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Evaluation of green residues management of selected grape varieties

Kamila E. Klimek[1], Magdalena Kapłan[2], Grzegorz Maj*[3], Kamil Buczyński[2]

[1] University of Life Sciences in Lublin, Department of Applied Mathematics and Computer Science, Głęboka St, 28, 20-612 Lublin, Poland

[2] University of Life Sciences in Lublin, Institute of Horticulture Production, Głęboka St, 28, 20-612 Lublin, Poland

[3] University of Life Sciences in Lublin, Department of Power Engineering and Transportation, Głęboka St, 28, 20-612 Lublin, Poland

* Corresponding author

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Abstract: The paper presents the possibilities of energy management of residues from the cultivation of grapes of the 'Regent', 'Rondo' and 'Seyval Blanc' cultivars. The research was conducted in southeastern Poland in the Sandomierska Upland in 2022. The aim of the research was to demonstrate the influence of grape variety on yield capacity in relation to the extraction of biomass residues in the form of leaves. An attempt was made to identify the variety that is characterised by obtaining the most effective and average parameters, i.e. yield size and quality, leaf mass and surface area, and their impact on energy and fuel parameters. The study analysed the following crop parameters, i.e. number and mass of grapes, number and mass of berries; leaf quality parameters, i.e. mass including petioles and area. An energy assessment in Laboratory in Department of Power Engineering and Transportation was carried out by performing proximate and ultimate analysis and estimating emission factors and volumetric composition of exhaust gas. The study showed that the material with the highest energy potential was characterised by 'Regent', while the lowest potential was shown for 'Rondo'. Grapevines of the 'Rondo' cultivar were characterised by the highest obtained biomass among the evaluated varieties. The research showed that the most effective in practical cultivation is the use of the Regent variety, which was characterised by the average parameters of the obtained yield and growth values, and the highest fuel energy potential.

Keywords: biomass, energetic properties, grapevine, renewable energy

INTRODUCTION

Vines are currently cultivated worldwide on more than 7.3 mln ha (OIV, 2021). In recent years, there has been an upward trend in interest in grapevine cultivation in Poland (Mikciński *et al.*, 2020). In order to achieve optimal development and yield parameters of grapevines, proper crop management practices are essential (Reynolds and Wardle, 2001). Some of the commonly used agronomic treatments that affect the quality of the yield obtained are shoot pruning, leaf removal and grape thinning (King, McClellan and Smart, 2012; Soltekin *et al.*, 2022). Vineyard maintenance treatments mainly focus on winter and summer pruning (Poni *et al.*, 2018). In order to reduce the negative effects of reduced labour availability in vineyards, there are increasing attempts to mechanise the vine pruning procedure through the use of rotary discs and cutting bars, among others (Intrieri *et al.*, 2011).

Due to increasingly limited fossil fuel resources which also results in their increasing cost of exploitation, alternative energy sources are becoming increasingly important (Dybek *et al.*, 2023). The energy dominance of individual countries resulting from the uneven distribution of fossil fuel sources around the world has led to political instability. Research into the use of biomass for energy purposes offers an opportunity to address the growing challenges in this sphere, while providing immediate solutions (Tapaskar *et al.*, 2018).

A current priority in climate policy is to systematically reduce fossil fuel consumption. Through international agreements, countries that have accepted them are promoting measures to reduce the demand for fossil fuels (Lazarus and Asselt van, 2018).

Bioenergy includes a range of combinations of feedstocks and technologies. It is currently extracted from a wide range of raw materials, including plants, but also from industrial and commercial plant residues. Bioenergy is produced from biomass and used to generate electricity, thus replacing fossil fuels (Kurchania, 2012). The third largest potential natural energy source in the world is biomass (Directive, 2001).

Recently, there has been a lot of emphasis on the issue of biomass utilisation for energy purposes, and new methods are being developed to recover energy from the resulting biomass from the entire wine sector (Brito, Oliveira and Rodrigues, 2014). Biomass is already considered a form of renewable energy, with the potential to be used for energy purposes and to reduce the use of fossil fuels (McKendry, 2002).

