energies

Article

Characterization of Post-Production Waste from Winemaking of Selected *Vitis vinifera* L. Varieties Grown in Temperate Climates and Their Energy Valorization

Magdalena Kapłan [1], Grzegorz Maj [2], Kamila E. Klimek [3,*], Kamil Buczyński [1], Anna Borkowska [3], Radek Sotolář [4], Richard Danko [4] and Mojmir Baroň [4]

[1] Institute of Horticulture Production, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland; magdalena.kaplan@up.lublin.pl (M.K.)
[2] Department of Power Engineering and Transportation, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland; grzegorz.maj@up.lublin.pl
[3] Department of Applied Mathematics and Computer Science, University of Life Sciences in Lublin, Głęboka 28, 20-612 Lublin, Poland; anna.borkowska@up.lublin.pl
[4] Department of Viticulture and Enology, Mendel University in Brno, 691-44 Lednice, Czech Republic; radek.sotolar@mendelu.cz (R.S.); richard.danko@mendelu.cz (R.D.); mojmir.baron@mendelu.cz (M.B.)
* Correspondence: kamila.klimek@up.lublin.pl

Abstract: The study assessed the yield and quality as well as the energy potential of biomass from stalks and pomace of four grape varieties, Riesling, Chardonnay, Zweigelt, and Merlot *Vitis vinifera* L., grown in temperate climate conditions. The research is innovative because the evaluation of the energy potential of biomass originating from *Vitis vinifera* L. has not been carried out so far in the northern wine-growing regions. Field studies were conducted in 2023 in the Experimental Vineyard of the University of Life Sciences in Lublin, located in southeastern Poland. Biometric yield assessment showed that Chardonnay vines were characterized by the lowest mass of clusters and peduncles, number of berries in the cluster, berry diameter, and peduncle size, and at the same time the highest berry mass among the assessed biotypes. Merlot clusters were characterized by the highest mass of clusters and the largest peduncles. Riesling had the most berries in the cluster, the heaviest peduncles, and the highest share of peduncles in the cluster mass (8.99%). For grape pomace, the LHV values range from 15.98 MJ kg^{-1} for the Chardonnay variety to 16.91 MJ kg^{-1} for Riesling, while for peduncles, these values range from 15.11 MJ·kg^{-1} for Merlot and Riesling to 15.26 MJ kg^{-1} for Chardonnay. The differences in pollutant emissions are more pronounced between grapevine varieties than between types of biomass (pomace vs. peduncles). The greatest variation among varieties was observed for carbon dioxide (CO_2) emissions in the pomace category, while the smallest differences were noted for sulfur dioxide (SO_2) emissions. Total gas emissions were highest for Zweigelt pomace (7.72 Nm^3 kg^{-1}) and lowest for Merlot (6.99 Nm^3 kg^{-1}), while for stalks, Chardonnay had the highest values (6.77 Nm^3 kg^{-1}) and Merlot the lowest (7.32 Nm^3 kg^{-1}). The largest variation among varieties was observed in the pomace category. These results indicate differences in exhaust gas emissions for different plant parts and grape varieties, which are relevant for optimizing production processes and ensuring sustainable development.

Keywords: grapevine yield; wine production waste biomass; energy potential; biofuel

Academic Editors: Franco Berruti and Alberto Maria Gambelli

Received: 16 December 2024
Revised: 13 January 2025
Accepted: 27 January 2025
Published: 31 January 2025

Citation: Kapłan, M.; Maj, G.; Klimek, K.E.; Buczyński, K.; Borkowska, A.; Sotolář, R.; Danko, R.; Baroň, M. Characterization of Post-Production Waste from Winemaking of Selected *Vitis vinifera* L. Varieties Grown in Temperate Climates and Their Energy Valorization. *Energies* **2025**, *18*, 663. https://doi.org/10.3390/en18030663

1. Introduction

The strain on energy markets, initially exacerbated by the COVID-19 pandemic, intensified considerably after the conflict between Russia and Ukraine erupted in late February

2022, which in turn triggered a worldwide energy crisis [1]. The ongoing depletion of finite fossil fuel resources has led to a re-evaluation of future energy strategies, anticipating a scenario where such resources will no longer be accessible. As a result, renewable energy sources have emerged as some of the most promising alternatives to fulfill future energy demands [2]. Understanding the link between energy consumption and well-being is essential for developing comprehensive energy policies. These policies must not only address the need to mitigate climate change caused by current fossil-based energy systems but also support human development, which is inherently dependent on energy access [3]. In scenarios designed to mitigate climate change, bioenergy holds a crucial role [4]. In 2020, renewable energy consumption saw a 3% increase, largely driven by a nearly 7% growth in renewable electricity production. This contributed significantly to the overall rise, pushing the share of renewables in global electricity generation to 29%, compared to 27% in 2019 [5]. As a result, in the gradual shift towards a bioeconomy, there has been a marked rise in interest in sustainable energy sources like solar, wind, geothermal, and biomass energy. Biomass, in particular, has become one of the primary raw materials within the global bioenergy network [6]. Throughout human evolution and technical development, biomass has consistently been a vital energy source. Since the onset of the Industrial Revolution, rapid economic growth has taken place. Alongside this, the global population has expanded exponentially, leading to a significant rise in energy demand, yet no long-term sustainable resource strategy has been established to adequately meet this growing demand [7]. The Sustainable Development Goals (SDGs), adopted by all UN Member States in 2015, serve as a framework to help societies attain a more sustainable and equitable future. At present, the growing shift in nations towards a bioeconomy is driving an increased demand for biomass. However, it is crucial to examine the various options for biomass allocation and distribution to identify any potential negative consequences they may entail [8].

Bioenergy derived from agriculture relies on crop cultivation and livestock farming, promoting an integrated model that combines plant, animal, and bioenergy production. However, the exact effect of this integrated system on alleviating the various environmental impacts linked to agricultural and livestock activities remains uncertain [9]. Agricultural residues, wood biomass, and dedicated energy crops are regarded as essential raw materials for improving energy security and decreasing reliance on fossil fuels. Over the past few decades, considerable efforts have been focused on advancing efficient and cost-effective technologies for converting biomass into energy [10]. A major environmental challenge in producing countries is the rise in lignocellulosic waste, a byproduct of the expansion of agroindustrial activities over the last century. To support environmental protection, these wastes are transformed through mechanical, chemical, or biological processes into raw materials for the creation of new products and applications. This strategy, rooted in the principles of a circular economy, strives to achieve the "zero waste" objective within society [11].

Grapes rank as the third most valuable horticultural crop globally, following potatoes and tomatoes. The cultivation of grapes for both fruit and wine dates back at least 7000 years to the Near East. Today, grapes are grown worldwide, predominantly in regions with a temperate, Mediterranean-like climate, and are utilized to produce a wide range of consumer goods, such as wine, table grapes, raisins, grape juice concentrate, and distillates [12]. In New World countries leading in wine consumption, there remains a notable and substantial increase in wine consumption, while emerging wine production markets are exhibiting rapid growth. Approximately 80% of these countries have demonstrated rising trends in wine imports, reflecting the influence of globalization on the wine market and the increasing demand for foreign wines [13]. Historically, grape cultivation and wine production have been important economic pursuits, profoundly shaping both the culture and the landscapes in which these activities have thrived [14]. Wine production is a major sector within global agriculture. Despite the wine industry being generally viewed as environmentally friendly, both grape cultivation and winemaking present various environmental challenges. A primary concern is the management of large volumes of organic waste, with the nature of the waste varying significantly depending on the specific winemaking processes employed [15,16]. Wine production results in substantial quantities of both organic and inorganic waste. During grape cultivation and harvest, about 5 tons of solid waste is generated per hectare each year. In the processing stage, it is estimated that wineries globally produce approximately 13 million tons of solid waste annually, which includes seeds, skins, and grape stalks, collectively known as grape pomace [17]. Annual wine production in Poland, regardless of the lack of power supply in recent years, allowed achieving efficiency in the 2022/2023 marketing year: 16,084 hl for white wines and 9591 hl for red wines. Currently, there are no statistics kept in Poland regarding the amount of waste produced in the wine production process [18]. Traditional waste processing methods are expensive due to the substantial financial and energy resources required to safely dispose of waste in an environmentally responsible manner [19]. Not all waste is appropriate for composting, and in some instances, the process can be inefficient and time-consuming. In such cases, thermal treatment may serve as a viable alternative; however, this method must be optimized to reduce greenhouse gas emissions to the minimum possible levels [20,21]. Biomass is commonly combusted in fixed-bed, fluidized-bed, or pulverized-bed boilers to produce high-pressure steam, which in turn powers a turbine to generate electricity [22]. Improving the global economic viability and competitiveness of biomass necessitates continuous research efforts, supportive legislation, and strengthened international cooperation [23].

Compared to conventional fossil fuels, bioenergy offers distinct advantages due to its renewability and high availability. This phenomenon is a key element in strengthening energy security.

Nevertheless, the development of bioenergy has the potential to cause significant environmental changes, the full extent of which remains not fully explored [24].

In order to address the challenges facing the wine sector in terms of waste management and to replace fossil fuels with renewable energy sources, this study analyzed and evaluated the energy potential of biomass derived from *Vitis vinifera* stalks and pomace grown under temperate climate conditions, with particular emphasis on Riesling, Chardonnay, Zweigelt, and Merlot varieties. The research conducted is innovative in that the analysis of *Vitis vinifera* L. varieties has not been conducted in northern wine-growing regions. The authors of the paper in earlier studies focused on evaluating the energy potential from leaves, vine pedicels, and post-production residues from wine-growing PIWI varieties [20,25–31].

2. Materials and Methods

Field studies were conducted in 2023 at the Experimental Vineyard of the University of Life Sciences in Lublin, located in southeastern Poland. *Vitis vinifera* L. grapevine varieties, including Chardonnay, Merlot, Riesling, and Zweigelt, were planted in the spring of 2020 with a spacing of 2.5 × 1.2 m (3333 plants per hectare) on loess soil. The grapevines were trained using a single Guyot system, with a trunk height of 40 cm, a single shoot approximately 1.0 m in length, and a single two-bud spur. Grapes were hand-harvested upon reaching optimal ripeness, between 23.5 and 24.5 °Brix. A total of 25 kg of grapes was collected from each combination. For morphological characterization, 50 clusters from each combination were analyzed, with the following parameters determined: cluster mass, the number of berries per cluster, the mass of 10 berries, and berry diameter. The stems were subjected to biometric measurements, including weight, length, and width, and the percentage of stems in the total mass of the bunches was determined. The stems were dried at a controlled temperature. Cluster, berry, and peduncle masses were estimated by weighing them on an AXIS A250 (AXIS Sp. z o.o. 80-125 Gdańsk, Poland, Kartuska 375B, 2015) electronic scale with an accuracy of 0.001 kg. Berry diameter was measured with an HG-DY064 (Benetech Poland Artur Rosa, Wrocławska 35-37, 62-800 Kalisz, Poland, 2017) digital caliper, and peduncle length and width were assessed with a caliper with an accuracy of 0.1 cm.

