# Analysis of the main physical and chemical characteristics of the vine shoots of three vine varieties from Veneto (Italy)

**Alessio Mencarelli, Raffaele Cavalli, Rosa Greco**

***Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro (PD), Italy***

## Abstract

In Italy, the agricultural residues resulting from the pruning of vineyards represent a potential energy Source, in particular for the Veneto region, which is the second Italian region by vineyard area. This study is aimed at analysing the main physical and chemical characteristics of vine shoots from the annual pruning of vineyards. This for use them as wood chips in small-medium size power plants. International and European standards for the analysis of biofuels were used to determine the moisture content, heating value, ash content, micro and macro elemental and fibrous fraction (lignin, cellulose, hemicellulose and extractives). The samples were collected from three different vineyards in the Vicenza area. The varieties analysed were Chardonnay, Glera, and Merlot. For each variety, the three different components of vine shoots were compared: internode, node, and pith, to investigate in which part of the vine shoot the most significant accumulation of metallic elements deriving from plant protection products occurs. The results show significant differences among the energy parameters of the three varieties and three vine shoot components. In particular, the pith shows low heating value and high ash content, while higher energy values characterise the woody components. Analysis of the chemical elements showed a high content of Cu and Zn in the wood components, node, and internode, causing the high ash content found. In particular, Cu content exceeds the limits set by the reference standard. As regards the analysis of the fibrous fraction, a high content of extractives was found in the pith. These extractives could explain why the pith of the three varieties analysed, especially in Chardonnay, have lower heating value on dry basis ($LHV_0$) values and high ash contents.

On the contrary, the node and internode components have a higher cellulose, hemicellulose, and lignin content. Overall, the vine shoots analysed have characteristics suitable for possible energy use. However, according to EN ISO 17225-9:2021 standard, these can only be used as wood chips for industrial purposes in large power plants due to the high ash and Cu content.

Correspondence: Rosa Greco, Department of Land, Environment, Agriculture and Forestry, University of Padova, viale dell'Università 16, 35020 Legnaro (PD), Italy.
E-mail: rosa.greco@unipd.it

Key words: Agricultural residues; biomass; energy utilisation; pruning residues; vine shoots; vineyard.

Received for publication: 1 March 2022.
Accepted for publication: 18 May 2022.


*Journal of Agricultural Engineering 2022; LIII:1396*
*doi:10.4081/jae.2022.1396*



## Introduction

The cultivation of vines in the world is fundamental for the economy of various countries. In 2020, the area planted with vines globally was estimated at 7.3 Mha and among the countries with the largest vineyard area, Italy is the fourth nation on a global scale with an area estimated at 719 kha (OIV, 2020b). Regarding wine production, Italy was in first place globally in 2019, with an annual production of 47.2 Mhl (OIV, 2020a). Among the Italian regions with the largest surface area occupied by vineyards, there is Veneto which represents the second region in terms of area with a value of 94,666 ha (Gismondi, 2020). Like other permanent crops, vineyards require annual pruning that produces huge quantities of residues (Di Blasi *et al*., 1997). Vine shoots are long slender branches with a prostrate or climbing habit produced after the cutting (Senila *et al*., 2020). The quantity of pruning residues that can be collected varies considerably according to vine variety and year (Manzone *et al*., 2016). Generally, annual production of between 1.5 and 2.9 t/ha of wine shoots is estimated depending on the variety, cultivation system, and plant vigour (Valer, 2010) (Mescalchin *et al*., 2009). Pruning is performed annually from November to February to control the vegetative-reproductive cycle of the plant. Once the biomass has been harvested, it can be managed in different ways. It can be chopped and consequently buried, helping maintain the soil's organic matter content. However, this can also represent a problem from a phytosanitary point of view, favouring the spread of diseases and pathogenic microorganisms (Jacometti *et al*., 2007), both causing the accumulation of zinc (Zn) and copper (Cu) deriving from the treatments to the crop (Brunetto *et al*., 2017). Vine shoots are also often burned at the edge of the field, causing environmental impacts due to the release of polluting compounds (Lemieux *et al*., 2004) (Estrellan and Iino, 2010). Therefore, both of these solutions present problems and an increase in management costs. Identifying an alternative use for vineyard pruning residues would make it possible to eliminate the problem relating to their disposal by converting them into collateral production and guaranteeing a possibility to reduce management costs (Spinelli *et al*., 2012). A valid alternative is the utilisation of this material for energy purposes.

Using biomass as an energy source has a strategic role in satisfying energy demand and achieving EU objectives in terms of renewable energy and reducing carbon dioxide emissions (Andersen *et al*., 2021). Almost 27% of the biomass used in the EU for energy purposes comes from the agricultural sector, and Italy is among the five European nations with the highest consumption of biomass for energy (Scarlat *et al*., 2019). Consequently, vine shoots can represent an essential renewable energy source being available in large quantities. However, before being used, the material must be subjected to physical and chemical analysis to verify its qualitative characteristics. In addition, vineyard management often involves using plant protection products that can remain in the vine shoots. These inorganic compounds, especially based on heavy metals, can remain on the surface of the plant, causing an increase in their concentration in the resulting biomass, causing the release of pollutants in fumes and ashes during their use (Obernberger *et al*., 2006). The important of this work is to analyse the main physical and chemical characteristics of the agricultural residues deriving from vine pruning of three varieties commonly found in Veneto to verify their energy application as wood chips. Therefore, the reference standard is represented by EN ISO 17225-4: 2021(ISO, 2021a). Studies on the characteristics of vine shoots for energy purposes are already available (Mendívil *et al*., 2013; Picchi *et al*., 2013; Mendívil *et al*., 2015; Duca *et al*., 2016; Giorio *et al*., 2019). This evidence shows that vine shoots are characterised by high levels of ashes and heavy metals. However, no study investigated how the anatomical components of the vine shoots can influence such physical-chemical characteristics. Therefore, this work aims at analysing the whole vine shoots and their individual components (node, internode, and pith) to highlight the relationship of these components with the physical-chemical characteristics of the vine shoots as influenced by phytosanitary treatments. In detail, tests were conducted for each variety and component of the vine shoots to determine moisture content (M), lower heating value on dry basis ($LHV_0$), expressed in terms of MJ/kg, and ash content (A). The chemical analyses aimed at assessing the presence of micro and macro chemical elements that could be released during the combustion process with a potential risk to human health and the environment. Finally, the fibrous fraction of the vine shoots was examined in terms of lignin, cellulose, hemicellulose and extractives.