Biomass may prove to be a key feedstock for energy generation in the future. In Vietnam, as well as other countries with high rice straw production, it can be used as a feedstock for power plants, with a number of benefits not only in terms of energy, but also in terms of the environment and climate (Cuong *et al*., 2021).

Lignocellulosic biomass from agricultural and forestry residues is a valuable source of feedstock for the chemicals and fuels produced from it, which can be environmentally friendly sources of heat, fuel and energy (Araujo *et al*., 2022).

Pre-processing of banana leaves by torrefaction offers the possibility of obtaining a feedstock that can be used as solid biofuel. The resulting feedstock is environmentally friendly and has sufficient combustion efficiency ratings (Alves *et al*., 2022).

Biomass is the most frequently used source of renewable energy in the EU (GUS, 2019a; GUS, 2020). Due to its properties, including biodegradability and ease of recirculation, it is a highly desirable raw material. Poland is considered a country with high energy biomass potential. This is due to the fact that Poland has a high share of land at the disposal of Polish agriculture. The development of agriculture and rural areas, as well as the development of renewable energy in Poland, based primarily on solid biomass (which includes, among others, residues wood from forests and straw), are strongly correlated (Jasiulewicz, 2015).

The management of renewable resources plays an important role in the development of the bioeconomy. Poland has a high share of agricultural land (oats, wheat, barley, rapeseed, potatoes, vegetables, vegetables including potatoes, fruit) amounting to approximately 14.7 mln ha and 9.4 mln ha of forests, which in total constitutes almost 80% of the total area of the country and 89.4% of the total area of agricultural farms (GUS, 2019b). Using the energy potential of biomass can significantly contribute to the diversification of energy sources (Jarosz, 2017). A good example of this is viticulture and the possibility of annual use of biomass in the form of fallen leaves or woody shoots. Until now, Poland has not been a typical wine country, but the changing climate has contributed to interest in this species and its cultivation. Despite numerous studies on the possibility of using vine biomass for energy purposes, this problem has not been recognised and researched in new cultivation regions, including cold regions of the world. It is worth emphasising that biomass production in a temperate climate, i.e. on less sunny, fertile and moist soils, is much higher than in warmer cultivation regions. The topic of the research undertaken is innovative in nature, as it will allow us to determine the energy potential of a species whose cultivation in the northern regions of the globe is only just developing. Large amounts of biomass harvested during summer and winter pruning and from leaves that naturally fall from the vine after the growing season can become a valuable alternative source of feedstock for energy purposes.

The aim of the study was to analyse three grape varieties (‘Regent’, ‘Rondo’ and ‘Seyval Blanc’) in terms of yield parameters, leaf weight and area. In order to determine their suitability for energy purposes, the remains of waste biomass generated during vine grape production were used and subjected to detailed analyses.

MATERIALS AND METHODS

The Nobilis vineyard (50°39´N; 21°34´E) is located in the south-eastern part of the country in the Sandomierz Upland. Self-rooted vines of the studied cultivars were planted in the spring of 2010 on loess soil at a spacing of 1.0–2.0 m (5000 pcs.$\cdot$ha^{-1}). The research covered three grape varieties: ‘Regent’, ‘Rondo’ and ‘Seyval Blanc’. The plants were grown in the form of a single fixed twine with a trunk 40 cm high and one immobile arm about 0.9 m long, on which. The following parameters were analysed: number of woody shoots on 1 bush, number of leaves on 1 shoot, number of leaves on an area of 1 ha, mass of 1 leaf (kg), leaf area (m^2), mass of leaves and leaf area on an area of 1 ha. All annual shoots (epiphylls) were counted on the shrubs included in the experiment in the fall after fruit harvest. In each set, leaves on 50 representative shoots were counted, and their mass including petioles was determined on an AXIS A250 electronics balance with an accuracy of 0.001 kg. Leaves were randomly colleted from three locations on the fruiting shoot, for a total of 30 leaves in each repetition. Each sample consisted of 1/3 of the leaves taken at the bottom, 1/3 in the middle and 1/3 at the top of the canopy. Leaf area was estimated using the Area Meter model 3100 on a sample of 30 leaves from each repetition. Based on the results, the number of annual shoots and leaves per plant, the area of 10 leaves and the area of all leaves per 1 ha, the mass of 10 leaves with and without petioles, and the mass of 10 petioles were determined; parameters determining the mass per hectare are also presented. The method of analysing energy properties are presented in Table 1.