The experiment was designed in a randomized block design, involving 4 combinations with 5 replications. Replications consisted of plots, each containing 3 plants. After the experiment was completed, the results obtained were subjected to a statistical analysis using a one-way analysis of variance (ANOVA), comparisons between varieties within each plant material separately, and comparisons of plant material for each variety separately. Statistical inference was carried out at a significance level of $p < 0.05$. In addition, the results were presented graphically. Multivariate data analysis techniques were applied, including a cluster analysis and principal component analysis. The results of the cluster analysis were presented using a dendrogram to show the yield and quality of the quantity of wine waste and the calorific value of stalks and pomace. The relationship between the components of the biomass of wine production vines not dependent on the plant material was determined for each variety separately. All analyses were carried out using STATISTICA 13 software (StatSoft, Inc.; TIBCO Software; Palo Alto, CA, USA; 2015).

The detailed methodology for the measured parameters is discussed in Tables 1–3. Before the tests, the material was placed in a room with a constant temperature and humidity, where it was naturally dried in air-dry conditions at 20 °C and 55% to 60% air humidity for two weeks to standardize the evaluation conditions. The material for the laboratory analysis was first crushed (0.5 mm) using a Retsch SM 100 mill (Retsch GmbH, Haan, Germany, 2022) with a power of 1.5 kW. For the purpose of this study, 100 g of material was obtained in 2 min, which consumed 0.045 kWh. Our results represent values in the analytical state; additionally, for HHV, the analytical state was converted to a dry state without ash.

Table 1. Fuel Characterization Analysis.

Parameter	Method	Equipment
	Energetic properties	
Higher heating value (HHV; MJ·kg^{-1})	EN-ISO 1928:2020 [32]	isoperibolic calorimeter LECO AC 600 (LECO Corporation, Saint Joseph, MI, USA, 2012)
Lower heating value (LHV; MJ·kg^{-1})		
	Proximate Analysis	
Ash (A; %)	EN-ISO 18122:2022 [33]	thermogravimetric analyzer LECO TGA 701 (LECO Corporation, Saint Joseph, MI, USA, 2013)
Volatile matter (V; %)	EN-ISO 18123:2023 [34]	
Moisture (M; %)	EN-ISO 18134:2023 [35]	
Fixed carbon (FC; %)	FC = 100 − V − A − M [36]	
	Ultimate Analysis	
Carbon (C; %)	EN-ISO 16948:2015 [37]	elemental analyzer LECO CHNS 628 (LECO Corporation, Saint Joseph, MI, USA, 2012)
Hydrogen (H; %)		
Nitrogen (N; %)		
Sulfur (S; %)	EN-ISO 16994:2016 [38]	
Oxygen (O; %)	O = 100 − A − H − C − S − N [39]	

Table 2. Emission Factors (Emission factors calculated according to study [40]).

Parameter	Method and Equipment
Carbon monoxide emission factor (Ec) of chemically pure coal (CO; kg·Mg^{-1})	$CO = \frac{28}{12} \cdot E_c \cdot (C/CO)$, CO—carbon monoxide emission factor (kg·kg^{-1}), $\frac{28}{12}$—molar mass ratio of carbon monoxide and carbon, E_C—emission factor of chemically pure coal (kg·kg^{-1}), C/CO—part of the carbon emitted as CO (for biomass 0.06).
Carbon dioxide emission factor (CO_2; kg·Mg^{-1})	$CO_2 = \frac{44}{12} \cdot \left(E_c - \frac{12}{28} \cdot CO - \frac{12}{16} \cdot E_{CH_4} - \frac{26.4}{31.4} \cdot E_{NMVOC}\right)$, CO_2—carbon dioxide emission factor (kg·kg^{-1})—molar mass ratio of carbon dioxide and pure coal—molar mass ratio of carbon dioxide and carbon monoxide—molar mass ratio of carbon and methane, E_{CH4}—methane emission factor, E_{NMVOC}—emission index of non-methane VOCs (for biomass 0.009).
Sulfur dioxide emission factor (SO_2; kg·Mg^{-1})	$SO_2 = \frac{2S}{100} \cdot (1 - r)$, SO_2—sulfur dioxide emission factor (kg·kg^{-1}), 2—molar mass ratio of SO_2 and sulfur, S—sulfur content in fuel (%), r—coefficient determining the part of total sulfur retained in the ash.
Emission factor was calculated from NO_X; kg·Mg^{-1}	$NO_x = \frac{46}{14} \cdot E_c \cdot N/C \cdot (N_{NO_x}/N)$, NO_x—NO_x emission factor (kg·kg^{-1})—molar mass ratio of nitrogen dioxide to nitrogen. The molar mass of nitrogen dioxide is considered due to the fact that nitrogen oxide in the air oxidizes very soon to nitrogen dioxide; N/C—nitrogen to carbon ratio in biomass, NO_x/N—part of nitrogen emitted as NO_x (for biomass 0.122).

Table 3. Exhaust gas composition (Exhaust gas composition was calculated according to [41,42]).

Parameter	Method and Equipment
Theoretical oxygen demand (VO_2; Nm^3·kg^{-1})	$V_{O_2} = \frac{22.41}{100} \cdot \left(\frac{C}{12} + \frac{H}{4} + \frac{S-O}{32}\right)$, C—biomass carbon content (%), H—biomass hydrogen content (%), S—biomass sulfur content (%), O—biomass oxygen content (%).
The stoichiometric volume of dry air required to burn 1 kg of biomass (V_{oa}; Nm^3·kg^{-1})	$V_{O_a} = \frac{V_{O_2}}{0.21}$, since the oxygen content in the air is 21%, which participates in the combustion process in the boiler, and is the stoichiometric volume of dry air required to burn 1 kg of biomass.
Carbon dioxide content of the combustion products (VCO_2; Nm^3·kg^{-1})	$V_{CO_2} = \frac{22.41}{12} \cdot \frac{C}{100}$
Content of sulfur dioxide (VSO_2; Nm^3·kg^{-1})	$V_{SO_2} = \frac{22.41}{32} \cdot \frac{S}{100}$
Water vapor content of the exhaust gas (VH_2O; Nm^3·kg^{-1})	$V^H_{H_2O} = \frac{22.41}{100} \cdot \left(\frac{H}{2} + \frac{M}{18}\right)$ is the component of water vapor volume from the hydrogen combustion process $\left(V^H_{H_2O}\text{; Nm}^3\text{H}_2\text{O·kg}^{-1}\text{ fuel}\right)$ $V^a_{H_2O} = 1.61 \cdot x \cdot V_{oa}$ and the volume of moisture contained in the combustion air $\left(V^a_{H_2O}\text{; Nm}^3\text{H}_2\text{O·kg}^{-1}\text{ fuel}\right)$ $V_{H2O} = V^H_{H2O} + V^a_{H2O}$; M—fuel moisture content (%), x—air absolute humidity (kg H_2O·kg^{-1} dry air).
The theoretical nitrogen content in the exhaust gas (V_{N2}; Nm^3·kg^{-1})	$V_{N2} = \frac{22.41}{28} \cdot \frac{N}{100} + 0.79 \cdot V_{oa}$, considering that the nitrogen in the exhaust comes from the fuel composition and the combustion air, and the nitrogen content in the air is 79%.
The total stoichiometric volume of dry exhaust gas (V_{gu}; Nm^3·kg^{-1})	$V_{gu} = V_{CO2} + V_{SO2} + V_{N2}$
The total volume of exhaust gasses (V_{ga}; Nm^3·kg^{-1})	$V_{ga} = V_{gu} + V_{H2O}$ Assuming that biomass combustion is carried out under stoichiometric conditions, i.e., using the minimum amount of air required for combustion (λ = 1), a minimum exhaust gas volume will be obtained.

3. Results

3.1. Biometric Characteristics

Table 4 presents the results of yield size and quality assessment of four *Vitis vinifera* L. grapevine varieties: Chardonnay, Merlot, Riesling, and Zweigelt. The analysis includes parameters such as cluster mass (g), the number of berries per cluster (pcs), mass of 10 clusters (kg), berry diameter (mm), and the mass of 10 berries (g). The study indicates statistically significant differences among the assessed varieties for most of the evaluated parameters, highlighting a distinct variation between the varieties.

Table 4. Analyses of the size and quality of the yield of four Vitis Vinifera grape varieties.

Variety	Bunch Weight (g)	Number of Berries in a Bunch (pcs.)	Berry Diameter (mm)	Weight of 10 Berries (g)
Chardonnay	102.30 ± 39.63 B *	48.80 ± 9.31 C	13.99 ± 1.06 B	20.93 ± 10.57 A
Merlot	200.20 ± 98.40 A	110.20 ± 28.21 A	14.22 ± 0.40 B	19.23 ± 12.67 A
Riesling	186.80 ± 69.38 A	113.20 ± 19.19 A	14.72 ± 0.93 AB	15.86 ± 7.47 A
Zweigelt	170.92 ± 83.93 AB	91.60 ± 13.33 B	15.09 ± 0.86 A	17.99 ± 9.67 A
p-value	0.0042	<0.0001	0.0034	0.5873

* Significant difference; ±—standard deviation; A, B, C, AB—different letters in a column indicate significant differences at $\alpha = 0.05$ for significant differences between the analyzed grapevine varieties.

The assessment of the yield size and quality of grapevines is essential not only for differentiating varieties but also for evaluating their potential applications in optimizing cultivation technologies, wine production, and the use of winemaking residues for energy purposes. An analysis of the data in Table 4 revealed that the Merlot variety had the highest average cluster mass (200.2 g), while Chardonnay had the lowest (102.3 g). In the study by Gombau et al. [43], Merlot clusters were found to be the smallest among the assessed *Vitis vinifera* L. varieties, including Garnacha, Tempranillo, and Cabernet Sauvignon. The opposite trend was observed in the present study. Kowalczyk et al. [44] demonstrated a significant effect of variety, rootstock type, and study year on cluster mass when evaluating hybrid grape varieties such as Solaris, Seyval Blanc, and Johanniter grown in a temperate climate.

Significant differences are observed in the number of berries per cluster. The Riesling variety had the highest number of berries per cluster (113.2 berries), while Chardonnay had significantly fewer (48.8 berries). The substantial effect of variety on the berry count per cluster was also demonstrated in the study by Gombau et al. [43]. In research by Klimek et al. [45], it was shown that a biotic factor, such as the type of rootstock used, can influence the number of berries per cluster, while Zombardo et al. [46] found no such effect.

Regarding berry diameter, the Zweigelt variety stands out with a significantly larger diameter (15.09 mm), distinctly different from Chardonnay (13.99 mm) and Merlot (14.22 mm). In the study by Tecchio et al. [47], berry size was assessed by analyzing both the length and width of this parameter, revealing a significant effect of *Vitis vinifera* L. grapevine variety on the evaluated parameters. Similarly, Kowalczyk et al. [48] determined this parameter by measuring berry length and width. Their study demonstrated a significant effect of variety on berry length, though no significant effect was found for width.

It was found that Chardonnay grapevines exhibited the highest mass of 10 berries, amounting to 20.93 g, while the Riesling variety had the lowest (15.86 g). Notably, the differences in the mass of 10 berries among varieties are not statistically significant, indicating that these values are comparable despite the observed variations. In the study by Tecchio et al. [47], which assessed the size and quality of the yield of five grapevine varieties, a significant effect of variety type on berry mass was demonstrated. The Merlot variety was found to have significantly smaller berries compared to Cabernet Franc, Syrah, and Sauvignon Blanc. Similarly, Kowalczyk et al. [48], in their evaluation of PIWI grape varieties, demonstrated a significant influence of variety on berry mass, a dependency further confirmed by Gombau et al. [43].