## Materials and methods

### Sampling

The samples were provided by a farm in Vicenza, Veneto. They were taken during the pruning of vineyards in January-February. The samples of one-year vine shoots analysed belong to the varieties cultivated on the farm: Chardonnay, Glera, and Merlot. These are among the major vine varieties grown in Veneto.

### Sample preparation

Four replicas weighing 1 kg each were used for each variety to ensure data's repeatability and obtain statistically significant results. Of the 4 sub-samples, 3 were subjected to fragmentation of the vine shoot components (nodes, internodes, and pith). The remaining subsample of each variety was used entirely, acting as a control parameter. The fragmentation procedure of the single sample into nodes and internodes was performed using shears. Instead, using a knife with a sharp blade, a longitudinal cut was made on each internode, and, using a scalpel, the pith was extracted. To ensure the analytical integrity of the internode samples, without any possible pith residue, sandpaper and compressed air were used. Table 1 shows the average percentage composition of each vine shoot of the three varieties in terms of their individual components. Each sample's anatomical component (node, pith less internode, and pith) and variety was ground using a Retsch SM 100 cutting mill for the coarser material. Instead, an IKA MF 10 cutting mill was used for the pith. Both procedures were conducted following the provisions of the reference standard, EN ISO 14780-2017 (ISO, 2017a). The ground samples were subjected to subsequent analysis.

### Physical analysis of vine shoots

The moisture content was measured on all the samples analysed. This parameter was determined in accordance with the provisions of the EN ISO 18134-1:2015 standard (ISO, 2015d). For each sample, 10 g of raw material was used. This is different from what is established in the standard due to limited material available. As for the pith, due to the limited sample availability, being present in small quantities on each vine shoot, the moisture content was determined at the same time as the ash content.

The lower heating value (LHV) represents the amount of thermal energy released by the complete combustion of a quantity of unit mass of fuel, assuming that the water released during combustion remains vapor (Hellrigl, 2006). It was determined on each sample by referring to what is reported in EN ISO 18125:2017 (ISO, 2017b). Thanks to the knowledge of the sample's moisture content, this parameter was expressed in terms of lower heating value on dry basis ($LHV_0$). The ash content was determined by calculating the mass of the residue of the sample remaining after its calcination in the muffle at 550°C, as defined by the EN ISO 18122:2015 standard (ISO, 2015c). The parameter is expressed in terms of ash content on a dry basis. The ash content is crucial for determining the main chemical components.

### Analysis and determination of macro and microelements and fibrous fraction

The elemental analysis of the microelements was performed according to the provisions of the EN ISO 16968:2015 standard (ISO, 2015b). The microelements analysed were arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn). Nitrogen (N) was determined as specified by the EN ISO 16948:2015 standard (ISO, 2015a). The chlorine (Cl) and sulphur (S) content were determined with reference to the EN ISO 16994:2016 standard (ISO, 2016). Finally, for the characterization of the fibrous fraction, the Van Soest method was used, which, using neutral and acid detergents, allows the constituents of the polymer, such as lignin and polysaccharides, present in vine shoot to be determined (Van Soest *et al*.,1991).

### Data analysis

For the statistical analysis, one and two-way ANOVA were performed. The parameters subjected to these analyses are llower heating value, ash content, and fibrous fraction. These variables are related to the two main factors: the variety of the vine shoots (Chardonnay, Glera, and Merlot) and the vine shoot component (node, internode, and pith). Regarding the lower heating value and ash content, a one-way ANOVA was performed to determine the differences between the average values of the vine variety and vine shoot component factors. This was also conducted for the analysis of the fibrous fraction. Regarding the lower heating value and ash content, a two-way ANOVA was performed to study the influence of the combination of vine variety and vine shoots component on these parameters. Finally, Fisher's least significant difference (LSD) procedure was used to identify the averages and ranges of statistically different variables with a 95% confidence level.

## Results and discussion

### Heating value

Table 1 shows the average $LHV_0$ values of the three vine shoots varieties and the three related components (node, internode, and pith). There are statistically significant differences between the $LHV_0$ average of Glera, having a higher average value, compared to Chardonnay and Merlot. Conversely, there are no significant differences between these last two varieties. To verify and identify the cause of the differences between vine varieties, the $LHV_0$ values of the three vine shoot components were compared, cumulative of the three vine varieties. In detail, the $LHV_0$ value of the pith is significantly lower than the internode and node. The statistical comparison between the variety and component factors also shows a significant difference. The $LHV_0$ value of Glera is higher than Chardonnay and Merlot. Subsequently, the results were compared for the interaction between the vine shoot component (internode, node, and pith) and variety. Figure 1 shows how the interaction is present only between vine variety and pith. In fact, the most statistically important data related to the pith component of Chardonnay, which has significantly lower values than the pith of Merlot and Glera.