The exhaust gas composition was determined based on stoichiometric equations according to the works by (Kovacs *et al*., 2016; Paraschiv *et al*., 2020). The theoretical oxygen demand (V_{O2}; m$^3\cdot$kg^{-1}) was determined from the Equation (1):

$$V_{O2} = \frac{22.41}{100}\left(\frac{C}{12} + \frac{H}{4} + \frac{S-O}{32}\right) \quad (1)$$

where: C = carbon content (%), H = hydrogen content (%), S = sulphur content (%), O = oxygen content (%).

Since the oxygen content in the air is 21%, which participates in the combustion process in the boiler, the

Table 1. Metodology regarding proximate and ultimate analysis

Analysis	Analysed parameter	Used tool/equation	Reference
Material pulverisation	≤0.5 mm	Retsch SM 100	ISO 14780:2017
Energetic	lower heating value (*LHV*)	LECO AC 600 isoperibolic calorimeter	ISO 1928:2020
Proximate	ash content (*A*)	LECO TGA 701 analyzer	ISO 18122:2022
	volatile matter content (*V*)		ISO 18123:2023
	moisture content (*M*)		ISO 18134-3:2020
	fixed carbon index (*FC*)	$FC = 100\% - M - A - V$	Choudhury *et al.* (2021)
Ultimate	carbon content (*C*)	LECO CHNS 628 analyser	EN-ISO 16948:2015-07
	hydrogen content (*H*)		
	nitrogen content (*N*)		
	sulphur content (*S*)		EN-ISO 16994:2016-10
	oxygen content (*O*)	$O = 100\% - C - H - N - S - A$	Alves *et al.* (2020)

Source: own elaboration.

stoichiometric volume of dry air required to burn 1 kg of biomass (V_{oa}; $m^3 \cdot kg^{-1}$) was calculated from the Equation (2):

$$V_{oa} = \frac{V_{O_2}}{0.21} \tag{2}$$

The carbon dioxide content of the combustion products (V_{CO2}; $m^3 \cdot kg^{-1}$) was calculated from the Equation (3):

$$V_{CO_2} = \frac{22.41}{12} \cdot \frac{C}{100} \tag{3}$$

The content of sulphur dioxide (V_{SO2}; $m^3 \cdot kg^{-1}$) in the exhaust gas was determined using the Equation (4):

$$V_{SO_2} = \frac{22.41}{32} \cdot \frac{S}{100} \tag{4}$$

The water vapour content of the exhaust gas (V_{H2O}; $m^3 \cdot kg^{-1}$) (Eq. 7) is the component of water vapour volume from the hydrogen combustion process ($V^H_{H_2O}$; $m^3 \cdot kg^{-1}$) (Eq. 5) and the volume of moisture contained in the combustion air ($V^a_{H_2O}$; $m^3 \cdot kg^{-1}$) (Eq. 6):

$$V^H_{H_2O} = \frac{22.41}{100}\left(\frac{H}{2} + \frac{M}{18}\right) \tag{5}$$

$$V^a_{H_2O} = 1.61x \cdot V_{oa} \tag{6}$$

$$V_{H_2O} = V^H_{H_2O} + V^a_{H_2O} \tag{7}$$

where: M = moisture content (%), x-air absolute humidity (kg $H_2O \cdot kg^{-1}$ dry air).

The calculations took into account the most commonly accepted value of this parameter, i.e., x = 10 g $H_2O \cdot kg^{-1}$, which, based on the Moliere diagram, corresponds to an air temperature of 25°C and a relative humidity of 50%.