Table 5 presents the results of the assessment of grape peduncle size and quality for four *Vitis vinifera* L. varieties: Chardonnay, Merlot, Riesling, and Zweigelt. The analysis includes various parameters such as peduncle mass (g), peduncle length (cm), peduncle width (mm), and the percentage contribution of the peduncle to the total cluster mass. The study reveals statistically significant differences among the examined varieties for most parameters, indicating a distinct variation between the varieties.

Table 5. Evaluation of size and quality of grape peduncles of four *Vitis vinifera* L. grape varieties.

Variety	Stem Weight (g)	Stem Length (cm)	Stem Width (cm)	Stem Share in Bunch Weight (%)
Chardonnay	6.00 ± 2.42 B *	5.80 ± 1.78 C	5.31 ± 1.52 C	6.54 ± 3.39 A
Merlot	8.14 ± 3.84 B	13.50 ± 3.86 A	10.35 ± 3.72 A	5.25 ± 4.06 A
Riesling	14.56 ± 6.37 A	7.97 ± 2.28 BC	6.71 ± 1.39 BC	8.99 ± 5.32 A
Zweigelt	8.16 ± 4.13 B	9.61 ± 2.43 B	8.55 ± 2.99 AB	5.85 ± 3.49 A
p-value	<0.0001	<0.0001	<0.0001	0.0814

* Significant difference; ±—standard deviation; A, B, C, AB, BC—different letters in a column indicate significant differences at α = 0.05 for significant differences between the analyzed grapevine varieties.

Data from Table 5 indicate that the Riesling variety had the significantly highest peduncle mass (14.56 g) among all evaluated varieties, while Chardonnay clusters had the lowest peduncle mass (6.00 g) among the assessed varieties. Gombau et al. [43] did not find a significant impact of variety on peduncle mass in their study of Tempranillo, Garnacha, Merlot, and Cabernet Sauvignon grapevines.

Among the varieties studied, significant differences were observed in peduncle length, with Merlot exhibiting the longest peduncles (13.50 cm) and Chardonnay the shortest (5.80 cm). In terms of peduncle width, the widest peduncles were found in Merlot (10.35 mm), while Chardonnay exhibited the narrowest (5.31 mm).

Regarding the peduncle's contribution to cluster mass, Riesling recorded the highest percentage (8.99%), while Merlot had the lowest (5.25%). However, it is worth noting that differences in the peduncle's contribution to cluster mass are not statistically significant, suggesting that these values are comparable across varieties, despite some observed differences. In the study by Gombau et al. [43], a significant effect of variety on the peduncle's contribution to cluster mass was demonstrated. The authors found that Merlot had the lowest percentage contribution of stem mass relative to cluster mass among Garnacha, Tempranillo, Merlot, and Cabernet Sauvignon, a finding corroborated by the present study.

The collected data may suggest which varieties are more efficient in terms of specific peduncle traits, offering valuable insights for selecting varieties suited to specific cultivation objectives, wine production, or energy use. Analyzing these parameters is essential not only for enhancing grape quality but also for optimizing cultivation and harvest techniques, which could lead to more efficient and sustainable production. The above data highlight the potential production capabilities of peduncles, which could be utilized in winemaking or as a byproduct with energy-generation potential.

The cluster analysis presented in Figure 1a classifies grapevine varieties according to their production potential, while Figure 1b classifies them based on the potential post-production waste in the form of grape peduncles.

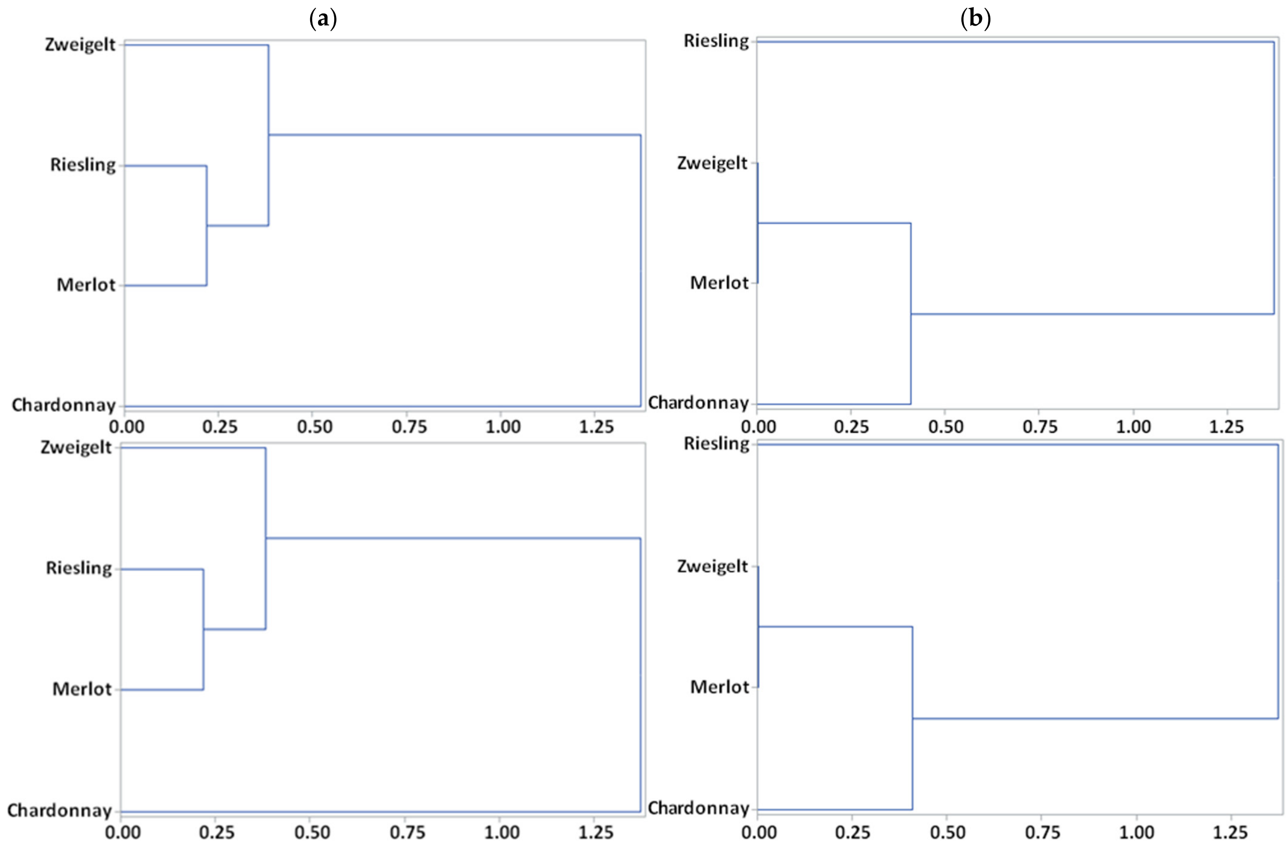

Figure 1. The principal component analysis of the parameters determining the yield and quality (**a**) and the amount of wine production waste (**b**) of four *Vitis vinifera* L. grape varieties.

Figure 1a displays a dendrogram with two main clusters, providing insight into the differences in yield size and quality among the grapevine varieties. Chardonnay forms a separate cluster, indicating marked differences in the assessment of these parameters compared to other varieties. Merlot and Riesling show the highest similarity to each other, while Zweigelt, clustering at a slightly higher level, demonstrates considerable similarity in these parameters as well.

Figure 1b classifies the similarity of the examined grapevine varieties in terms of post-production waste in the form of peduncles. Merlot and Zweigelt cluster closely at an early level, indicating very similar values for the analyzed parameters. Chardonnay forms a separate cluster, joining the previously mentioned varieties at the next level, indicating a slightly divergent difference. Riesling is located in a distinct cluster, showing its uniqueness.

3.2. Energy Potential Assessment

Table 6 presents the results of a proximate and ultimate analysis for pomace and peduncles from the four grapevine varieties. The analyzed parameters include the lower heating value (LHV), higher heating value (HHV), moisture content (M), volatile compounds (V), ash content (A), fixed carbon (FC), and elemental composition—carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O). Additionally, the analysis includes ratios such as hydrogen to carbon (H/C), nitrogen to carbon (N/C), and oxygen to carbon (O/C). The results illustrate differences between pomace and peduncles across the varieties, allowing for an assessment of the energy potential and thermal properties of these biomaterials. Furthermore, statistically significant differences were found among grapevine varieties for both pomace and peduncles across all analyzed parameters, suggesting that both the choice of grapevine variety and plant part significantly impact the energy and thermal properties of the biomass.

Table 6. Proximate and ultimate analysis for pomace and peduncles depending on variety used in viticulture.