### Ash content

Table 2 summarises the results of the statistical analysis on the percentage of ash based on varieties and vine shoot components examined. There are statistically significant differences between the three vine varieties. Also, in this case, it was necessary to deepen the analysis to verify the influence of the three vine shoot components on this parameter. Statistically significant differences were found. In detail, internode and node show limited differences with average values lower than 4.00%. Conversely, the pith has a much higher ash content. The influence of the three components within the three varieties was then evaluated. Although a there are statistically significant differences between the three varieties, Chardonnay has a higher average ash value than Glera and Merlot.

As for $LHV_0$, the interaction between the vine shoot component (internode, node, and pith) and vine variety was observed. This verifies the influence of the pith on the ash content value for Chardonnay, Glera, and Merlot varieties. Figure 2 shows that also,

**Table 1. Average percentage composition of each vine shoot of the three varieties in terms of their individual components.**

| Component | Unit | Chardonnay | Glera | Merlot |
|---|---|---|---|---|
| Internode | % db | 56.32 | 42.18 | 39.61 |
| Node | % db | 17.97 | 10.50 | 15.78 |
| Pith | % db | 1.00 | 1.44 | 1.09 |

db, dry basis.

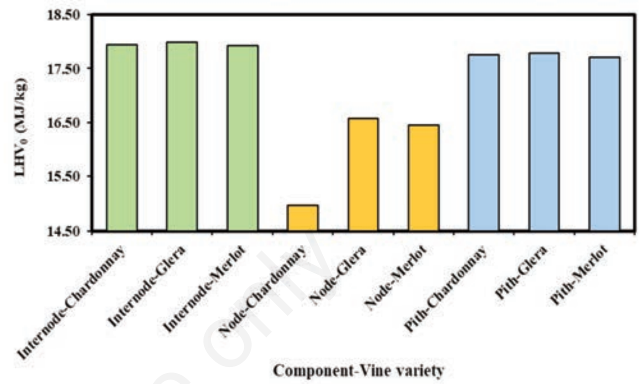


**Figure 1. Interactions of the three vine shoot components for each variety on $LHV_0$.**



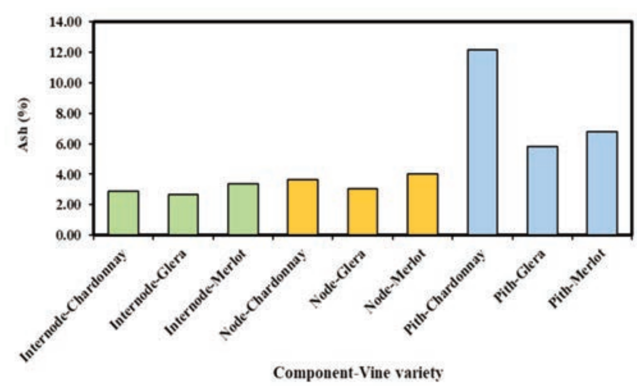


**Figure 2. Interactions of the three vine shoot components for each variety on ash content.**

**Table 2. Results of the ANOVA test relating to ash content applied to vine shoots of the three vine varieties and the three related components.**

| | Vine varieties | | | Component | | |
|---|---|---|---|---|---|---|
| | Chardonnay | Glera | Merlot | Internode | Node | Pith |
| Average (MJ/kg) | 17.71 | 17.93 | 17.73 | 17.95 | 17.75 | 16.00 |
| Minimum (MJ/kg) | 17.69 | 17.89 | 17.71 | 17.92 | 17.63 | 14.84 |
| Maximum (MJ/kg) | 17.73 | 17.96 | 17.76 | 18.02 | 17.87 | 16.58 |
| Number of observations | 3 | 3 | 3 | 9 | 9 | 9 |
| F-ratio | 56.41 | | | 51.65 | | |
| P-value | 0.0001 | | | 0.0000 | | |
| LSD | ±0.06 | ±0.06 | ±0.06 | ±0.44 | ±0.44 | ±0.44 |

pagepress

in this case, the pith is the component that most influences the parameter, in particular, the Chardonnay variety.

### Macro elements analysis

The results of the analysis of macro elements of Cl, S, and N show a greater presence of the latter element with values around 0.90% (Figure 3). Sulphur and chlorine are present in concentrations lower than 0.10% on the dry fraction. Table 3 shows the values of Cl, S, and N distributed within the three vine shoot components of the three vine varieties.

### Microelements analysis

Figure 4 reports the analysis results concerning the microelements in the vine shoots of the three varieties. Differences in terms of composition were found. In detail, the three varieties present high zinc and copper content. On the other hand, arsenic, cadmium, lead, and mercury are present in concentrations below the instrument detection limit. To verify where these elements tend to accumulate more in vine shoots, chemical analyses were performed in the internode, node, and pith of the three vine varieties. The results of the analysis are summarised in Table 4.

### Analysis of the fibrous fraction

Figure 5 reports the results of the analysis of the fibrous fraction of the entire vine shoot of the three vine varieties. Merlot has a lower cellulose content than the other two varieties (32.99%). Very similar values were observed for Chardonnay (37.76%) and Glera (37.37%). Also, as regards extractives, Chardonnay (23.50%) and Glera (23.99%) have closer values, while a higher quantity was found in Merlot (27.32%). As for hemicelluloses and lignin, the values are very close in all three vine varieties. Figure 6 shows the results of the fibrous fraction analysis of the three components of vine shoots. A strong presence of cellular extractives was found in the pith (39.37%); a much higher quantity than what was found in the internode (22.64%) and node (24.66%). Pith also has lower cellulose, hemicellulose, and lignin than the other two components.