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 theoretical nitrogen content in the exhaust gas (V_{N_2}; $m^3 \cdot kg^{-1}$) was calculated from the Equation (8):

$$V_{N_2} = \frac{22.41}{28}\frac{N}{100} + 0.79V \tag{8}$$

The total stoichiometric volume of dry exhaust gas (V_{gu}; $m^3 \cdot kg^{-1}$) was determined by the Equation (9):

$$V_{gu} = V_{CO_2} + V_{SO_2} + V_{N_2} \tag{9}$$

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. The total volume of exhaust gases (V_{ga}; $m^3 \cdot kg^{-1}$) was calculated according to the Equation (10):

$$V_{ga} = V_{gu} + V_{H_2O} \tag{10}$$

RESULTS AND DISCUSSION

The number of woody shoots per bush ranged from 13.2 to 14.8, and varied significantly by variety. Bushes of the 'Rondo' and 'Seyval Blanc' varieties had significantly fewer shoots than 'Regent'. In a study conducted in 2020–2022 by Klimek, Kapłan and Maj (2023), the average number of woody shoots per 1 bush of the 'Rondo', 'Seyval Blanc' and 'Regent' varieties ranged from 12.5 to 15.5 (Tab. 2).

The number of leaves per 1 shoot significantly depended on the variety and varied from 14.4 to 18.0 pcs, i.e. on an area of 1 ha from 986,400.0 to 1,188,000.0 pcs. Shrubs of the 'Seyval Blanc' cultivar significantly formed the most leaves while 'Rondo' significantly formed the least. The number of leaves in the 'Regent' variety oscillated between the previously mentioned varieties and differed significantly. The mass of 1 leaf significantly depended on the variety. Shrubs of the 'Rondo' variety formed significantly the heaviest leaves, while 'Seyval Blanc' significantly the lightest (Tab. 2).

Table 2. Evaluation of biomass form of selected leaf parameters in grapevines of 'Regent', 'Rondo' and 'Seyval Blanc' varieties

Parameter	Value for cultivar			*p*-value
	'Regent'	'Rondo'	'Seyval Blanc'	
Number of woody shoots on 1 bush (pcs)	14.8 ±0.3 A	13.7 ±0.1 B	13.2 ±0.2 B	0.0001
Number of leaves on 1 shoot (pcs)	15.0 ±0.2 B	14.4 ± 0.2 C	18.0 ±0.1 A	0.0001
Number of leaves on an area of 1 ha (pcs)	11,100,00.0 ±8,855.8 B	986,400.0 ±7,893.7 C	1,188,000.0 ±10,559.2 A	0.0001
Mass of 1 leaf (g)	61.0 ± 0.0 B	72.0 ± 0.0 A	51.0 ±0.0 C	0.0002
The mass of leaves on an area of 1 ha (Mg)	67.7 ± 2.1 A	71.0 ±2.1 A	60.6 ±3.5 B	0.0068
Area of 1 leaf (m^2)	0.92 ± 0.01 B	1.04 ±0.03 A	0.86 ±0.01 C	0.0001
Leaf area per 1 ha (m^2)	1,021,200.0 ±5429.3 AB	1,025,856.0 ±37,128.0 A	1,021,680.0 ±13246.3 B	0.0509

Explanations: A, B, C = different letters in the row indicate significant differences at α = 0.05.
Source: own study.

The mass of leaves on 1 ha ranged from 6,058.8 to 7,102.1 kg. The leaves of the 'Seyval Blanc' cultivar had significantly the smallest leaf mass per 1 ha area among the grape varieties evaluated. There were no significant differences in the evaluation of the analysed parameter between the 'Regent' and 'Rondo' varieties. The area of 1 leaf of the assessed grape varieties ranged from 0.86 to 1.04 m^2 and differed significantly. Significantly the largest leaves were in the 'Rondo' variety, while significantly the smallest were in the 'Seyval Blanc' variety (Tab. 2). In a study by Intrigliolo and Castel (2010) on the 'Tempranillo' grape variety, the average area of 1 leaf depending on the irrigation rate applied was 0.789 and 0.816 m^2. Results obtained by Buttaro *et al.* (2015) showed significant differences in the average area of a single leaf depending on the variety. In their research, a total of nine varieties were tested, the highest average area of a single leaf was characterised by the variety 'Victoria' and amounted to 204.6 cm^2, and the lowest average area of 1 leaf, 116.5 cm^2 was characterised by the variety 'Crimson'.

