JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2024.150281
2024, No. 62 (VII–IX): 50–56

Effect of 'Regent' grapevine rootstock type on energy potential parameters

Kamila E. Klimek[1], Magdalena Kapłan*[2],
Grzegorz Maj[3], Anna Borkowska[1], Tomasz Słowik[3]

[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

RECEIVED 26.11.2023 ACCEPTED 30.04.2024 AVAILABLE ONLINE 17.10.2024

Abstract: The paper presents the possibilities of energy management of residues from the production of 'Regent' grapevines. Field tests were conducted under conditions of temperate climate in 2022 on six types of rootstocks viz: 101-14, 125 AA, 161-49, 5 BB, SO4, SORI, the control were ungrafted vines growing on their own roots. The study analysed the following crop parameters, i.e. number and mass of grapes, number and mass of berries; quality parameters of woody shoots. Technical and elemental analysis was performed, and the heat of combustion and calorific value were determined to define fuel quality parameters. In addition, emission factors of CO, CO_2, SO_2, NO_x and ash were estimated to demonstrate the degree of impact of potential bio-residue from the combustion process. An assessment was made on the basis of stoichiometric equations of flue gas composition, as well as theoretical oxygen demand and total fuel gas volume. The study showed that cultivation on 125 AA rootstock is characterised by obtaining significantly the highest yield, shoot mass and bio-residues suitability for energy purposes. The research showed that the most effective in practical cultivation is the use of SORI and SO4 rootstocks in cultivation, which are characterised by average parameters of obtained yield, growth value and fuel.

Keywords: energy potential, grapevine, horticultural residues, rootstock, woody biomass

INTRODUCTION

Contemporary climatic changes favour grapevine cultivation in Poland (Lisek, 2008; Filipiak and Maciejczak, 2017). Therefore, in recent years, a dynamic increase in interest in this form of cultivation can be observed, primarily for winemaking purposes. It is estimated that the total area of vineyards in Poland is more than 620 ha. Still, this type of production remains fragmented, and the acreage of vine cultivation varies greatly, ranging from a dozen or so acres to as much as a dozen hectares (Izajasz-Parchańska, Cioch and Tuszyński, 2014; Rusnak, 2016; Filipiak and Maciejczak, 2017; Olewnicki, 2018; KOWR, 2023). Due to the cooler climate in Poland differing from the traditional grape growing area, growers face many challenges such as choosing the right variety to achieve a high quality yield. Nowadays, with the proper selection of rootstock with specific growth strength and frost resistance, growers have the opportunity to plant cultivars that are better adapted and more productive under given soil and climate conditions and improve scion and rootstock compatibility (Reisch, Owens and Cousins, 2012; Lisek *et al.*, 2016; Harris, 2018; Provost, Cambell and Dumont, 2021).

'Regent' grapevine is a new cultivar originating from Germany. It is characterised by an early fruiting period and an abundant yield. 'Regent' vines are characterised by high resistance to fungal diseases, resistance to temperature drops to –25°C, as well as a significant number of woody shoots from the growing area. Unfortunately, the root system of this variety is susceptible to phylloxera, so its cultivation requires a properly selected rootstock (Myśliwiec, 2006; Myśliwiec, 2013; Klimek, Kapłan and Maj, 2023).

A lot of maintenance is required in vine cultivation, including annual sanitary pruning of the vines, which generates significant amounts of woody biomass (Sánchez-Gómez *et al.*, 2017). Residues become problematic, left in inter rows that can be a potential source of disease or become a habitat for pests and larger rodents. Moreover, they can cause difficulties the movement of orchard equipment and manpower, and thus hinder the performance of subsequent treatments. Removal of these residues is an important procedure that has a significant impact on the efficiency of the entire production process (Gaworski and Malinowski, 2011; Aniszewska *et al.*, 2015). Until recently, the most common practice was to mulch or push garden residues out of the inter-rows and dispose of them by burning, allowing the area to be quickly cleaned up (Gonçalves *et al.*, 2011; Spinelli *et al.*, 2014). In connection with the reduction of greenhouse gas emissions and the search for new solutions that can provide a source of energy, there is growing interest in the possibility of energetic use of woody biomass from horticultural production (Borkowska and Lipiński, 2007; Jagustyn, Bątorek-Giesa and Wilk, 2011).

Such raw material is an environmentally friendly and, most importantly, renewable resource that can supplement and, in the long term, eventually replace fossil fuels. The use of vineyard pruning residues would solve the problem of residues disposal and turn it into side production, with the possibility of revenue or reduced management costs (Spinelli *et al.*, 2012; Mendivil *et al.*, 2015). According European Residues Directive 2008/98/EC on residues management, recycling and conversion to energy, the biomass from vineyards obtained during production can be used as a renewable energy source (Directive, 2008).