## Discussion

### Heating value

The average $LHV_0$ value of every single variety obtained is similar to what was reported in other works. Analyses conducted by Picchi *et al*. (2013) and by Spinelli *et al*. (2010) on Italian vine shoots showed an $LHV_0$ of 17.80 MJ/kg and 17.32 MJ/kg, respectively. However, at the same time, the values found in this study differ considerably from the results obtained by Manzone *et al*.

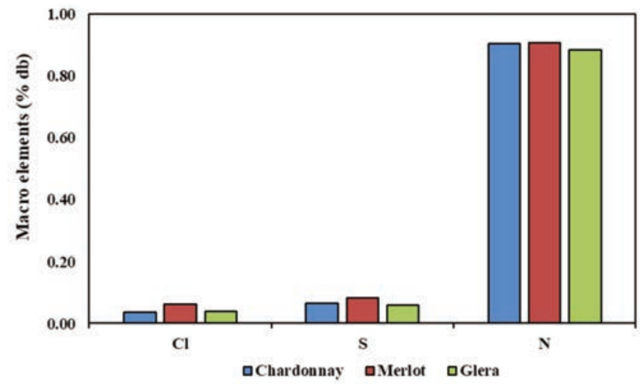


**Figure 3. Comparison of macro elements among the vine shoots of Chardonnay, Merlot, and Glera. db, dry basis.**

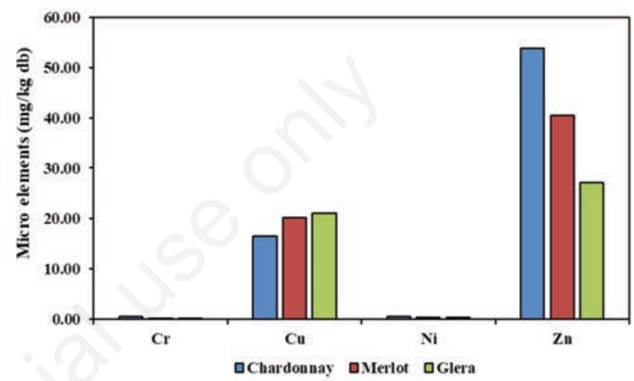


**Figure 4. Comparison of microelements among the vine shoots of Chardonnay, Merlot, and Glera. db, dry basis.**

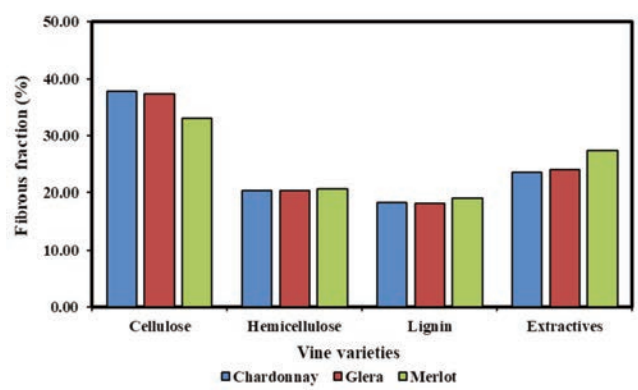


**Figure 5. Comparison of cellulose, hemicellulose, lignin, and extractives content among the vine shoots of Chardonnay, Merlot, and Glera.**

**Table 3. Results of the analysis of macro elements of the components of the three varieties of vine shoot analysed.**

| | Vine varieties | | | Component | | |
|---|---|---|---|---|---|---|
| | Chardonnay | Glera | Merlot | Internode | Node | Pith |
| Average (%) | 3.26 | 2.95 | 4.01 | 2.97 | 3.59 | 8.26 |
| Minimum (%) | 3.13 | 2.90 | 3.95 | 2.67 | 3.00 | 5.67 |
| Maximum (%) | 3.35 | 2.97 | 4.04 | 3.40 | 4.09 | 12.34 |
| Number of observations | 3 | 3 | 3 | 9 | 9 | 9 |
| F-ratio | 157.05 | | | 24.97 | | |
| P-value | 0.0000 | | | 0.0000 | | |
| LSD | ±0.15 | ±0.15 | ±0.15 | ±1.69 | ±1.69 | ±1.69 |

(2016), who determined an average $LHV_0$ of vine pruning between 7.34 and 7.96 MJ/kg. However, in this case, the moisture content value was significantly higher, reaching around 50%. As highlighted by Mendívil, the differences in LHV between Chardonnay, Glera, and Merlot found in this study are due to the different vine varieties (Mendívil *et al*., 2015). A further aspect of this study was to analyse the individual vine shoot components of the three varieties to verify the differences in energy content in the components. This was to verify which component has the most significant influence on the value of the whole vine shoot. The results obtained show a high energy difference between the components. These differences were found both within the same vine shoot and between varieties. The pith is characterised by lower heating value and is statistically different compared to the other two vine shoot components. Therefore, a greater proportion of pith inside the vine shoot determines an overall calorific value reduction.

On the contrary, node and internode have an average value close to the $LHV_0$ value of the whole vine shoot. In particular, the influence of the component factor on the heating value of the vine variety is highlighted by observing what was found for the pith (Figure 1). Chardonnay is the most influenced variety, with a lower $LHV_0$ of the pith compared to Glera and Merlot, which in turn have values lower than the $LHV_0$ of node and internode. As stated by Hellrigl (2006), these differences are due to a different composition of the fibrous fraction and ash content of the three components. The polymers forming the wood have different energy properties and, according to the chemical composition of the vine shoot components, these will specifically affect the heating value (Demirbas and Demirbas, 2009) for each variety.