Parameter		Chardonnay	Merlot	Riesling	Zweigelt	*p*-Value
LHV ($MJ \cdot kg^{-1}$)	pomace	15.98 ± 0.07 Ca *	16.60 ± 0.03 Ba	16.91 ± 0.02 Aa	16.74 ± 0.10 ABa	0.0001
	stalks	15.26 ± 0.11 Ab	15.11 ± 0.02 Ab	15.11 ± 0.06 Ab	14.55 ± 0.05 Bb	0.0001
	p-value	0.0007	0.0001	0.0001	0.0001	
HHV ($MJ \cdot kg^{-1}$)	pomace	17.14 ± 0.07 Ca	17.79 ± 0.03 Ba	18.07 ± 0.02 Aa	17.90 ± 0.10 ABa	0.0001
	stalks	16.41 ± 0.11 Ab	16.25 ± 0.02 Ab	16.25 ± 0.06 Ab	15.66 ± 0.05 Bb	0.0001
	p-value	0.0006	0.0001	0.0001	0.0001	
M (%)	pomace	6.43 ± 0.01 Aa	4.23 ± 0.02 Db	5.97 ± 0.06 Ba	5.65 ± 0.02 Cb	0.0001
	stalks	6.44 ± 0.02 Aa	6.47 ± 0.06 Aa	5.78 ± 0.07 Bb	6.36 ± 0.03 Aa	0.0001
	p-value	0.6087	0.0001	0.0246	0.0001	
V (%)	pomace	68.22 ± 0.21 ABa	67.59 ± 0.37 Ba	68.51 ± 0.26 Aa	67.86 ± 0.32 ABa	0.0224
	stalks	65.05 ± 0.33 Bb	62.77 ± 0.35 Cb	66.24 ± 0.27 Ab	64.45 ± 0.53 Bb	0.0001
	p-value	0.0001	0.0001	0.0001	0.0001	
A (%)	pomace	8.33 ± 0.06 Aa	3.51 ± 0.46 Cb	7.66 ± 0.10 Bb	7.59 ± 0.06 Bb	0.0001
	stalks	9.03 ± 0.35 Db	10.47 ± 0.12 Ba	9.73 ± 0.03 Ca	12.75 ± 0.11 Aa	0.0001
	p-value	0.0259	0.0001	0.0001	0.0001	
FC (%)	pomace	17.01 ± 0.26 Cb	24.67 ± 0.81 Aa	17.86 ± 0.22 BCa	18.90 ± 0.27 Ba	0.0001
	stalks	19.48 ± 0.04 Aa	20.30 ± 0.39 Ab	18.26 ± 0.30 Ba	16.44 ± 0.46 Cb	0.0001
	p-value	0.0001	0.0011	0.1337	0.0001	
C (%)	pomace	45.03 ± 0.34 Ca	46.19 ± 0.13 Ba	46.66 ± 0.06 Aa	47.10 ± 0.11 ABa	0.0001
	stalks	44.43 ± 0.23 ABa	44.81 ± 0.15 Ab	44.08 ± 0.26 BCb	43.41 ± 0.40 Cb	0.0016
	p-value	0.0671	0.0003	0.0001	0.0001	
H (%)	pomace	7.37 ± 0.01 Aa	7.24 ± 0.03 Ba	7.29 ± 0.02 Ba	7.18 ± 0.03 Ca	0.0001
	stalks	6.71 ± 0.06 Ab	5.83 ± 0.73 Ab	6.33 ± 0.58 Ab	6.36 ± 0.06 Ab	0.2209
	p-value	0.0001	0.028	0.0444	0.0001	
N (%)	pomace	1.69 ± 0.04 Aa	1.06 ± 0.01 Bb	1.65 ± 0.05 Aa	1.67 ± 0.02 Aa	0.0001
	stalks	1.75 ± 0.08 Aa	1.39 ± 0.05 Ca	1.49 ± 0.06 BCb	1.60 ± 0.09 ABa	0.0016
	p-value	0.2805	0.0004	0.0256	0.2541	
S (%)	pomace	0.13 ± 0.01 Ba	0.08 ± 0.01 Ca	0.12 ± 0.01 Ba	0.15 ± 0.01 Aa	0.0001
	stalks	0.07 ± 0.00 Bb	0.04 ± 0.00 Cb	0.06 ± 0.00 Bb	0.08 ± 0.00 Ab	0.0001
	p-value	0.0001	0.0002	0.0001	0.0001	
O (%)	pomace	37.46 ± 0.43 Ba	41.91 ± 0.60 Aa	36.62 ± 0.12 BCb	36.31 ± 0.20 Ca	0.0001
	stalks	38.00 ± 0.51 Aa	37.46 ± 0.81 Ab	38.32 ± 0.46 Aa	35.81 ± 0.43 Ba	0.0029
	p-value	0.2314	0.0016	0.0034	0.1371	
H/C (%)	pomace	1.64 ± 0.01 Aa	1.57 ± 0.00 Ba	1.56 ± 0.00 Ba	1.52 ± 0.00 Ca	0.0001
	stalks	1.51 ± 0.01 Ab	1.30 ± 0.16 Ab	1.44 ± 0.14 Aa	1.46 ± 0.01 Ab	0.1627
	p-value	0.0002	0.0432	0.1817	0.0001	
N/C (%)	pomace	0.04 ± 0.00 Aa	0.02 ± 0.00 Cb	0.04 ± 0.00 Ba	0.04 ± 0.00 Ba	0.0001
	stalks	0.04 ± 0.00 Aa	0.03 ± 0.00 Ca	0.03 ± 0.00 BCa	0.04 ± 0.00 ABa	0.0026
	p-value	0.1822	0.0003	0.2415	0.3951	
O/C (%)	pomace	0.62 ± 0.01 Ba	0.68 ± 0.01 Aa	0.59 ± 0.00 Cb	0.58 ± 0.00 Cb	0.0001
	stalks	0.64 ± 0.01 ABa	0.63 ± 0.02 ABb	0.65 ± 0.01 Aa	0.62 ± 0.01 Ba	0.0438
	p-value	0.1453	0.0089	0.0002	0.0001	

* Significant difference: a and b mean that different letters in the column, and A–D mean that different letters in the row, indicate significant differences at α = 0.05.

For grape marc, LHV values range from 15.98 $MJ \cdot kg^{-1}$ for the Chardonnay variety to 16.91 $MJ \cdot kg^{-1}$ for Riesling, while for stalks, the values range from 15.11 $MJ \cdot kg^{-1}$ for Merlot and Riesling to 15.26 $MJ \cdot kg^{-1}$ for Chardonnay. The results indicate small differences in biomass energy potential between varieties, amounting to 5.50% for pomace and 0.98 for stalks.

In the case of grape marc, the highest HHV was recorded for the Riesling variety (18.02 $MJ \cdot kg^{-1}$), and the lowest for Chardonnay (17.14 $MJ \cdot kg^{-1}$). For stalks, the highest HHV was observed for Chardonnay (16.41 $MJ \cdot kg^{-1}$), while the lowest values were found for Merlot and Riesling (16.25 MJ·kg^{-1}). The difference in biomass energy potential between varieties is 4.88% for pomace, respectively, and the difference for cones is 0.97%.

Analyzing the data from Tables 6 and 7 and comparing the obtained results with findings from the literature, it is noteworthy that the pomace from the Merlot variety exhibits similar HHVs to the woody residues of this variety. Additionally, the pomace from Chardonnay, Zweigelt, and Merlot has HHVs comparable to the woody residues from Cabernet Sauvignon and Chardonnay grapevines. For peduncles, the HHV of the Chardonnay variety shows a resemblance to the wood waste from Pinot grapevines [49,50]. In the study by Montari et al. [51] regarding grape marc obtained from wine production in the southern region of Brazil, it was shown that the pre-treatment of grape marc has a significant impact on the level of the higher heating value.

Table 7. Comparison of HHV and LHV of wood vineyard pruning residues.

Grape Variety	HHV (MJ·kg^{-1})	LHV (MJ·kg^{-1})
Merlot [49]	17.8	-
Prosecco	18.5	-
Cabernet	18.6	-
Verduzzo	18.9	-
Sauvignon Blanc [50]	18.7	17.3
Pinot	16.5	15.1
Cabernet Sauvignon	17.6	16.2
Chardonnay	17.6	16.2
Carmenere	18.7	17.3
RGP [I] [51]	21.2	-
WLGP [II]	22.1	-
RGPS [III]	27.4	-
RGPF [IV]	24.7	-
WLGPS [V]	28.4	-
WLGPF [VI]	30.9	-

[I] Raw Grape Pomace; [II] Water-Leached Grape Pomace; [III] RGP—Slow Pyrolysis; [IV] RGP—Fast Pyrolysis; [V] WLGP—Slow Pyrolysis; [VI] WLGP—Fast Pyrolysis.

When examining the LHV results, it is observed that the peduncles from Merlot and Riesling have values comparable to the woody residues of the Pinot variety [50]. In other cases, lower LHV values are found in comparison to the woody residues of grapevines. Comparing the HHV and LHV of peduncles to grapevine wood biomass indicates that peduncles have a lower energy value than pomace and the woody biomass derived from grapevine cultivation.

Moisture content, a key parameter influencing combustion quality, shows minor variations, indicating a relatively similar moisture level across biomass from different grape varieties. For pomace, moisture values (M) range from 4.23% in Merlot to 6.43% in Chardonnay, while for peduncles, values range from 5.78% in Riesling to 6.47% in Merlot. These results reveal differences in biomass moisture between varieties, amounting to 2.20% for pomace and 0.69% for peduncles. These small differences suggest that biomass moisture remains relatively consistent regardless of variety, which is beneficial for combustion and energy processing, ensuring stability and predictability in combustion efficiency and minimizing the need for additional drying.

In terms of volatile compounds (V), values for pomace and peduncles range from 67.59% and 62.77% in Merlot to 68.51% and 66.24% in Riesling. The results indicate differences in volatile content among the biomass of different varieties, amounting to 0.92% for pomace and 3.47% for peduncles. These differences are relatively minor, indicating a similar level of volatile content in the biomass of various grape varieties. This similarity suggests that differences in volatile content may have a limited impact on combustion processes and may not necessitate significant adjustments in processing technology depending on the choice of variety.

For grape pomace, ash content (A) ranges from 3.51% in Merlot to 8.33% in Chardonnay. For peduncles, values range from 9.03% in Chardonnay to 12.75% in Zweigelt. These findings reveal differences in ash content in biomass between varieties, amounting to 4.82% for pomace and 3.72% for peduncles. Although these differences are more noticeable in pomace, they remain relatively modest, indicating a comparable level of ash content in the biomass of various grape varieties. The results suggest that ash content has a moderate effect on combustion quality, and the differences between grapevine varieties may not necessitate substantial modifications in biomass processing. High ash content was demonstrated for fuel, without being different from the ash content in biomass of an agricultural origin [52]. In practice, such a high ash content negatively affects energy yield and the creation of large dust emissions. However, the high content of microelements and macroelements, especially potassium, calcium, and magnesium, may contribute to the use of ash for fertilizing purposes. Ash also affects the occurrence of the boiler slagging phenomenon; therefore, the composition of ash should be tested in order to assess its fertilizing capacity and possible boiler slagging.

Fixed carbon (FC) values for grape pomace range from 17.01% in Chardonnay to 24.67% in Merlot. For peduncles, these values range from 16.44% in Zweigelt to 20.30% in Merlot. The results indicate differences in fixed carbon content among the biomass of different varieties, amounting to 7.66% for pomace and 3.86% for peduncles. Although these differences are noticeable, they remain relatively minor, indicating a similar level of fixed carbon content in the biomass of various grapevine varieties.

For organic carbon content (C), pomace values range from 45.03% for the Chardonnay variety to 47.10% for Zweigelt. An inverse relationship is observed in peduncles, with values ranging from 43.41% for Zweigelt to 44.81% for Chardonnay. These differences, amounting to 2.07% for pomace and 1.40% for peduncles, indicate a relatively uniform chemical composition of biomass across grape varieties. This suggests that organic carbon content does not significantly impact the energetic and combustion characteristics of grapevine biomass, allowing for the use of various varieties without substantial changes to processing technology.

Hydrogen content (H) in grape pomace ranges from 7.18% for Zweigelt to 7.37% for Chardonnay. For peduncles, hydrogen content ranges from 5.83% in Merlot to 6.71% in Chardonnay. Differences of 0.19% for pomace and 0.53% for peduncles suggest relatively similar hydrogen content in biomass across different grape varieties, despite minor intervarietal differences. These small differences in hydrogen content indicate the stability of the energetic properties of grapevine biomass, regardless of whether it is pomace or peduncles, positively influencing combustion uniformity.

Nitrogen content (N) for grape pomace ranges from 1.06% in Merlot to 1.69% in Chardonnay. For peduncles, values range from 1.39% in Merlot to 1.75% in Chardonnay. These results show that nitrogen content is relatively consistent across varieties, for both pomace and peduncles. The minor differences, at 0.63% for pomace and 0.36% for peduncles, suggest that different plant parts and grape varieties have minimal impact on nitrogen content in biomass. These small variations indicate nitrogen stability, which may lead to similar combustion properties and nutritional values in biomass across grape varieties.

For sulfur content (S), grape pomace values range from 0.08% in Merlot to 0.15% in Zweigelt. For peduncles, values range from 0.04% in Merlot to 0.08% in Zweigelt. These results indicate that sulfur content varies across varieties for both pomace and peduncles. Differences of 0.07% for pomace and 0.04% for peduncles suggest that both grape variety and biomass type (pomace vs. peduncles) can influence sulfur content. Although moderate, these differences may be relevant for pollution emissions during combustion, as a sulfur presence contributes to sulfur compound emissions, with implications for air quality and industrial emission regulations.

