. The remaining two-thirds primarily come from Eastern Europe due to competitive prices and good quality (Mirabella et al. 2014). The workers have their niche markets; however, this is an important issue that must be resolved to develop a forest-wood chain able to survive the increasing import of wood products, such as Norway spruce or other imported species.

Small sawmills do not always have the opportunity to invest in innovation due to strong competition with imported wood. These sawmills must be encouraged to take advantage of various financial tools based on innovation (e.g. through rural development plans). Reliable statistics regarding the use of chestnut wood and the volume produced by various regions and sawmills are not available. Based on research and implementation projects, Piedmont, Tuscany, Lazio, and Veneto appear to be the most developed regions for chestnut woodwork in Italy. The marketing of chestnut products and services is characterised by a wide variety of options. Because chestnut producers are typically small-scale, non-industrial forest owners who live in rural, marginal areas, successful marketing must be effectively supported by external institutions. Partnerships and the coordination of initiatives between public authorities and private operators may be necessary for the development of this promising multi-functional forest resource (Pettenella 2001). In 2001, the prices for most important products were as follows: for sawn wood in euro 387/m$^3$; for construction beams, 516–671/m$^3$, which was lower than the cost for construction beams from France at 748/m$^3$ (Pettenella et al. 2001). Current market prices have not changed significantly since 2001, although pole prices have increased (Artena legnami pers. communications).

## Sweet chestnut wood products

A list of the most important products that can be obtained directly from sawmills is reported in Table 4, according to the estimated diameters and lengths of the original logs.

Poles for bioengineering and telecommunication applications, with an average diameter of 12–15 cm

**Table 4** - A list of basic traditional sweet chestnut uses (Romagnoli et al. 2013).

| Assortments | Diameter (cm) | Length (m) | Use |
|---|---|---|---|
| Beams | >20 | >4 | Carpentry, Building |
| Beams | >20 | 2-4 | Joinery, furniture |
| Floorboards | >20 | 0.80–2.00 | Parquet |
| Joists | 17–24 | (3) 4–5 | Carpentry, building |
| Small joists | 12–16 | 2–4 | Carpentry, building |
| Poles for bioengineering | 15–25 | 4 | Environmental restoration |
| Poles for agriculture | 6–15 | Variable depending on the use | Support for vine |
| Tutors | 2–5 | 1–2 | Support for young plants |
| Telecommunications poles | 12–15 (base); 9 (tip) | 7–12 | Support for electric lines |
| Vineyards ponds | 3–7 | 2–4 | |
| Firewood | Variable | 1 | Firewood, chips |
| Small shoots | – | – | Bread oven |
| Tannins | ≥10 | 1 | Industry |

at the base and 9 cm at the tip, and a length of 7–12 m (Tab. 4), do not require any special care or working processes except for debarking by automatic machines. Pole production is interesting because this industry is strongly tied to the typical Italian production of vineyards. In the Piedmont region, the use of treated wooden poles as a substitute for concrete is recommended in the disciplines of production (PDO-PGI) (Regione Piemonte 2003, 2019). Chestnut poles have an added value from this perspective due to their high natural durability, which makes chemical wood preservation treatments unnecessary. In the handbook of biological viticulture in Tuscany (2009), chestnut wood poles are highly recommended (Mazzilli and Braccini 2010).

Another issue that must be standardised along the sweet chestnut chain is the use of different local naming conventions for the poles, which can make the promotion of a national and international market difficult, as these markets require the use of common terminology and comparable technical standards. Some weaknesses should also be addressed for sweet chestnut poles because sometimes these poles are not as durable as expected (Militz et al. 2003).

Another product that has been extremely successful in the past is the sweet chestnut pole for telecommunications, ruled with the reference standard "UNI 3514 and UNI 3515 (1984)" in Italy. Currently, telegraphic poles, which require dimensional regularity of the stem, are not easily accessible in Italy. Wooden telegraphic poles have been replaced in many cases with impregnated Scots pine, Austrian black pine and European larch poles, which remain preferable to concrete.

The most important recent innovation in sweet chestnut is the use of this wood inload-bearing structures. This innovation is the result of efforts made by Italian researchers, who have inserted sweet chestnut beams into the package of European standards that are used to assess structural products under the CE certification mark (UNI EN 338, UNI EN 1912, Nocetti et al. 2016). The technical standard EN 14081-1 is related only to structural assortments that use a rectangular cross-section, and in many Italian regions, the working process is related to "USO FIUME" assortments (i.e. square-edged chestnut logs with wane along the entire length of the beam). FEDERLEGNO with CONLEGNO, Italian industrial associations which unites many companies that work with wood, obtained European Technical Approval (ETA-12/0540); therefore, the companies working within this Consortium were able to obtain the CE marking in their assortments. At the national level, according to UNI 11035 Part 1, Part 2, and Part 3, the assortments must be traded within national boundaries, and their sizes must be measured individual rather than treated a nominal size.