## Ash content

Vine shoots are characterised by high ash content compared to forest wood species and other agricultural residues. In fact, forest wood species such as spruce and beech tend to have limited ash content, even lower than 1.00% (Hellrigl, 2006). Vine shoots often have higher values with a range of variation between 3.70% and 4.00% (Picchi *et al*., 2013; Manzone *et al*., 2016). High ash values have numerous adverse effects both on the energy yield released during the combustion process due to a reduction in the heating value and on the maintenance of the combustion chamber, favouring erosion processes (García *et al*., 2014). Based on the data collected in this study, a significant difference in ash content is evident for the varieties analysed. Merlot has a higher ash content (4.01%), followed by Chardonnay (3.26%) and Glera (2.95%). A difference is observed in comparing the average value of the variety and the average ash content in the components of the three varieties. In the analysis of the whole shoot, there is a proportional distribution between node, internode, and pith, while in the analysis of single components, this proportion is altered. This explains the higher ash content in components average compared to that of the whole vine shoot. This comparison is useful to underline how the single component affects the value of the whole vine shoot. Based on these results, Chardonnay is the variety most affected by the pith component, which has an ash content of 12.16%. The values determined on the pith of Glera (5.80%) and Merlot (6.82%) are

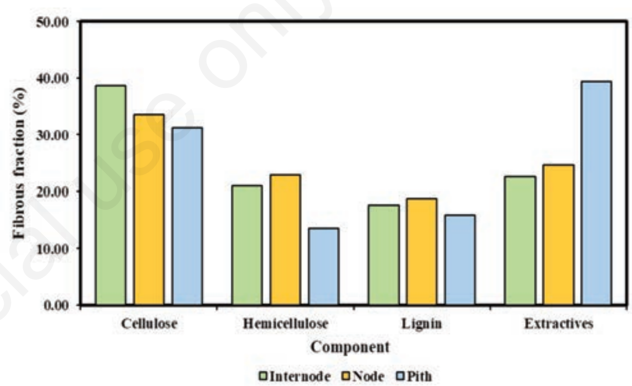


**Figure 6. Results of the fibrous fraction analysis of the three components of vine shoots.**



**Table 4. Results of the analysis.**

| Elements | Unit | Standard limits (EN ISO 17225-4:2021) | Chardonnay Internode | Chardonnay Node | Chardonnay Pith | Glera Internode | Glera Node | Glera Pith | Merlot Internode | Merlot Node | Merlot Pith |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cl | % db | 0.05 | 0.09 | 0.08 | 0.07 | 0.05 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| S | % db | 0.1 | 0.06 | 0.07 | 0.02 | 0.05 | 0.06 | 0.02 | 0.08 | 0.08 | 0.02 |
| N | % db | 1.0 | 0.78 | 0.88 | 0.37 | 0.82 | 0.94 | 0.36 | 0.84 | 0.89 | 0.42 |

db, dry basis.

**Table 5. Results of the analysis of the microelements of the components of the three varieties of vine shoot analysed.**

| Elements | Unit | Standard limits (EN ISO 17225-4:2021) | Chardonnay Internode | Chardonnay Node | Chardonnay Pith | Glera Internode | Glera Node | Glera Pith | Merlot Internode | Merlot Node | Merlot Pith |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cr | mg/kg db | ≤10 | 6.59 | 1.08 | 2.13 | 0.22 | 0.20 | 1.35 | 0.79 | 0.51 | 1.08 |
| Cu | mg/kg db | ≤10 | 12.44 | 19.66 | 9.46 | 16.81 | 18.22 | 4.95 | 12.60 | 22.84 | 5.30 |
| Ni | mg/kg db | ≤10 | 3.46 | 0.92 | 0.59 | 0.34 | 0.34 | 0.36 | 0.67 | 0.67 | 0.37 |
| Zn | mg/kg db | ≤100 | 17.83 | 50.70 | 8.98 | 24.93 | 42.15 | 7.60 | 14.81 | 42.63 | 8.04 |

db, dry basis.

half that. This aspect also has a repercussion on heating value. In fact, the Chardonnay pith has the lowest $LHV_0$ because a high ash content also determines a reduction in the heating value of the fuel (Lieskovský *et al*., 2017) (García *et al*., 2014). The high ash content in vine shoots is due to the inorganic components but, above all, to phytosanitary treatments made on the vine during its production cycle. The presence of these compounds, mainly antifungals, and insecticides, can cause an accumulation of heavy metals in the external surface of vine shoot (Picchi, 2012). A comparison must be made between vine shoots grown under organic management practices to verify this aspect. The accumulation of Zn and Cu in the vine shoot varies according to the treatment type; indeed, their concentrations depend on the quantities distributed during treatments (Duca *et al*., 2016). High ash values may also be due to a high content of young tissues in vine shoots (Kumar *et al*., 2010).