Oxygen content (O) in grape pomace ranges from 36.31% in Zweigelt to 41.91% in Chardonnay. For peduncles, values range from 35.81% in Zweigelt to 38.32% in Riesling. These results show oxygen content differences across varieties, with ranges of 5.60% for pomace and 2.51% for peduncles, indicating that both grape variety and biomass type (pomace vs. peduncles) may influence oxygen content. These differences may be important in combustion processes, as oxygen content affects combustion characteristics and the energy efficiency of biomass.

The hydrogen-to-carbon (H/C) ratio for grape pomace ranges from 1.52% in Zweigelt to 1.64% in Chardonnay. For peduncles, these values range from 1.30% in Merlot to 1.51% in Chardonnay. These results show that the H/C ratio in biomass varies among varieties within a similar range for both pomace and peduncles. Differences of 0.12% for pomace and 0.21% for peduncles suggest that grape varieties have comparable hydrogen-to-carbon proportions in their biomass, regardless of whether it is pomace or peduncles. These minor differences may influence combustion characteristics but generally indicate homogeneity in the H/C ratio, potentially facilitating standardization in grapevine biomass processing.

The nitrogen-to-carbon (N/C) ratio for grape pomace ranges from 0.02% in Merlot to 0.04% in other varieties. For peduncles, these values range from 0.03% in Merlot and Riesling to 0.04% in Zweigelt and Chardonnay. Differences of 0.02% for pomace and 0.01% for peduncles are minimal, suggesting a similar nitrogen level relative to carbon across all grapevine varieties analyzed. This stability in the N/C ratio is advantageous, as it suggests that different grape varieties can be used in combustion processes without significantly impacting nitrogen oxide (NO_x) emissions, one of the primary air pollutants.

The oxygen-to-carbon (O/C) ratio for pomace ranges from 0.58% in Zweigelt to 0.68% in Merlot. For peduncles, this parameter ranges from 0.62% in Zweigelt to 0.65% in Riesling. These results indicate that the O/C ratio is relatively similar across grape varieties for both pomace and peduncles. Differences of 0.10% for pomace and 0.03% for peduncles suggest that the oxygen content relative to carbon is fairly stable in grapevine biomass.

In summary, while the analysis shows general stability and uniformity across many parameters, there are noticeable differences that may require some adjustments depending on the specific variety and intended biomass processing purpose. These differences could affect combustion quality, pollutant emissions, and the overall energy efficiency of grapevine biomass.

The ash content for the studied pomace and peduncles is high (Table 8). When comparing these results with the literature, a similar ash content is observed for Merlot pomace and wood residues from the Salamino [53] and Thomson Seedless [54] varieties. In other cases, significantly higher ash content is noted. Additionally, for Concord pomace, Madadian et al. [55] reported lower values. The volatile matter content obtained for both pomace and peduncles aligns closely with comparable materials. Carbon content is comparable to wood biomass; however, Madadian et al. [55] noted a higher carbon concentration for Concord. For peduncles, hydrogen content was similar to that of grapevine wood residues, while hydrogen content for pomace was on average 1–1.5% higher than for other grapevine residues.

Table 8. Comparison of ultimate and approximate analysis of vine residue.

Grape Variety	A (%)	V (%)	C (%)	H (%)	N (%)	S (%)
Cabernet Sauvignon—wood [53]	1.99	83.03	48.39	6.65	0.49	-
Salamino—wood [54]	3.50	-	43.78	6.47	0.43	0.00
Thomson Seedless—wood [56]	3.54	-	47.41	5.57	0.99	0.19
Concord—pomace [55]	2.80	63.94	53.71	5.14	2.27	0.42

Nitrogen content was significantly higher (on average by 1%) compared to grapevine wood residues and 0.5% lower than in Concord pomace (Table 8). Sulfur content results were at a similar level across all samples.

3.3. Emission Characteristics

Table 9 presents the results of emission analyses for waste biomass in the form of pomace and peduncles from four grapevine varieties. The analyzed parameters include emissions of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter, expressed in kg·Mg^{-1}. The results demonstrated significant differences depending on the variety and type of biomass.

Table 9. Pollutant emission parameters for pomace and peduncles depending on the variety used in viticulture.

Parameter		Chardonnay	Merlot	Riesling	Zweigelt	*p*-Value
CO (kg·Mg^{-1})	pomace	55.47 ± 0.42 Ca *	56.91 ± 0.16 Ba	57.49 ± 0.07 ABa	58.03 ± 0.14 Aa	0.0001
	stalks	54.74 ± 0.28 ABa	55.20 ± 0.19 Ab	54.30 ± 0.32 BCb	53.48 ± 0.50 Cb	0.0016
	p-value	0.0671	0.0003	0.0001	0.0001	
CO_2 (kg·Mg^{-1})	pomace	1358.42 ± 10.41 Ca	1393.56 ± 4.03 Ba	1407.78 ± 1.77 ABa	1421.00 ± 3.37 Aa	0.0001
	stalks	1340.40 ± 6.94 ABa	1351.72 ± 4.65 Ab	1329.80 ± 7.94 BCb	1309.59 ± 12.14 Cb	0.0016
	p-value	0.0671	0.0003	0.0001	0.0001	
NO_x (kg·Mg^{-1})	pomace	0.34 ± 0.01 Ab	0.21 ± 0.01 Bb	0.32 ± 0.01 Aa	0.32 ± 0.01 Ab	0.0001
	stalks	0.37 ± 0.01 Aa	0.30 ± 0.01 Ca	0.32 ± 0.01 Ba	0.36 ± 0.01 Aa	0.0016
	p-value	0.0028	0.0004	0.2256	0.0025	
SO_2 (kg·Mg^{-1})	pomace	0.25 ± 0.01 Ba	0.17 ± 0.01 Ca	0.24 ± 0.01 Ba	0.29 ± 0.01 Aa	0.0001
	stalks	0.13 ± 0.01 Bb	0.09 ± 0.00 Cb	0.12 ± 0.01 Bb	0.16 ± 0.00 Ab	0.0001
	p-value	0.0001	0.0002	0.0001	0.0001	
Dust (kg·Mg^{-1})	pomace	10.52 ± 0.07 Ab	4.44 ± 0.58 Cb	9.68 ± 0.13 Bb	9.58 ± 0.07 Bb	0.0001
	stalks	11.41 ± 0.44 Da	13.22 ± 0.15 Ba	12.29 ± 0.04 Ca	16.11 ± 0.13 Aa	0.0001
	p-value	0.0259	0.0001	0.0001	0.0001	

* Significant difference: a and b mean that different letters in the row, and A, B, C and D mean that different letters in the column, indicate significant differences at α = 0.05.

Carbon monoxide (CO) emissions were highest for Zweigelt pomace, reaching 58.03 kg·Mg^{-1}, and lowest for Chardonnay pomace, at 55.47 kg·Mg^{-1}. In the case of peduncles, the highest CO emissions were recorded for Merlot (55.20 kg·Mg^{-1}), while the lowest were for Zweigelt (53.48 kg·Mg^{-1}). The greatest variation among varieties was observed in the pomace category, with a difference of 2.56 kg·Mg^{-1}.

Carbon dioxide (CO_2) emissions for pomace were highest for Zweigelt, at 1421.00 kg·Mg^{-1}, and lowest for Chardonnay, at 1358.42 kg·Mg^{-1}. For peduncles, the highest CO_2 emissions were recorded for Merlot (1351.72 kg·Mg^{-1}), while the lowest were for Zweigelt (1309.59 kg·Mg^{-1}). The largest variation among varieties occurred in the pomace category, with a difference of 62.58 kg·Mg^{-1}.

The nitrogen oxide (NO_x) emissions analysis showed that the highest emissions for pomace were recorded for Chardonnay (0.34 kg·Mg^{-1}) and the lowest for Merlot (0.21 kg·Mg^{-1}). For peduncles, the highest NO_x values were observed for Chardonnay (0.37 kg·Mg^{-1}) and the lowest for Merlot (0.30 kg·Mg^{-1}). The greatest variation among varieties was noted in the pomace category, with a difference of 0.17 kg·Mg^{-1}.

For sulfur dioxide (SO_2), emissions for pomace ranged from 0.17 kg·Mg^{-1} for Merlot to 0.29 kg·Mg^{-1} for Zweigelt. For peduncles, the highest SO_2 emissions were recorded for Chardonnay (0.13 kg·Mg^{-1}), and the lowest for Merlot (0.09 kg·Mg^{-1}). Variations among varieties were relatively small, particularly in the peduncle category.

Particulate emissions for pomace were highest for Chardonnay (10.52 kg·Mg^{-1}) and lowest for Merlot (4.44 kg·Mg^{-1}). For peduncles, the highest particulate emissions were recorded for Zweigelt (16.11 kg·Mg^{-1}) and the lowest for Riesling (12.29 kg·Mg^{-1}). The largest variation among varieties occurred in the pomace category, with a difference of 6.17 kg·Mg^{-1}.

The differences in pollutant emissions are more pronounced between grapevine varieties than between types of biomass (pomace vs. peduncles). The greatest variation among varieties was observed for carbon dioxide (CO_2) emissions in the pomace category, while the smallest differences were noted for sulfur dioxide (SO_2) emissions. Understanding these differences is crucial for optimizing grapevine biomass processing and managing pollutant emissions, which significantly impact energy efficiency and environmental protection.

The emission factor analysis revealed similar CO and CO_2 emission rates for the materials studied when compared to pomace of the Regent, and a bit lower than from shoots of the Regent and Solaris varieties (Table 10). A notably lower NO_x emission was observed, along with significantly higher SO_2 emissions. Peduncles from all varieties show higher levels of particulate emissions compared to vine shoots.

Table 10. Comparison of emission factors for bio-waste from viticulture.

Grape Variety	CO	CO_2	NOx	SO_2	Dust
Regent—grape pomace [25]	56.80	1390.50	4.60	0.10	8.50
Regent—shoots [31]	60.60	1484.06	1.78	0.14	4.65
Solaris—shoots [31]	59.98	1468.87	1.78	0.12	5.14

The results presented in Table 11 display the composition of exhaust gasses generated during the combustion of pomace and peduncles from four grape varieties: Chardonnay, Merlot, Riesling, and Zweigelt. The analysis covers eight key combustion-related parameters, V_{O2}, V_{oa}, V_{CO2}, V_{SO2}, V_{H2O}, V_{N2}, V_{gu}, and V_{ga}, expressed in normal cubic meters per kilogram ($Nm^3·kg^{-1}$). Statistically significant differences were found in most parameters between grape varieties and biomass types, indicating variability in exhaust gas emissions among the different grape varieties as well as between pomace and peduncles.

Table 11. Composition of exhaust gasses for pomace and stalks for four grape varieties tested.