Analysing the entrustment of leaves on an area of 1 ha showed other statistical relationships. Significant differences were shown between the shrubs of the 'Rondo' and 'Seyval Blanc' varieties, while in the 'Regent' variety the entrustment of leaves per unit area did not differ significantly between the varieties in question (Tab. 2).The energetic analysis of the biomass showed the highest lower calorific value for the 'Rondo' variety and was 2.5% higher than the lowest value shown for 'Seyval Blanc' (Tab. 3). Statistical analysis showed no significant difference between the leaves of the 'Regent' and 'Seyval Blanc' varieties, indicating similar energy potential for potential biofuel. Similar values are shown in the literature for chestnutshell, tomato plant residues or vineshoot chips (Güleç *et al.*, 2022), while significantly higher values are obtained for shoots of the varieties 'Feteasca Neagra', 'Feteasca Alba', 'Feteasca Regala', 'Muscat Ottonel', 'Pinot Noir', 'Cabernet Sauvignon', 'Sauvignon Blanc' and 'Busuioacă de Bohotin' (Țenu *et al.*, 2021). As for carbon content, the highest content was shown for the leaves of the 'Rondo' variety and the lowest for the 'Regent' variety with a difference of 2% between the two. A significantly lower carbon content was observed in leaves than in vine shoots by about 5–7% (Florindo *et al.*, 2022), indicating a lower energy yield from this type of raw material. A similar content was recorded for vineshoot chips and vineshoot residues (Güleç *et al.*, 2022). A different situation was noted for hydrogen content where its highest content was

Table 3. Energy parameters for the biomass tested

Parameter	Value for cultivar			*p*-value
	'Regent'	'Rondo'	'Seyval Blanc'	
LHV (MJ·kg^{-1})	14.36 ±0.05 B	14.89 ±0.13 A	14.54 ±0.06 B	0.0011
C (%)	39.88 ±0.26 B	40.75 ±0.06 A	40.23 ±0.24 B	0.0057
H (%)	7.16 ±0.02 A	6.97 ±0.44 A	7.18 ±0.03 A	0.5584
N (%)	1.86 ±0.04 B	2.25 ±0.05 A	1.95 ±0.02 B	0.0001
S (%)	0.16 ±0.00 A	0.08 ±0.00 B	0.04 ±0.00 C	0.0001
MC (%)	9.24 ±0.04 A	8.16 ±0.15 B	8.07 ±0.06 B	0.0001
O (%)	38.83 ±0.30 A	39.17 ±0.20 A	39.2 ±0.30 A	0.2902
A (%)	12.12 ±0.04 A	10.79 ±0.25 C	11.4 ±0.03 B	0.0001
V (% DM)	66.29 ±0.38 B	68.58 ±0.64 A	67.31 ±0.16 B	0.0211
FC (%)	12.36 ±0.30 A	12.47 ±0.68 A	13.22 ±0.22 A	0.1077

Explanations: *LHV* = lower heating value, *A* = ash content, *V* = volatile matter content, *MC* = moisture content, *FC* = fixed carbon, *C* = carbon content, *H* = hydrogen content, *N* = nitrogen content, *S* = sulphur content, *O* = oxygen content, DM = dry matter. A, B, C A, B, C as in Tab. 2.
Source: own study.