## Analysis of micro and macro elements

These analyses assessed the real presence of inorganic chemical elements, representing a risk to human health and the environment, with particular attention to heavy metals. These can be introduced by applying chemical compounds remaining on the surface of vine shoots. The elements most involved are Cu and Zn. A high quantity of heavy metals, especially concentrated in the ashes, causes great difficulty in the disposal of combustion residues and represents a higher risk to the environment and potentially also to human health. Copper is particularly present in vine shoots due to the use of antifungals (Mescalchin *et al*., 2009). Furthermore, contamination with soil during pruning and harvesting causes an increase in the quantity of Cu in vine shoots (Duca *et al*., 2016). This metal exceeds the limits allowed in the EN ISO 17225-4:2021 standard in the analysis of the whole vine shoot of the three varieties and in the internode and node components. There are statistically significant differences between the three varieties. In detail, Glera has a higher amount of copper (21.04 mg/kg), followed by Merlot (20.25 mg/kg) and Chardonnay (16.54 mg/kg). A greater quantity of copper in Glera is due to a greater number of phytosanitary interventions and greater susceptibility to biological adversities compared to other vine varieties. The treatments applied on the Chardonnay are medium and even less for the Merlot. About the components of shoots, there is a strong presence of Cu, especially in the node, compared to what is found in the internode. High node values are due to the anatomical structure of the component. Indeed, the leaves are inserted in the nodes, and at the base of the petiole are the buds, whose budding takes place in spring. In this period, the first and preventive phytosanitary treatments occur, and the residues of these products probably tend to accumulate in the node. In addition to copper, zinc is also present in large quantities with higher values than the previous one but in any case, lower than the limits of the EN ISO 17225-4:2021 standard. Also, in this case, statistically significant differences were found between the three varieties examined. The variety with the greatest concentration of Zn is Chardonnay (53.80 mg/kg), followed by Merlot (40.38 mg/kg) and Glera (21.10 mg/kg). As for the previous element, a higher concentration in the node was found compared to the other two components. The accumulation of Cu and Zn in the node could be due to their leaching, which, following the flow along the internode, stops at the buds. Overall, as the treatments are distributed onto the plant to create a protective barrier against pathogens, it is more probable to find a greater concentration of these elements in the components of the node and internodes rather than in the pith. Traces in the latter component may be due to radical absorption alone; therefore, deriving from the soil where Cu and Zn can accumulate because of prolonged antifungal treatments over the years (Komárek *et al*., 2010; Brunetto *et al*., 2014; Sonoda *et al*., 2019). These elements could be transported to the central cells of the pith, which, when dying, serve only for the mechanical transport of liquids (Manaresi, 1951). Once they reach the node, these elements are deposited, waiting to be used by the buds, leaves, and bunches, using the node as a storage chamber for microelements. As far as Ni and Cr are concerned, these are present in measurable concentrations but, in any case, lower than the limits of the standard for using them as wood chips. Other important elements are S and Cl. Indeed, high concentrations can cause the emission of toxic substances such as sulphur oxides or hydrochloric acid, which are corrosive to the boiler, as well as dioxins and furans, which are highly dangerous to human health (Mendívil *et al*., 2013). In particular, the Cl contained in biomass, during its combustion, is also responsible for releasing other molecules such as $Cl_2$, KCl, and NaCl (Obernberger *et al*., 2006). Both elements must be present in a concentration of less than 0.10% on a dry basis to avoid problems during combustion (Obernberger *et al*., 2006). In all samples, sulphur and chlorine are below this threshold. However, the concentration of Cl in the whole vine shoots of Merlot is higher than the limit established by the EN ISO 17225-4:2021 standard. Instead, from the analysis of the single components, it is highlighted that the Cl content is high in all three components of the three vine varieties. Overall, the concentration in the individual components, in particular node and internode, tends to be higher than the values of the entire vine shoots. This is due to greater exposure of these wood components to phytosanitary treatments. Finally, nitrogen concentration is an important parameter to evaluate. During biomass combustion, highly polluting compounds can be released into the atmosphere with particular attention to nitrogen oxides NOx (Ozgen *et al*., 2021). Pizzi *et al*. (2018) and Zanetti *et al*. (2017) observed that vine shoots during combustion can release high quantities of NOx, greater than other woody biomass. To avoid NOx problems, the nitrogen concentration in the biomass should not exceed 0.60% on a dry basis (Obernberger *et al*., 2006). In this case, the values found for all three varieties of vine shoots are greater than this threshold, with a nitrogen content of around 0.90% on a dry basis. In the literature, a nitrogen concentration above this threshold has also been found for other vine varieties (Mendívil *et al*., 2013).

## Fibrous fraction

The content of holocellulose, representing the combination of cellulose and hemicellulose, of the analysed vine shoots is about 50.00%, while the lignin is about 18.00%. The extractives content is around 25.00%. The first two polymers are less than what Jimenez *et al*. (2006) found on vine shoots, whose holocellulose and lignin values were 67.14% and 20.27%, respectively. However, from the analysis conducted, it was impossible to define the real composition of the pith. In the literature, the only information about it comes from Manaresi (1951), who identified the presence of starch and other reserve substances absorbed by the plant. However, asserting that the pith consists only of starch is not possible. According to Hellrigl (2006), this is a polysaccharide carbohydrate and has a high-energy potential, around 34.00-36.00 MJ/kg. However, in this case, from the analysis conducted, significantly lower values were found, around 16.00 MJ/kg. Relative to lignin, as reported previously, this is more present in the node and internode than in the pith. Since this polymer has a high heating value, around 26.00-27.00 MJ/kg (Hellrigl, 2006), this could contribute to explaining the greater capacity of the node and internode components compared to the pith. At the same time, it should be considered that cellulose and hemicellulose have an energy potential of around 16.00-17.00 MJ/kg (Hellrigl, 2006). Therefore, the holocelluloses, with a value higher than 56.51%, represent the most present fibrous component, influencing the heating value of the vine shoot more than lignin (18.56%) and extractives (24.93%). The heating value of the entire vine shoot of the three vine varieties (17.80 MJ/kg) is close to those of the holocelluloses (16-17.5 MJ/kg). Finally, the pith, even if present in limited quantities in the internode, could significantly contribute to the reduction of the energy potential of the whole vine shoot.