Compliance with European standards on solid wood requires knowledge of wood quality characteristics, and specific attention must be paid to modifying the original sizes of assortments in order to do not lower the initial mechanical grading. Therefore, homogeneous and consolidate products, such as glulams, are preferred in building projects.

The introduction of machine-assisted grading of mechanical strength profiles has allowed for the production of quantitative yields, producing better quality beams associated with higher grading in mechanical stress, reduced classification times, and greater guarantees of repeatability (Brunetti et al. 2013). The use of this instrument allows sweet chestnut load-bearing beams to compete with established species, such as Norway spruce, because they can obtain a grading higher of D24 (24 MPa to bending strength) which was a fixed limit for visual grading by UNI EN 338. The potential for machine grading is not always known by the sawmill workers, and some view it as unnecessarily expensive; the formation of consortia among producers would allow these users to be aware of the technology and to share the costs.

Furthermore in the recent times FEDERLEGNO has provided a technical report, by the results obtained by mechanical tests of italian CNR-IBE, which allows to overcome the limits of grading classification reported in Technical standards, the beams can be so classified with an higher mechanical strength by means of visual grading.

Major gaps in the chain of load-bearing structures have been identified, some of which have potential solutions. The gap in this field is associated with the promotion of the product and awareness of its performance. Furniture, which was a primary application production of sweet chestnut in the past, is not more appreciated by customers, whereas the possibility to obtain veneers may deserve further attention. The sweet chestnut chain is currently losing many companies due to the economic recession and the low ability to innovate due to the mandatory requirements in this field. This is a disadvantage in terms of loss of expertise, but may allow the surviving companies to develop into larger, modern, and organised operations, able to face the competition of other sectors, countries, and wood species.

Recently, projects have reported the development of glulams (Brunetti et al. 2014, Carbone et al. 2020), which would be advantageous for the sweet chestnut forest chain because the product could be used as a substitute for glued spruce beams. In Spain, a sweet chestnut glulam has been produced and marketed using the CE label according to an ETA approval; however, the standard regulations differed at the time of approval, allowing for successful CE certification. In the recent times FEDERLEGNO has provided to his members new chances for the classification by means of mechanical properties compared to higher class graded conifers. In Italy, this pathway should be investigated together with other hardwoods, such as European beech, which have also been already considered by the market of structural beams.

Sweet chestnut would likely benefit from the concept of cascade use. Although the opportunity to produce a sufficient quantity of wood exists to makes this species a potential feedstock for energy (Delfanti et al. 2014, Colantoni et al. 2013, Zambon et al. 2016), several valuable products can be obtained before considering this final end-use. Tannin wood extracts represent an important by-product with ubiquitous uses in many field applications (Tab. 5), and even the residues from tannin extraction could be useful (Giovando et al. 2019). Tannins in sweet chestnut belong to the larger group of hydrolysable tannins (Vázquez et al. 2009). Tannins have been heavily investigated and are well-known to possess for many appreciated properties. Traditionally, tannins were used to increase the lifespan of leather. Due to antioxidant and astringent features, tannins are also used in pharmacological products and the cosmetics industry (Aires et al. 2016). Tannins are also added to animal feed because they can act against pathogens (Krueger et al. 2010). Tannins also have environmental applications because they can absorb heavy metals from aqueous solutions (Akunwa et al. 2014, Fan et al. 2014). Finally, adhesives must be considered, and tannins have been, and continue to remain a meaningful ingredient in natural adhesives and coatings (Spina et al. 2013, Aires et al. 2016, Santos et al. 2017). All of these applications indicate that tannins from natural origins represent an important resource for the achievement of sustainable development and a circular economy (Zikeli et al. 2018, 2019, 2020), and the reuse of crop and industrial wood waste represents a major achievement for combating environmental issues (Aires et al. 2016, Ham et al. 2015, Kim et al. 2015, Vázquez et al. 2008). Earlier studies have evaluated where extractive located in wood, providing differing and sometimes contrasting results. New attempts in the field of biochar could improve the rational use of residuals and further strengthen the concept of cascade use. Sweet chestnut processing residues have also been increasingly used for energy purposes, not only in terms of biomass (e.g. chipboard) but in some regions have been applied to pellet production, with good characteristics as fuel after tannin removal (Gotti et al. 2009).

The application of biochar from shells has shown interesting potential as a source of energy. Some studies on the topic (Ozçimen and Ersoy-Mericçboyu 2010, Casini et al. 2019) have demonstrated that biochar products can be characterised as carbon-rich, with a highheating value, and may serve as a relatively pollution-free potential solid biofuel.