determined for leaves of the 'Seyval Blanc' variety and the lowest for the 'Rondo' variety. No statistically significant difference was shown for the leaves tested in this case. Literature studies indicate that similar hydrogen content was recorded for the residues of the 'Cabernet Sauvignon' grape cultivar (Ion *et al.*, 2021). Nitrogen content was in the range of 1.86–2.25%. Its highest concentration was recorded for leaves of the 'Rondo' variety and the lowest for 'Regent'. Such a high concentration of nitrogen is also found in the leaves of trees, i.e. hazelnut tree, Vine shoots, as well as the shoots of 'Cabernet Sauvignon' vines (Ion *et al.*, 2021; Güleç *et al.*, 2022). Sulphur content showed a statistically significant difference between all varieties. In this case, the highest concentration was shown for the leaves of the 'Regent' variety and the lowest for 'Seyval Blanc' and the difference between the extremes was 0.12%. The 'Rondo' and 'Seyval Blanc' varieties show a similar concentration of sulphur in the leaves as can be observed in pruning Gorse Scrub (Torreiro *et al.*, 2020), while the 'Regent' variety as chestnut tree chips, hazellnut shell, and straw pellets

(Güleç *et al.*, 2022). Statistically significant differences between all varieties were also shown for ash content. For this trait, the highest content was recorded for leaves of the 'Regent 'variety and the lowest for 'Rondo' with a difference of 1.3%. Such a high content of ash was also recorded for corn stover, wheat husk (Rahimi, Anand and Gautam, 2022) or cardoon (Cavalaglio *et al.*, 2020). For the content of volatile parts, a statistically significant difference was shown between 'Rondo' and 'Regent' and 'Seyval Blanc' varieties. In this case, the 'Rondo' variety has the highest content and 'Regent' the lowest with a difference of 2.3%. The same results were also shown for vine shoots (Nunes *et al.*, 2021; Florindo *et al.*, 2022). No statistical difference was shown for oxygen content and bound carbon. The analysed values were similar and did not exceed 1% difference. For bound carbon, the results obtained can be compared with grapevine residues, vineshoot residues (Güleç *et al.*, 2022) and maize cob, sugarcane bagasse, coconut shell (Alves *et al.*, 2020) for agrobiomass.

The combustion heat value of a biofuel depends on various parameters of the fuel, such as its ash or bound carbon content and their ratio to *LHV*. The level of ash content can affect the overall calorific value, causing heat-absorbing reactions and reducing the net energy output. Thus, it should be noted that the higher the ash content of the fuel, the lower the calorific value obtained from the biofuel. With this in mind, the leaves of the 'Rondo' variety have the highest energy suitability from this angle. In contrast, the ratio of bound carbon to heat of combustion is inverted. The higher the bound carbon content, the calorific heat also increases. For the materials studied, it was observed that the calorific value increases with the content of volatile parts and inversely proportional for bound carbon, which is different for solid fuels. In this respect, the leaves of the 'Rondo' variety also have the highest energy suitability. The calorific value also depends on the content of hydrogen, which, reacting with oxygen, additionally influences thermal energy. On the other hand, high sulphur and ash content inversely affects the energy yield of fuels including biomass biofuels. Hence, the leaves of the 'Regent' variety are characterised by the lowest energy usefulness among the tested varieties.

Analysing the results for estimating the composition of the combustion products, it was shown that there was no statistical difference for two parameters, i.e. theoretical oxygen demand (V_{O2}) and stoichiometric dry air volume (V_{oa}), where the differences between the leaves of the different varieties did not exceed 0.1% (Tab. 4). The content of CO_2 in the products of combustion was statistically different, while the highest concentration was recorded for the leaves of the 'Rondo' variety and the 'Regent' and 'Seyval Blanc' varieties showed content at the same level. The highest SO_2 content among those tested was estimated for leaves of the 'Regent' and 'Rondo' varieties, and the difference between the 'Seyval Blanc' variety was 30%. Nitrogen in the flue gas composition had the highest concentration for leaves of the 'Rondo' variety and the lowest for 'Regent' with a difference of 6%. For the total volume of exhaust gas (V_{ga}), a statistically significant difference was shown for the tested leaves. In this case, the leaves of the 'Regent' variety show the highest volume, while the leaves with the lowest volume are those of the 'Rondo' variety with a difference of 26%. The total stoichiometric volume of dry exhaust gas (V_{gu}) ranged from 5.53–5.62 $m^3 \cdot kg^{-1}$ for the analysed leaves. The leaves of the 'Regent' variety had the lowest and the 'Rondo' variety the highest total volume of dry flue gases. Comparing the theoretical amount of dry flue gases, lower by about 1 $Nm^3 \cdot kg^{-1}$ results were obtained for knotweed, timothy grass, meadow hay (Malaťák, Bradna and Velebil, 2017) while higher by about 2 $Nm^3 \cdot kg^{-1}$ for energy sorrel pellets, lucerne pellets and oat grain (Malaťák and Passian, 2011).