## Conclusions

This work highlights how vine shoots have suitable physical-chemical characteristics for energy uses. Indeed, as found in other works, this material is a valid resource for energy purposes, an alternative to other biomass, especially if used in power plants equipped with special systems, preventing the emission of dangerous compounds into the environment (Mendívil *et al*., 2013; Picchi *et al*., 2013). However, in this study, significant differences were found between vine varieties and the different vine shoot components. In particular, the low energy potential and high ash content of vine shoots are potentially attributable to the pith component. Although this represents a small portion of the vine shoot, it influences its energy properties. The analysis of the chemical elements and composition of the vine shoot also revealed how the anatomical structure and the presence of different chemical compounds have a fundamental influence on the energy potential of the fuel. The chemical analysis shows a strong presence of Cu and Zn in vine shoots that, in addition to representing a potential danger to the environment and human health, cause an increase in ash content, remaining as unburned elements. In particular, the copper concentration is higher than the limits set by the EN ISO 17225-4:2021 standard. The presence of these metals is attributable to the phytosanitary treatments applied to plants, which were more intense (number of interventions) in the case of Glera, medium for Chardonnay, and less for Merlot because of the different susceptibility of the three varieties to biological adversity. From the analysis of the fibrous fraction, a strong content of extractives was found in the pith of vine shoots. However, it was not possible to determine its real composition. Therefore, it is necessary to conduct further investigations verifying the influence of the anatomical components on the energy properties of vine shoots. Due to their high ash, nitrogen, and copper content, as already stated by Giorio *et al*. (2019), and according to EN ISO 17225-9:2021 (ISO, 2021b), the vine shoots should be used in medium-sized boilers equipped with a pollutant abatement system, in particular capable of reducing NOx (Ozgen *et al*., 2021), and a mobile grate for removal of ashes from the combustion chamber. In conclusion, the results of this study have to be considered at the scientific level because their practical application is not likely. In fact, the elimination of the pith, negatively affecting the characteristics of the vine shoots for energy purposes, would involve excessive costs affecting the economic sustainability of this residual biomass.

## References


Andersen SP, Allen B, Domingo GC, 2021. Biomass in the EU Green Deal: Towards consensus on the use of biomass for EU bioenergy. Policy report, Institute for European Environmental Policy (IEEP), Bruxelles, Belgium.

Brunetto G, Ferreira PAV, Melo GW, Ceretta CA, Toselli M, 2017. Heavy metals in vineyards and orchard soils. Rev. Bras. Frutic. 39.

Brunetto G, Miotto A, Ceretta CA, Schmitt DE, Heinzen J, de Moraes MP, Canton L, Tiecher TL, Comin JJ, Girotto E, 2014. Mobility of copper and zinc fractions in fungicide-amended vineyard sandy soils. Arch. Agron. Soil. Sci. 60:609-24.

Demirbas T, Demirbas C, 2009. Fuel properties of wood species. Energ. Source Part A 31:1464-72.

Di Blasi C, Tanzi V, Lanzetta M, 1997. A study on the production of agricultural residues in Italy. Biomass. Bioenerg. 12:321-31.

Duca D, Toscano G, Pizzi A, Rossini R, Fabrizi S, Lucesoli G, Servilli A, Mancini V, Romanazzi G, Mengarelli C, 2016. Evaluation of the characteristics of vineyard pruning residues for energy applications: effect of different copper-based treatments. J. Agr. Eng. 47:22-27.

Estrellan CR, Iino F, 2010. Toxic emissions from open burning. Chemosphere. 80:193-207.

García R, Pizarro C, Lavín AG, Bueno JL, 2014. Spanish biofuels heating value estimation. Part II: Proximate analysis data. Fuel. 117:1139-47.

Giorio C, Pizzini S, Marchiori E, Piazza R, Grigolato S, Zanetti M, Cavalli R, Simoncin M, Soldà L, Badocco D, Tapparo A, 2019. Sustainability of using vineyard pruning residues as an energy source: combustion performances and environmental impact. Fuel. 243:371-80.

Gismondi R, 2020. Un'analisi integrata delle principali fonti statistiche e amministrative sulla produzione di vino in Italia. ISTAT working paper N. 8/2020.

Hellrigl B, 2006. Elementi di xiloenergetica. Definizione, formule, tabelle. AIEL, Padova, Italy.

ISO, 2015a. Solid biofuels - Determination of total content of carbon, hydrogen and nitrogen. EN ISO 16948:2015. International Organization for Standardization, Geneva, Switzerland.

ISO, 2015b. Solid biofuels - Determination of minor elements. EN ISO 16968:2015. International Organization for Standardization, Geneva, Switzerland.

ISO, 2015c. Solid biofuels - Determination of ash content. EN ISO 18122:2015. International Organization for Standardization, Geneva, Switzerland.

ISO, 2015d. Solid biofuels - Determination of moisture content - Oven dry method - Part 1: Total moisture. EN ISO 18134-1:2015. International Organization for Standardization, Geneva, Switzerland.

ISO, 2016. Solid biofuels - Determination of total content of sulfur and chlorine. EN ISO 16994:2016. International Organization for Standardization, Geneva, Switzerland.

ISO, 2017a. Solid biofuels - Sample preparation. EN ISO 14780:2017. International Organization for Standardization, Geneva, Switzerland.