**Table 5** - A list of topics related to tannins usage.

| Authors | Topics related to tannins |
|---|---|
| (Li et al. 2013, Pizzi 1978, Pichelin et al. 1999, Santos et al. 2017, Spina et al. 2013, Vázquez et al. 2012, Pizzi 2016). | Tannin adhesives |
| (Zhou et al. 2013, Tondi et al. 2009). | Wood/foam |
| (Rezar et al. 2017, Buccioni et al. 2017, Bilić-Šobot et al. 2016, Minieri et al. 2016, Liu et al. 2011, Liu et al. 2012, Carreño et al. 2015, Maisak et al. 2013, Gai et al. 2011, Budriesi et al. 2010). | Pet diet |
| (Kolayli et al. 2016, Sorice et al. 2016, Wani et al. 2017). | Medical properties |
| (Sanz et al. 2012, Frost et al. 2017, Pascual et al. 2017, Rinaldi et al. 2017, Gambuti et al. 2010, Ghanem et al. 2017, Soares et al. 2012, Alañón et al. 2013, Kyraleou et al. 2015, Vazallo-Valleumbrocio et al. 2017). | Wine utilization |
| (Bargiacchi et al. 2012) | Fertilizer |
| (Jaén et al. 2003, Beltrán et al. 2009, Beltrán et al. 2011). | Ingegneristic function |

## Discussion

Extending rotation lenght, timely of thinning and modification of the standard on the ground pattern methods are the key points for relaunching the production of chestnut wood in order to increase its quality and value.

The chestnut coppice is also facing the consequences of global change in terms of increased summer aridity and the invasion of potentially pathogenic alien species. It will therefore be necessary to ensure through silvicultural management greater resilience to the chestnut ecosystem by improving forest structure complexity and biodiversity. Some studies have highlighted the richness of vascular species in the chestnut coppice undergrowth, especially in those subject to thinning (Gondard et al. 2001, Gondard and Romane 2005, Mattioli et al. 2016). These are mostly species related to open or semi-open environments. Nemoral species only begin to appear towards the end of the rotation (Barkham 1992, Mason and Macdonald 2002, Mattioli et al. 2009). Therefore, the extension of the production cycles can facilitate the conservation of species able to grow under the forest canopy. Management of biodiversity on a landscape scale is also relevant, based on the identification in the territorial mosaic of areas, even if small in size, where the chestnut appears less competitive with other tree species for edaphic or microclimatic reasons. These areas, frequent in the hilly orography where chestnut forests grow in Italy, can be managed as reserve areas, favoring the conversion of coppice into mixed multiaged high forests. Also the presence of chestnut orchards in the landscape favors the floristic diversity (Gondard et al. 2006).

Well thought out thinning protocols could also improve the resilience of stands to climate change (Marini et al. 2019). Thinning can support the reduction of competition for water and nutrients, with a consequent improvement in the health conditions of the released shoots as well as the wood quality, if performed timely and gradually in order to avoid sudden incremental recovery.

In this regard, the main challenge is to make thinning economically sustainable, which requires adding further value to products obtainable from small shoots, such as biochar or glued products (Carbone et al. 2020) which may be of interest indoors. About biochar production from lignocellulosic biomass from chestnut some preliminary results are now available (Casini et al. 2019).

Different ways of selling standing stands could be developed from traditional ones. It can be assumed that the forest owner gives a costly concession for stands at the beginning or mid-rotation, leaving the holder of the concession with the burden of thinning but also the right to harvest the trees at the end of the rotation after having implemented all the silvicultural practices suitable for improve the quality of assortments. In Lazio region, both the final cutting in a forest comparment and the thinning to be carried out in some younger compartments of the same public property were included in a single call.

Another potential best practice is the promotion of local market organisations through “virtual landing” with the aim of producing a suitable and quantitatively adequate supply of logs. For small and medium enterprises, Massa and Gessa (2011) introduced the Quality Function Deployment methodology (QFD) in the wood sector, which appears to represent a potential method for improving the chestnut value chain. The underlying concept is to view a supply chain, or an SME network, as a Virtual Enterprise, in which each actor represents a fundamental member that contributes to the realisation of the final product, similar to different departments in a complex industry.

Planning the reconversion of coppice stands towards high forest management may be difficult. Some silvicultural operations meant to increase the efficiency of coppices include lowering the height of the stools (high stool height limits shoot sprouting and complicates thinning and forest harvesting operations) and reducing the shoots density within a forest (resulting in reduced competition for resources and the production of shoots with regular shapes). These silvicultural operations can be quite expensive, and such measuresare unlikely to be adopted by private owners without strong public economic support.