Table 5 shows the multivariate correlation, which shows that with the increase in leaf area, the parameters *LHV*, *N*, V_{N2}, V_{gu}

Table 4. Results of estimation of exhaust gas composition for selected biofuels

Parameter	Value ($Nm^3 \cdot kg^{-1}$) for cultivar			*p*-value
	'Regent'	'Rondo'	'Seyval Blanc'	
V_{O2}	0.87 ±0.01 A	0.88 ±0.03 A	0.88 ±0.01 A	0.9408
V_{oa}	4.17±0.04 A	4.18 ±0.12 A	4.19 ±0.04 A	0.9408
V_{CO2}	0.75 ±0.005 B	0.76 ±0.001 A	0.75 ±0.004 B	0.0057
V_{SO2}	0.001 ±0.00 A	0.001 ±0.00 B	0.0003 ±0.00 C	0.0011
V_{H2O}	48.55 ±6.70 A	8.40 ±6.93 C	28.59 ±6.94 B	0.0011
V_{N2}	4.78 ±0.06 B	5.10 ±0.06 A	4.87 ±0.04 B	0.0012
V_{ga}	54.07 ±6.70 A	14.27 ±6.99 C	34.22 ±6.99 B	0.0012
V_{gu}	5.53 ±0.07 B	5.87 ±0.06 A	5.62 ±0.05 B	0.0011

Explanations: V_{O2} = the theoretical oxygen demand, V_{oa} = stoichiometric volume of dry air required to burn 1 kg of biomass, V_{CO2} = the carbon dioxide content, V_{SO2} = the content of sulphur dioxide, V_{H2O} = the water vapour content of the exhaust gas, V_{N2} = the theoretical nitrogen content in the exhaust gas, V_{gu} = the total stoichiometric volume of dry exhaust gas, V_{ga} = the total volume of exhaust gases; other symbol; A, B, C as in Tab. 2.
Source: own study.

Table 5. Correlation analysis of biomass parameters, and combustion values

Parameter	Leaf area on an area of 1 ha	Mass of leaves on an area of 1 ha	Number of leaves on 1 shoot	Number of leaves on an area of 1 ha	Leaf area (m^2)	Mass of 1 leaf (kg)	Number of woody shoots per 1 ha
LHV ($MJ \cdot kg^{-1}$)	0.6521	0.4234	–0.2962	–0.7049	0.7532	0.6199	–0.5043
C (%)	0.4675	0.3338	–0.2205	–0.6521	0.6558	0.5480	–0.5729
H (%)	–0.4373	–0.4952	0.3006	0.3755	–0.4173	–0.4688	–0.0092
N (%)	0.6340	0.5584	–0.4081	–0.8011	0.8142	0.7422	–0.4368
S (%)	0.0775	0.3902	–0.3244	–0.1500	0.0933	0.2388	0.9696