Parameter		Chardonnay	Merlot	Riesling	Zweigelt	*p*-Value
Vo_{O2} ($Nm^3·kg^{-1}$)	pomace	0.99 ± 0.01 Ba *	0.98 ± 0.01 Ba	1.02 ± 0.00 Aa	1.03 ± 0.00 Aa	0.0001
	stalks	0.94 ± 0.01 Ab	0.90 ± 0.05 Aa	0.91 ± 0.03 Ab	0.92 ± 0.01 Ab	0.4825
	p-value	0.0029	0.0602	0.0037	0.0001	
V_{oa} ($Nm^3·kg^{-1}$)	pomace	4.73 ± 0.05 Ba	4.65 ± 0.04 Ba	4.88 ± 0.01 Aa	4.90 ± 0.02 Aa	0.0001
	stalks	4.48 ± 0.04 Ab	4.29 ± 0.23 Aa	4.33 ± 0.16 Ab	4.36 ± 0.06 Ab	0.4825
	p-value	0.0029	0.0602	0.0037	0.0001	
V_{CO2} ($Nm^3·kg^{-1}$)	pomace	0.84 ± 0.01 Ca	0.86 ± 0.00 Ba	0.87 ± 0.00 ABa	0.88 ± 0.00 Aa	0.0001
	stalks	0.83 ± 0.00 ABa	0.84 ± 0.00 Ab	0.82 ± 0.00 BCb	0.81 ± 0.01 Cb	0.0016
	p-value	0.0671	0.0003	0.0001	0.0001	
V_{SO2} ($Nm^3·kg^{-1}$)	pomace	0.0009 ± 0.00 Ba	0.0006 ± 0.00 Ca	0.0009 ± 0.00 Ba	0.0010 ± 0.00 Aa	0.0001
	stalks	0.0005 ± 0.00 Bb	0.0003 ± 0.00 Cb	0.0004 ± 0.00 Bb	0.0006 ± 0.00 Ab	0.0001
	p-value	0.0001	0.0002	0.0001	0.0001	
V_{H2O} ($Nm^3·kg^{-1}$)	pomace	0.91 ± 0.00 Aa	0.86 ± 0.00 Da	0.89 ± 0.00 Ca	0.88 ± 0.00 Ba	0.0001
	stalks	0.83 ± 0.01 Ab	0.73 ± 0.08 Aa	0.78 ± 0.06 Ab	0.79 ± 0.01 Ab	0.2185
	p-value	0.0001	0.0493	0.0405	0.0001	
V_{N2} ($Nm^3·kg^{-1}$)	pomace	5.09 ± 0.06 Ba	4.52 ± 0.04 Ca	5.17 ± 0.05 ABa	5.21 ± 0.03 Aa	0.0001
	stalks	4.94 ± 0.05 Ab	4.50 ± 0.14 Ba	4.62 ± 0.11 Bb	4.73 ± 0.03 ABb	0.0031
	p-value	0.0363	0.8973	0.0014	0.0001	
V_{gu} ($Nm^3·kg^{-1}$)	pomace	5.93 ± 0.07 Ba	5.38 ± 0.04 Ca	6.04 ± 0.05 ABa	6.09 ± 0.03 Aa	0.0001
	stalks	5.77 ± 0.05 Ab	5.34 ± 0.15 Ba	5.44 ± 0.11 Bb	5.54 ± 0.03 ABb	0.0031
	p-value	0.0331	0.6862	0.0009	0.0001	
V_{ga} ($Nm^3·kg^{-1}$)	pomace	7.59 ± 0.08 Ba	6.99 ± 0.05 Ca	7.72 ± 0.05 ABa	7.75 ± 0.04 Aa	0.0001
	stalks	7.32 ± 0.05 Ab	6.77 ± 0.26 Ba	6.92 ± 0.20 ABb	7.03 ± 0.03 ABb	0.0194
	p-value	0.0080	0.2200	0.0024	0.0001	

* Significant difference: a and b mean that different letters in the row, and A, B, C and D mean that different letters in the column, indicate significant differences at α = 0.05.

Oxygen consumption was highest for Zweigelt pomace (1.03 $Nm^3 \cdot kg^{-1}$) and lowest for Merlot pomace (0.98 $Nm^3 \cdot kg^{-1}$). For peduncles, Merlot had the lowest oxygen consumption (0.90 $Nm^3 \cdot kg^{-1}$), while the highest was observed for Chardonnay (0.94 $Nm^3 \cdot kg^{-1}$). The greatest variation among varieties occurred in the pomace category (0.05 $Nm^3 \cdot kg^{-1}$). These relatively small differences in oxygen consumption between grape varieties and between pomace and peduncles could still influence combustion efficiency, impacting the emission management and optimization of grapevine biomass processing.

V_{oa} emissions were highest for Zweigelt pomace (4.90 $Nm^3 \cdot kg^{-1}$) and lowest for Merlot (4.65 $Nm^3 \cdot kg^{-1}$), while for peduncles, Chardonnay recorded the highest values (4.48 $Nm^3 \cdot kg^{-1}$) and Merlot the lowest (4.29 $Nm^3 \cdot kg^{-1}$). The greatest variation among varieties was seen in the pomace category (0.25 $Nm^3 \cdot kg^{-1}$). These results highlight the variability in V_{oa} emissions depending on grape variety and plant part, which may be significant for crop management and biomass processing.

CO_2 emissions were highest for Zweigelt pomace (0.88 $Nm^3 \cdot kg^{-1}$) and lowest for Chardonnay (0.84 $Nm^3 \cdot kg^{-1}$). In peduncles, Merlot recorded the highest CO_2 emissions (0.84 $Nm^3 \cdot kg^{-1}$) and Zweigelt the lowest (0.81 $Nm^3 \cdot kg^{-1}$). The largest variation among varieties occurred in the pomace category (0.04 $Nm^3 \cdot kg^{-1}$). These differences in CO_2 emissions among grape varieties and plant parts may be relevant for environmental impact assessments and the optimization of biomass combustion processes.

For sulfur dioxide (SO_2) emissions, Zweigelt had the highest values for both pomace (0.0010 $Nm^3 \cdot kg^{-1}$) and peduncles (0.0006 $Nm^3 \cdot kg^{-1}$), while the lowest values were noted for Merlot pomace (0.0006 $Nm^3 \cdot kg^{-1}$) and peduncles (0.0003 $Nm^3 \cdot kg^{-1}$). The greatest variation among varieties occurred in the pomace category (0.0004 $Nm^3 \cdot kg^{-1}$). These differences in sulfur emissions highlight the variation in combustion properties and sulfur content among grape varieties, with implications for the environmental impact and optimization of biomass combustion.

V_{H2O} emissions for pomace range from 0.86 $Nm^3 \cdot kg^{-1}$ for Merlot to 0.91 $Nm^3 \cdot kg^{-1}$ for Chardonnay. For peduncles, similar trends were noted, with values ranging from 0.73 $Nm^3 \cdot kg^{-1}$ for Merlot to 0.83 $Nm^3 \cdot kg^{-1}$ for Chardonnay. The greatest variation among varieties was seen in the peduncle category (0.10 $Nm^3 \cdot kg^{-1}$). Differences between pomace and peduncles within each variety were relatively small, with the largest differences for Merlot (0.13 $Nm^3 \cdot kg^{-1}$). Variations in water vapor emissions between grape varieties and plant parts may influence combustion processes and biomass energy efficiency.

Nitrogen emissions were highest for Riesling pomace (5.21 $Nm^3 \cdot kg^{-1}$) and lowest for Merlot (4.52 $Nm^3 \cdot kg^{-1}$). For peduncles, the highest values were recorded for Chardonnay (4.94 $Nm^3 \cdot kg^{-1}$) and the lowest for Merlot (4.50 $Nm^3 \cdot kg^{-1}$). The greatest variation among varieties occurred in the pomace category (0.69 $Nm^3 \cdot kg^{-1}$).

V_{gu} emissions were highest for Zweigelt pomace (6.09 $Nm^3 \cdot kg^{-1}$) and lowest for Merlot (5.38 $Nm^3 \cdot kg^{-1}$). In peduncles, the highest values were observed for Chardonnay (5.77 $Nm^3 \cdot kg^{-1}$) and the lowest for Merlot (5.34 $Nm^3 \cdot kg^{-1}$). The largest variation among varieties was noted in the pomace category (0.71 $Nm^3 \cdot kg^{-1}$).

Total gas emissions were highest for Zweigelt pomace (7.72 $Nm^3 \cdot kg^{-1}$) and lowest for Merlot (6.99 $Nm^3 \cdot kg^{-1}$), while for peduncles, Chardonnay had the highest values (6.77 $Nm^3 \cdot kg^{-1}$) and Merlot the lowest (7.32 $Nm^3 \cdot kg^{-1}$). The largest variation among varieties was observed in the pomace category (0.73 $Nm^3 \cdot kg^{-1}$).

These results indicate differences in exhaust gas emissions for different plant parts and grape varieties, which are relevant for optimizing production processes and ensuring sustainable development.

Comparing the total volume of exhaust gasses, it was noted that the grape stalks and grape pomace have higher volumes of gasses than vine shoots. The total stoichiometric volume of dry exhaust gas (V_{gu}) was found to be higher than that of grape pomace or shoots from different grape varieties (Table 12).

Table 12. The comparison of the total volume of exhaust gasses (V_{ga}) and the total stoichiometric volume of dry exhaust gas (V_{gu}) for different grape varieties ($Nm^3 \cdot kg^{-1}$).

Grape Variety	V_{ga}	V_{gu}
Regent—grape pomace [25]	7.3	5.7
Regent—shoots [31]	6.36	4.88
Solaris—shoots [31]	6.25	4.82

The cluster analysis presented in Figure 2a classifies grape varieties based on the higher heating value (HHV) of stalks, while Figure 3b classifies them according to the HHV of pomace.

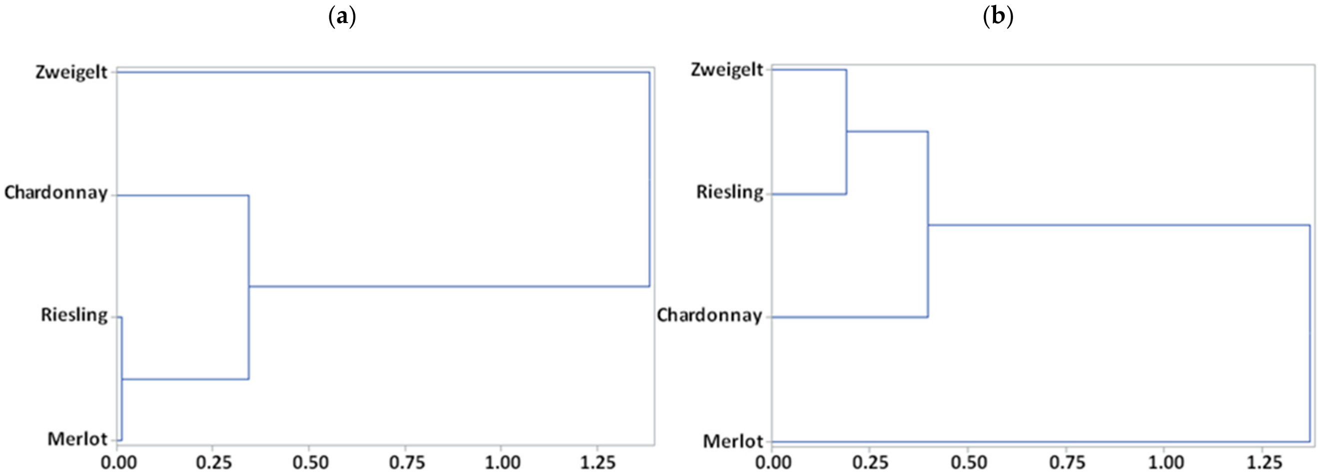

Figure 2. Cluster analysis of calorific value (HHV) of stalks and pomace.