A short-term approach would be the relaunch the use of material towards products with added value, to improve the versatility of the final end-use. By this point of view, it is possible to formulate a report in which the quality of assortments is assessed at the landing to boost the versatility in the use of the species in other products instead to stop to the alone production of load-bearing structures and poles, looking also for sinergies with architects and designers. Visual grading is already used for the operational management of some valuable species, such as oaks and beech (UNI EN 1316 part 1 and 2).

## Conclusion

In this commentary, the current state and the main gaps in forest wood supply chains have been examined, and the main strengths and weaknesses are assessed in Table 6.

Potential actions that can be taken to support the sweet chestnut value chain include political actions, such as increasing the awareness of the advantages of sweet chestnut wood use, as follows:

(i) The chance to support a short supply chain, according to the bioeconomic principles. The primary advantage is to improve economic activities associated with the exploitation of sweet chestnut wood while reducing the carbon footprint;

(ii) Additional support comes from the assessment of “local value chain” (in which the producer and customer are in the same territory, resulting in zero-logistic transfer). Moving customers to the use of local production and revisiting the traditional uses of wood can be particularly appropriate. From this perspective, the restoration and requalification of historical building techniques that use chestnut wood may represent an opportunity. Starting with a short or local supply chain and looking forward to the European market might represent a promising strategy for the re-exploitation of the chestnut value chain;

(iii) The support of regional projects that can help sawmills to reach higher levels of innovation is crucial. Sawmills must improve their technologies to provide materials improved finishing qualities to compete with other species (i.e. poles of Scots pine or telegraphic poles of other species);

(iv) Supportive business networks, such as the Interregional Agreement for the Increase in Woody Harvest in Verona Woodland in 2016, the consolidation of product innovations, and supportive

**Table 6** - Main strengths and weaknesses of the sweet chestnut forest chain in Italy.

| STRENGTHS | WEAKNESSES | ACTIONS |
|---|---|---|
| Acceptable supply for Italy | The species is threatened by pathogens | Actions to reduce pathogenic vulnerabilities |
| Good quality timber (generally lacking ring shake), suitable for many applications if well-managed. Good ratio between weight and mechanical strength. | Low size and irregular shape of stems reduce wood quality and the opportunity for use in more products | Silviculture focused on enhancing species resilience and wood quality |
| Good understanding of the species by companies in woodworking | Not appreciated by customers for uses that are different from structural purposes. | Action to exploit the strengths of the species from this point of view. |
| Environmentally sustainable: low carbon footprint, durable, suitable for wood value chains | This aspect is not known to customers and has not been sufficiently exploited. | Implementation with interregional or similar projects |
| Chance to be used for composite products | Not yet used for modern composite products (glulams etc.), and only prototypes have been investigated | Additional research |
| Wood residues can be used to extract valuable products (tannins) | Little diversification in the products in the actual organisation of the chain | Pilot plants for the chemical extraction and application of the principle of cascade use |
| Integral part of the landscape as sweet chestnut management. | Not well-known by other professionals working with wood products (architects, engineers) | Cross-cut among different professions (architects, engineering, foresters) |
| Used for structural purposes in line with European standards | The number of sawmills at national level is decreasing they produce only chestnut timbers. | Support for primary processing and actions to support their diversification |
| Suitable for short forest-wood supply chain | A lack of reliable statistics regarding wood assortment production, use, and marketing | Collect statistics on the produced products and on the whole chain |

services for businesses, such as promoting "sponsorship" actions can promote the preference for the "Use of sweet chestnut wood in a marketing perspective of 100% Italian wood". This represents an agreement for the promotion of "proximity products" strategies by public works. A proper wood supply chain cannot be exhausted by the production of a quality product; however, it should be implemented through collaboration at various institutional levels, such as encouraging the local use of sweet chestnut wood through public procurement and by private consumers;

(v) Support the implementation of projects that use chestnut woods in innovative design applications to support diversification. More active collaboration with architects should be pursued.

The application of innovative silvicultural approaches, as allowed by local, social, and economic conditions, can be applied to exploit the full potential of sweet chestnut wood products. Through silviculture practices, high-quality logs can be produced, with large diameters, regular growth patterns, and few defects. However, substantial changes in sweet chestnut coppice management are fundamental to producing higher quality products, and a transition from "silviculture waiting" and sporadic interventions to an "active, participatory and sustained silviculture" is necessary. Active silviculture requires particular attention to be paid to the local context when making choices among multiple options. A participatory and publicly sustained silvicultural initiative is necessary due to the prevalence of private owners, which should aim to drive forest management towards shared silvicultural practices and the establishment of associations or consortia.

Chestnut wood is durable overtime and has the potential to store carbon for centuries.

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