cont. Tab. 5

Parameter	Leaf area on an area of 1 ha	Mass of leaves on an area of 1 ha	Number of leaves on 1 shoot	Number of leaves on an area of 1 ha	Leaf area (m^2)	Mass of 1 leaf (kg)	Number of woody shoots per 1 ha
M (%)	–0.1731	0.1712	–0.4293	0.0713	–0.1489	0.0072	0.9322
O (%)	0.0793	0.0280	0.2343	–0.0158	0.0597	0.0555	–0.4623
A (%)	–0.3941	–0.2556	0.0992	0.5769	–0.5831	–0.4747	0.6863
V (% d.m.)	0.4938	0.4206	–0.1951	–0.6164	0.6391	0.5797	–0.5640
MC (%)	–0.3456	–0.4012	0.4000	0.4890	–0.4471	–0.6063	0.5968
V_{O2} ($m^3 \cdot kg^{-1}$)	–0.1703	–0.2844	0.1150	–0.0033	–0.0429	–0.1479	–0.2331
V_{oa} ($m^3 \cdot kg^{-1}$)	–0.1703	–0.2844	0.1150	–0.0033	–0.0429	–0.1479	–0.2331
V_{CO2} ($m^3 \cdot kg^{-1}$)	0.4675	0.3338	–0.2205	–0.6521	0.6558	0.5480	–0.5729
V_{SO2} ($m^3 \cdot kg^{-1}$)	0.0775	0.3902	–0.4244	–0.1500	0.0933	0.2388	0.9696
V_{H2O} ($m^3 \cdot kg^{-1}$)	–0.5901	–0.2943	0.1308	0.5927	–0.6527	–0.5018	0.6484
V_{N2} ($m^3 \cdot kg^{-1}$)	0.5407	0.4296	–0.3462	–0.7592	0.7555	0.6509	–0.4943
V_{ga} ($m^3 \cdot kg^{-1}$)	–0.5895	–0.2926	0.1288	0.5903	–0.6507	–0.4997	0.6486
V_{gu} ($m^3 \cdot kg^{-1}$)	0.5391	0.4273	–0.3427	–0.4568	0.7533	0.6486	–0.4974

Explanations as in Tabs. 3 and 4.
Source: own study.

increase, and V_{H2O} and V_{ga} decrease. It was observed that with the increase in the number of leaves per 1 ha and the number of woody shoots per 1 ha, A, FC, V_{H2O} and V_{ga} increased significantly, while LHV, C, V, V_{CO2}, V_{N2} and V_{gu} decreased. Inverse significant relationships were observed for the leaf area (m^2) and the mass of 1 leaf (kg).

The cluster analysis of the energy parameters and estimation of exhaust composition showed similarities between the 'Seyval Blanc' and 'Regent' varieties (Fig. 1). The analysed values in the 'Rondo' variety differed from the others (Fig. 1).

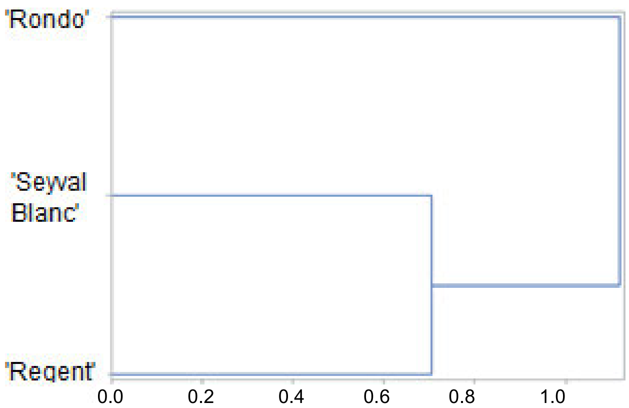

Fig. 1. Cluster analysis of the examined combustion parameters in relation to the assessed varieties; source: own study

CONCLUSIONS

1. The vines of the 'Regent' variety were characterised significantly by the largest number of woody shoots among the grape varieties evaluated.
2. Indeed, the bushes of the 'Rondo' variety formed the heaviest leaves and with the largest surface area.
3. Grapevines of the 'Seyval Blanc' variety formed significantly the most leaves per shoot and on the area of 1 ha among the evaluated varieties.
4. The biomass of vines of the 'Regent' and 'Rondo' varieties was characterised significantly better than that of 'Seyval Blanc'. The same relationship was confirmed by the results of exhaust composition estimation.
5. The leaves of the 'Rondo' variety were characterised by the highest energy efficiency, while the leaves of the 'Regent' variety had the lowest among the evaluated varieties.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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