Figure 2a identifies two main clusters, offering insight into the differences in the energy potential of grape stalks across varieties. Merlot forms a distinct cluster, indicating unique properties in terms of the higher heating value (HHV) of its stalks. Riesling, Chardonnay, and Zweigelt are grouped together, showing greater similarity in the HHV of their stalks.

Similarly, Figure 2b also distinguishes two main clusters for pomace HHV. Merlot again forms a separate cluster, suggesting specific characteristics regarding the HHV of its pomace as well. Riesling and Zweigelt cluster together, while Chardonnay forms an independent cluster, indicating distinct energy properties in its pomace compared to the other varieties.

Both dendrograms (Figure 2a,b) demonstrate that Merlot possesses unique properties in terms of the HHV of both its stalks and pomace. This implies that Merlot may offer a higher or differentiated energy profile relative to the other varieties, potentially beneficial for energy applications. The grouping of Riesling and Zweigelt in both dendrograms suggests similarities in their heating values, indicating that these varieties might be well suited for more standardized energy production from both stalks and pomace. Chardonnay, which forms a separate cluster with regard to pomace, suggests distinct energy properties in its pomace compared to other varieties.

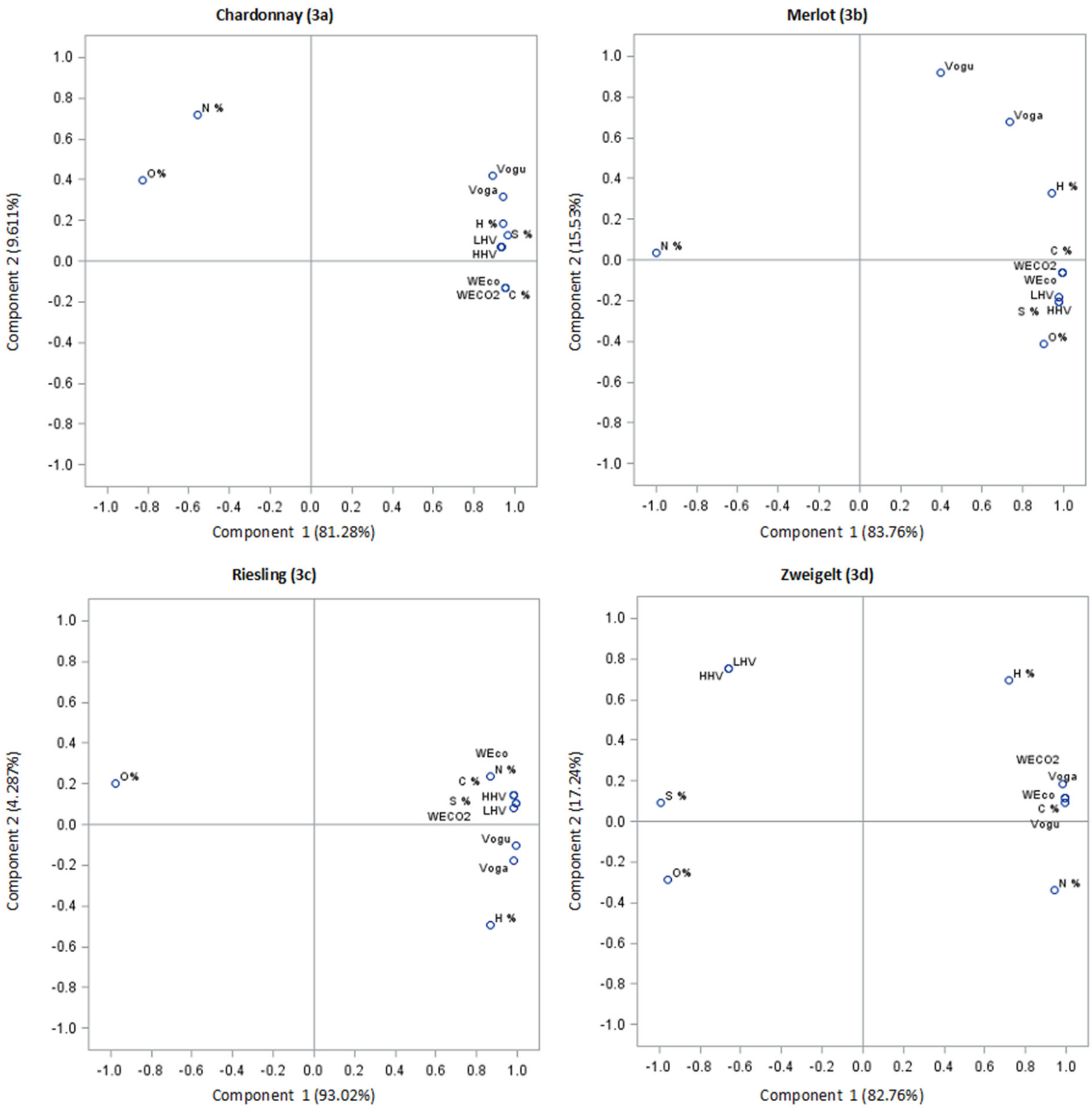

Figure 3. The analysis of the main components of grapevine biomass from wine production, tested varieties, regardless of the plant material.

The collected data highlight which grape varieties are more efficient for biomass-based energy production, providing a useful reference for selecting varieties for energy-specific purposes. Merlot, with its unique properties, could be preferred where high heating values are essential. Riesling and Zweigelt, with their similarities, may be chosen for more conventional energy applications, while Chardonnay, with its distinct pomace properties, could be considered for specialized uses requiring different energy characteristics.

This analysis enables improved planning and management of grape biomass resources, aligning with specific energy needs and maximizing energy production efficiency.

Figure 3 shows the results of the principal component analysis conducted on biomass obtained after wine production, regardless of its type (stem, pomace), dividing it into four tested varieties. The obtained results indicate the existence of two main physicochemical parameters in the case of Chardonnay, Merlot, and Risling varieties, and four in the case of Zweigelt. In the case of the Chardonnay variety, the first cluster includes parameters related to the energy potential of shoots, i.e., LHV, HHV, H, V_{ga}, and V_{gu}. The strong correlation between LHF and HHF suggests that a higher content of H, V_{ga}, and V_{gu} leads to a higher calorific value, which is crucial for assessing the quality of biomass as fuel.

Further correlations were observed between parameters, i.e., C, CO, and CO_2, and O and N. Similar relationships were demonstrated for Merlot and Riesling varieties, except for nitrogen and oxygen, which are single uncorrelated outliers.

4. Conclusions

1. The biometric assessment of the yield of the studied *Vitis vinifera* L. grape varieties revealed that Chardonnay vines had the smallest cluster and peduncle mass, berry count per cluster, berry diameter, and peduncle size, yet the highest berry mass among the evaluated biotypes.
2. Merlot clusters exhibited the highest cluster mass and the largest peduncles. Riesling had the highest number of berries per cluster, the heaviest peduncles, and the largest peduncle-to-cluster mass ratio (8.99%).
3. The examined grapevine peduncles and pomace showed a high level of energy parameters, similar to those of grapevine shoots. Hence, the assessed material can be a supplement to the solid biofuel market as an additional fuel, and their use can contribute to a positive path of their utilization in viticulture.
4. The assessed material is characterized by similar emission properties as vine shoots. However, the high ash content is problematic, which should be taken into account when using this material for energy purposes. Both pomace and yak and peduncles are characterized by high ash content of about 8%. In the case of gaseous emissions, the emission parameters are similar to those obtained for typical plant biomass.

Author Contributions: Conceptualization, M.K., G.M. and K.E.K.; methodology, M.K. and G.M.; software, K.E.K.; validation, K.B. and A.B.; formal analysis, M.K., G.M. and K.E.K.; investigation, M.K., G.M. and K.E.K.; resources, M.K., G.M. and K.E.K.; data curation, K.E.K.; writing—original draft preparation, M.K., G.M., K.E.K., K.B. and A.B.; writing—review and editing, G.M., M.K., K.E.K., A.B. and K.B.; visualization, K.E.K.; supervision, M.B.; project administration, R.S. and R.D.; funding acquisition, R.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was conducted as part of a project financed by the Implementation of ecosystem services with a focus on water balance in viticultural practice: QK21010189.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: This research was performed within the Programme NAZV ZEMĚ/QK21010189/2020—Implementation of ecosystem services with a focus on water balance in viticultural practice.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. International Energy Agency (IEA). Available online: https://www.iea.org/topics/global-energy-crisis (accessed on 21 August 2024).
2. Sazali, N. Emerging Technologies by Hydrogen: A Review. *Int. J. Hydrogen Energy* **2020**, *45*, 18753–18771. [CrossRef]
3. Tho Pesch, G.; Einarsdóttir, A.K.; Dillman, K.J.; Heinonen, J. Energy Consumption and Human Well-Being: A Systematic Review. *Energies* **2023**, *16*, 6494. [CrossRef]
4. Næss, J.S.; Cavalett, O.; Cherubini, F. The Land–Energy–Water Nexus of Global Bioenergy Potentials from Abandoned Cropland. *Nat. Sustain.* **2021**, *4*, 525–536. [CrossRef]
5. International Energy Agency (IEA). Available online: https://www.iea.org/reports/global-energy-review-2021/renewables (accessed on 21 August 2024).
6. Markandan, K.; Chai, W.S. Perspectives on Nanomaterials and Nanotechnology for Sustainable Bioenergy Generation. *Materials* **2022**, *15*, 7769. [CrossRef] [PubMed]
7. Jablonowski, N.D.; Schrey, S.D. Bioenergy Crops: Current Status and Future Prospects. *Agronomy* **2021**, *11*, 316. [CrossRef]
8. Beuchelt, T.D.; Nassl, M. Applying a Sustainable Development Lens to Global Biomass Potentials. *Sustainability* **2019**, *11*, 5078. [CrossRef]