ISO, 2017b. Solid biofuels - Determination of calorific value. EN ISO 18125:2017. International Organization for Standardization, Geneva, Switzerland.

ISO, 2021a. Solid biofuels - Fuel specifications and classes - Part 4: Graded wood chips. EN ISO 17225-4:2021. International Organization for Standardization, Geneva, Switzerland.

ISO, 2021b. Solid biofuels - Fuel specifications and classes - Part 9: Graded hog fuel and wood chips for industrial use. EN ISO 17225-9:2021. International Organization for Standardization, Geneva, Switzerland.

Jacometti MA, Wratten SD, Walter M, 2007. Management of understorey to reduce the primary inoculum of Botrytis cinerea: Enhancing ecosystem services in vineyards. Biol.

Control 40:57-64.
Jiménez L, Angulo V, Ramos E, De la Torre MJ, Ferre JL, 2006. Comparison of various pulping processes for producing pulp from vine shoots. Ind. Crop. Prod. 23:122-30.
Komárek M, Čadková E, Chrastný V, Bordas F, Bollinger JC, 2010. Contamination of vineyard soils with fungicides: a review of environmental and toxicological aspects. Environ. Int. 36:138-51.
Kumar R, Pandey KK, Chandrashekar N, Mohan S, 2010. Effect of tree-age on calorific value and other fuel properties of Eucalyptus hybrid. J. Forestry Res. 21:514-6.
Lemieux PM, Lutes CC, Santoianni DA, 2004. Emissions of organic air toxics from open burning: a comprehensive review. Prog. Energ. Combust. 30:1-32.
Lieskovský M, Jankovský M, Trenčiansky M, Merganič J, Dvořák J, 2017. Ash content vs. the economics of using wood chips for energy: Model based on data from Central Europe. BioResour. 12:1579-92.
Manaresi A, 1951. Trattato di viticoltura. 3rd ed. Edagricole, Bologna, Italy.
Manzone M, Paravidino E, Bonifacino G, Balsari P, 2016. Biomass availability and quality produced by vineyard management during a period of 15 years. Renew. Energ. 99:465-71.
Mendívil MA, Muñoz P, Morales MP, Juárez MC, García-Escudero E, 2013. Chemical characterization of pruned vine shoots from la Rioja (Spain) for obtaining solid bio-fuels. J. Renew. Sustain. Ener. 5:033113.
Mendívil MA, Muñoz P, Morales MP, Juárez Castelló MC, 2015. Energy potential of vine shoots in La Rioja (Spain) and their dependence on several viticultural factors. Cienc. Investig. Agrar. 42:443-51.
Mescalchin E, Cristoforetti A, Magagnotti N, Silvestri S, Spinelli R, 2009. Utilizzo dei residui di potatura della vite a fini energetici. Fondazione Edmund Mach.
Obernberger I, Brunner T, Bärnthaler G, 2006. Chemical properties of solid biofuels-significance and impact. Biomass Bioen. 30:973-82.
OIV, 2020a. 2020 Wine production. International Organization of Vine and Wine. Paris, France.
OIV, 2020b. State of the world vitivinicultural sector in 2020. International Organization of Vine and Wine. Paris, France.
Ozgen S, Cernuschi S, Caserini S, 2021. An overview of nitrogen oxides emissions from biomass combustion for domestic heat production. Renew. Sust. Energ. Rev. 135:110113.
Picchi G, 2012. Valutazione qualitativa biomassa combustibile derivata da rimozione di frutteto (pesco, Prunus persica L.). IVALSA-Istituto per la Valorizzazione del Legno e delle Specie Arboree, Firenze.
Picchi G, Silvestri S, Cristoforetti A, 2013. Vineyard residues as a fuel for domestic boilers in Trento Province (Italy): Comparison to wood chips and means of polluting emissions control. Fuel 113:43-9.
Pizzi A, Foppa Pedretti E, Duca D, Rossini G, Mengarelli C, Ilari A, Mancini M, Toscano G, 2018. Emissions of heating appliances fuelled with agropellet produced from vine pruning residues and environmental aspects. Renew. Energ. 121:513-20.
Scarlat N, Dallemand J, Taylor N, Banja M, 2019. Brief on biomass for energy in the European Union. Sanchez Lopez J, Avraamides M, Publications Office of the European Union, Luxembourg.
Senila L, Neag E, Torok I, Cadar O, Kovacs E, Ţenu I, Roman C, 2020. Vine shoots waste - new resources for bioethanol production. Rom. Biotech. Lett. 25:1253-9.
Sonoda K, Hashimoto Y, Wang SL, Ban T, 2019. Copper and zinc in vineyard and orchard soils at millimeter vertical resolution. Sci. Total Environ. 689:958-62.
Spinelli R, Nati A, Pari L, Mescalchin E, Magagnotti N, 2012. Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues. Appl. Energ. 89:374-9.
Spinelli R, Negrin M, Francescaro V, 2010. Recupero delle potature di vigneti e frutteti finalizzato alla valorizzazione energetica. AIEL, Padova, Italy.
Valer M, 2010. Quale macchina scegliere per accogliere i residui di potatura. Inf. Agrario 8:16-9.
Van Soest PJ, Robertson JB, Lewis BA, 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-97.
Zanetti M, Brandelet B, Marini D, Sgarbossa A, Giorio C, Badocco F, Tapparo A, Grigolato S, Rogaume C, Rogaume Y, Cavalli R, 2017. Vineyard pruning residues pellets for use in domestic appliances: a quality assessment according to the EN ISO 17225. J. Agr. Eng. 48:99.