9. Xing, J.; Song, J.; Liu, C.; Yang, W.; Duan, H.; Yabar, H.; Ren, J. Integrated Crop–Livestock–Bioenergy System Brings Co-Benefits and Trade-Offs in Mitigating the Environmental Impacts of Chinese Agriculture. *Nat. Food* **2022**, *3*, 1052–1064. [CrossRef] [PubMed]
10. Roni, M.S.; Lin, Y.; Hartley, D.S.; Thompson, D.N.; Hoover, A.N.; Emerson, R.M. Importance of Incorporating Spatial and Temporal Variability of Biomass Yield and Quality in Bioenergy Supply Chain. *Sci. Rep.* **2023**, *13*, 6813. [CrossRef]
11. Mateo, J.J.; Maicas, S. Valorization of Winery and Oil Mill Wastes by Microbial Technologies. *Food Res. Int.* **2015**, *73*, 13–25. [CrossRef]
12. Alston, J.M.; Sambucci, O. Grapes in the World Economy. In *The Grape Genome*; Cantu, D., Walker, M.A., Eds.; Compendium of Plant Genomes; Springer International Publishing: Cham, Switzerland, 2019; pp. 1–24, ISBN 978-3-030-18600-5.
13. Ohana-Levi, N.; Netzer, Y. Long-Term Trends of Global Wine Market. *Agriculture* **2023**, *13*, 224. [CrossRef]
14. Dougherty, P.H. Introduction to the Geographical Study of Viticulture and Wine Production. In *The Geography of Wine*; Dougherty, P.H., Ed.; Springer: Dordrecht, The Netherlands, 2012; pp. 3–36, ISBN 978-94-007-0463-3.
15. Maicas, S.; Mateo, J.J. Sustainability of Wine Production. *Sustainability* **2020**, *12*, 559. [CrossRef]
16. Christ, K.L.; Burritt, R.L. Critical Environmental Concerns in Wine Production: An Integrative Review. *J. Clean. Prod.* **2013**, *53*, 232–242. [CrossRef]
17. Zacharof, M.-P. Grape Winery Waste as Feedstock for Bioconversions: Applying the Biorefinery Concept. *Waste Biomass Valor.* **2017**, *8*, 1011–1025. [CrossRef]
18. Krajowy Ośrodek Wsparcia Rolnictwa (KOWR). Available online: https://www.gov.pl/web/kowr/administrowanie-potencjalem-produkcyjnym-produktow-sektora-wina (accessed on 3 January 2025).
19. Baiano, A. An Overview on Sustainability in the Wine Production Chain. *Beverages* **2021**, *7*, 15. [CrossRef]
20. Postawa, K.; Klimek, K.; Maj, G.; Kapłan, M.; Szczygieł, J. Advanced Dual-Artificial Neural Network System for Biomass Combustion Analysis and Emission Minimization. *J. Environ. Manag.* **2024**, *349*, 119543. [CrossRef] [PubMed]
21. Monteiro, T.O.; Barradas Filho, A.O.; Villa-Vélez, H.A.; Cruz, G. Estimation of the Main Air Pollutants from Different Biomasses under Combustion Atmospheres by Artificial Neural Networks. *Chemosphere* **2024**, *352*, 141484. [CrossRef] [PubMed]
22. Wiese, A. Biomass Combustion for Electricity Generation. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R.A., Ed.; Springer: New York, NY, USA, 2012; pp. 1231–1268, ISBN 978-0-387-89469-0.
23. Ali, F.; Dawood, A.; Hussain, A.; Alnasir, M.H.; Khan, M.A.; Butt, T.M.; Janjua, N.K.; Hamid, A. Fueling the Future: Biomass Applications for Green and Sustainable Energy. *Discov. Sustain.* **2024**, *5*, 156. [CrossRef]
24. Wu, Y.; Zhao, F.; Liu, S.; Wang, L.; Qiu, L.; Alexandrov, G.; Jothiprakash, V. Bioenergy Production and Environmental Impacts. *Geosci. Lett.* **2018**, *5*, 14. [CrossRef]
25. Maj, G.; Klimek, K.E.; Kapłan, M.; Buczyński, K.; Borkowska, A. Combustion and Energy Parameters of Grape Pomace/Skin Waste in Wine Production—Regent Variety Grafted onto Rootstocks. *Energies* **2024**, *17*, 5426. [CrossRef]
26. Klimek, K.E.; Kapłan, M.; Borkowska, A.; Maj, G.; Słowik, T. Effect of 'Regent' grapevine rootstock type on energy potential parameters. *J. Water Land. Dev.* **2024**, 50–56. [CrossRef]
27. Klimek, K.E.; Kapłan, M.; Maj, G.; Borkowska, A.; Buczyński, K.; Sotolář, R.; Danko, R. Evaluation and Analysis of the Energy Potential of Grapevine Peduncles of PIWI Group Varieties. *Energies* **2024**, *17*, 6043. [CrossRef]
28. Klimek, K.E.; Kapłan, M.; Maj, G.; Buczyński, K. Evaluation of green residues management of selected grape varieties. *J. Water Land. Dev.* **2024**, 68–75. [CrossRef]
29. Kapłan, M.; Maj, G.; Klimek, K.E. The analysis of energy potential in vine leaves of the 'Regent' cultivar as bio-waste depending on the year of cultivation and the type of rootstock used. *J. Water Land. Dev.* **2023**, 171–177. [CrossRef]
30. Klimek, K.E.; Kapłan, M.; Maj, G. The evaluation of energy from grapevine shoots used as biomass depending on the cultivar. *J. Water Land. Dev.* **2023**, 120–128. [CrossRef]
31. Maj, G.; Klimek, K.; Kapłan, M.; Wrzesińska-Jędrusiak, E. Using Wood-Based Waste from Grapevine Cultivation for Energy Purposes. *Energies* **2022**, *15*, 890. [CrossRef]
32. *EN-ISO 1928:2020*; Coal and Coke—Determination of Gross Calorific Value. ISO: Geneva, Switzerland, 2020.
33. *EN-ISO 18122:2022*; Solid Biofuels—Determination of Ash Content. ISO: Geneva, Switzerland, 2022.
34. *EN-ISO 18123:2023*; Solid Fuels—Determination of Volatile Matter. ISO: Geneva, Switzerland, 2023.
35. *EN-ISO 18134-1:2023*; Solid Biofuels—Determination of Moisture Content Part 1: Reference Method. ISO: Geneva, Switzerland, 2022.
36. Choudhury, N.D.; Saha, N.; Phukan, B.R.; Kataki, R. Characterization and Evaluation of Energy Properties of Pellets Produced from Coir Pith, Saw Dust and Ipomoea Carnea and Their Blends. *Energy Sources Part A Recover. Util. Environ. Eff.* **2021**, 1–18. [CrossRef]
37. *EN-ISO 16948:2015-07*; Solid Biofuels—Determination of Total Content of Carbon, Hydrogen and Nitrogen. ISO: Geneva, Switzerland, 2015.
38. *ISO 16994:2016*; Solid Biofuels—Determination of Total Content of Sulphur and Chlorine. ISO: Geneva, Switzerland, 2016.

39. Alves, J.L.F.; da Silva, J.C.G.; Mumbach, G.D.; Domenico, M.D.; da Silva Filho, V.F.; de Sena, R.F.; Machado, R.A.F.; Marangoni, C. Insights into the Bioenergy Potential of Jackfruit Wastes Considering Their Physicochemical Properties, Bioenergy Indicators, Combustion Behaviors, and Emission Characteristics. *Renew. Energy* **2020**, *155*, 1328–1338. [CrossRef]
40. Maj, G. Emission Factors and Energy Properties of Agro and Forest Biomass in Aspect of Sustainability of Energy Sector. *Energies* **2018**, *11*, 1516. [CrossRef]
41. Kovacs, H.; Szemmelveisz, K.; Koós, T. Theoretical and Experimental Metals Flow Calculations during Biomass Combustion. *Fuel* **2016**, *185*, 524–531. [CrossRef]
42. Paraschiv, L.S.; Serban, A.; Paraschiv, S. Calculation of Combustion Air Required for Burning Solid Fuels (Coal/Biomass/Solid Waste) and Analysis of Flue Gas Composition. *Energy Rep.* **2020**, *6*, 36–45. [CrossRef]
43. Gombau, J.; Pons-Mercadé, P.; Conde, M.; Asbiro, L.; Pascual, O.; Gómez-Alonso, S.; García-Romero, E.; Miquel Canals, J.; Hermosín-Gutiérrez, I.; Zamora, F. Influence of Grape Seeds on Wine Composition and Astringency of Tempranillo, Garnacha, Merlot and Cabernet Sauvignon Wines. *Food Sci. Nutr.* **2020**, *8*, 3442–3455. [CrossRef] [PubMed]
44. Kowalczyk, B.; Bieniasz, M.; Błaszczyk, J.; Banach, P. The Effect of Rootstocks on the Growth, Yield and Fruit Quality of Hybrid Grape Varieties in Cold Climate Condition. *Hortic. Sci.* **2022**, *49*, 78–88. [CrossRef]
45. Klimek, K.; Kapłan, M.; Najda, A. Influence of Rootstock on Yield Quantity and Quality, Contents of Biologically Active Compounds and Antioxidant Activity in Regent Grapevine Fruit. *Molecules* **2022**, *27*, 2065. [CrossRef]
46. Zombardo, A.; Mica, E.; Puccioni, S.; Perria, R.; Valentini, P.; Mattii, G.B.; Cattivelli, L.; Storchi, P. Berry Quality of Grapevine under Water Stress as Affected by Rootstock–Scion Interactions through Gene Expression Regulation. *Agronomy* **2020**, *10*, 680. [CrossRef]
47. Tecchio, M.A.; Silva, M.J.R.D.; Sanchez, C.A.P.C.; Callili, D.; Vedoato, B.T.F.; Hernandes, J.L.; Moura, M.F. Yield Performance and Quality of Wine Grapes (*Vitis vinifera*) Grafted onto Different Rootstocks under Subtropical Conditions. *Bragantia* **2022**, *81*, e1622. [CrossRef]
48. Kowalczyk, B.A.; Bieniasz, M.; Kostecka-Gugała, A. Flowering Biology of Selected Hybrid Grape Cultivars under Temperate Climate Conditions. *Agriculture* **2022**, *12*, 655. [CrossRef]
49. Spinelli, R.; Nati, C.; Pari, L.; Mescalchin, E.; Magagnotti, N. Production and Quality of Biomass Fuels from Mechanized Collection and Processing of Vineyard Pruning Residues. *Appl. Energy* **2012**, *89*, 374–379. [CrossRef]
50. Fernández-Puratich, H.; Hernández, D.; Tenreiro, C. Analysis of Energetic Performance of Vine Biomass Residues as an Alternative Fuel for Chilean Wine Industry. *Renew. Energy* **2015**, *83*, 1260–1267. [CrossRef]
51. Mortari, D.A.; Perondi, D.; Rossi, G.B.; Bonato, J.L.; Godinho, M.; Pereira, F.M. The Influence of Water-Soluble Inorganic Matter on Combustion of Grape Pomace and Its Chars Produced by Slow and Fast Pyrolysis. *Fuel* **2021**, *284*, 118880. [CrossRef]
52. Zając, G.; Szyszlak-Bargłowicz, J.; Gołębiowski, W.; Szczepanik, M. Chemical Characteristics of Biomass Ashes. *Energies* **2018**, *11*, 2885. [CrossRef]
53. Ion, V.; Mot, A.; Popa, V.; Calcan, S.; Badulescu, L.; Ionut-Ovidiu, J.; Baniţă, C.; Parvulescu, O. Physicochemical characterisation of vine waste used for producing biochar. *Sci. Papers. Ser. B Hortic.* **2021**, *65*, 268–273.
54. Puglia, M.; Pedrazzi, S.; Allesina, G.; Morselli, N.; Tartarini, P. Vine Prunings Biomass as Fuel in Wood Stoves for Thermal Power Production. *Int. J. Heat Technol.* **2017**, *35*, S96–S101. [CrossRef]
55. Madadian, E.; Rahimi, J.; Mohebbi, M.; Simakov, D.S.A. Grape Pomace as an Energy Source for the Food Industry: A Thermochemical and Kinetic Analysis. *Food Bioprod. Process.* **2022**, *132*, 177–187. [CrossRef]
56. Nasser, R.A.; Salem, M.Z.M.; Al-Mefarrej, H.A.; Abdel-Aal, M.A.; Soliman, S.S. Fuel Characteristics of Vine Prunings (*Vitis vinifera* L.) as a Potential Source for Energy Production. *BioResources* **2013**, *9*, 482–496. [CrossRef]