Given the legislative requirements of the energy industry, imposing a systematic increase in the proportion of the total mass of biomass burned – of "agro" origin residues. The aim of the work was to present the possibilities of energy utilisation of residue biomass generated during the production of 'Regent' vine grafted on six types of rootstocks and self-rooted shrubs.

MATERIALS AND METHODS

GENERAL INFORMATION

Field tests were conducted under temperate climate conditions in 2022 on six types of rootstocks viz: 125 AA, SORI, 101-14, SO4, 5 BB, 161-49, the control were ungrafted vines growing on their own roots. In the conducted study, the effect of the type of 'Regent' grape rootstock used on the parameters of energy potential, obtained from cutting shrubs of woody biomass was checked. The following characteristics of woody shoots were analysed, i.e. number, diameter and mass of shoots. The results obtained in the experiment were subjected to statistical analysis using SAS Enterprise Guide 5.1 software. For the results obtained, normality of distribution was checked using the Shapiro–Wilk test, followed by ANOVA analysis, and significance was assessed using Tukey's HSD test.

STUDY METHODS

The Nobilis vineyard (50°39′N; 21°34′E) is located in the south-eastern part of the country in the Sandomierz Upland. Grapevines of the tested cultivar limbed on rootstocks: 125 AA, SORI, 101-14, SO4, 5 BB, 161-49 were planted in spring 2010 on loess soil at a spacing of 1.0 × 2.0 m (5000 units$\cdot$ha^{-1}). The control group consisted of ungrafted shrubs growing on their own roots. Plants were grown in the form of a single fixed string with a 40 cm high trunk and one stationary arm about 0.9 m long, on which. After a short pruning, 6 shoots per year were left, which yielded 12 to 16 fruiting shoots, known as vines. The experiment was set up in a randomized block design and included 4 combinations with 5 repetitions. The repetitions were plots with 10 plants. Lignified shoots before cutting were counted, and their diameter at the base was measured with calipers to the nearest 0.01 mm. After cutting, shoots from all plants included in the experiment were weighed using a PS R2 RADWAG precision balance with an accuracy of 0.001 kg. Fifty representative shoots from each grape variety under evaluation were selected for further processing.

Metodology regarding proximate and ultimate analysis is detailed shown by Klimek *et al.* (2024) in the other paper published in this issue.

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_{O_2}; m$^3\cdot$kg^{-1}) was determined from the relationship:

$$V_{O_2} = \frac{22.41}{100}\left(\frac{C}{12} + \frac{H}{4} + \frac{S-O}{32}\right) \tag{1}$$

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

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

The carbon dioxide content of the combustion products (V_{CO_2}; m$^3\cdot$kg^{-1}) was calculated from the formula:

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

The content of sulphur dioxide (V_{SO_2}; m$^3\cdot$kg^{-1}) in the exhaust gas was determined using the formula:

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

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 relationship:

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

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

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

Assuming that biomass combustion is carried out under stoichiometric conditions, i.e., using the minimum amount of air required for combustion ($\lambda = 1$), a minimum exhaust gas volume will be obtained. The total volume of exhaust gases (V_{ga}; m^3·kg^{-1}) was calculated according to the formula:

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

RESULTS AND DISCUSSION

The measured analysis of the number of shoots showed that the number of woody shoots varied from 14.8 to 15.1 units (Tab. 1). There was no significant difference between the number of shoots and the evaluated combinations. Similar results were obtained by Kapłan and Baryła (2006) in a study on the effect of rootstock type on the growth of apple tree whorls, where it was shown that the type of rootstock used had no significant effect on the number of woody shoots. Gudarowska and Szewczuk (2011), in a study conducted on apple trees, showed that there were no significant differences in terms of the studied trait and the number of shoots.

Table 1. Effect of rootstock type on woody shoot biomass parameters

Rootstock type	Number of lignified shoots ±*SD* (pcs.)	Diameter of the woody shoot (mm)	Mass of woody shoot (kg)	Mass of woody shoot (Mg·ha^{-1})
101-14	15.0 ±0.2^{A}	7.7 ±0.1^{E}	0.041 ±0.001^{EF}	3,074.33 ±34.01^{DE}
125 AA	14.9 ±0.2^{A}	8.7 ±0.1^{A}	0.067 ±0.002^{A}	4,956.33 ±164.11^{A}
161-49	15.0 ±0.2^{A}	7.9 ±0.1^{DE}	0.039 ±0.002^{F}	2,948.66 ±139.29^{E}
5 BB	15.1 ±0.1^{A}	8.0 ±0.1^{CD}	0.043 ±0.001^{DE}	3,239.67 ±97.83^{D}
SO4	15.0 ±0.1^{A}	8.4 ±0.1^{B}	0.047 ±0.001^{C}	3,524.83 ±66.25^{C}
SORI	14.9 ±0.1^{A}	8.4 ±0.1^{B}	0.053 ±0.001^{B}	3,957.50 ±88.34^{B}
Control	14.8 ±0.3^{A}	8.3 ±0.1^{BC}	0.045 ±0.001^{CD}	3,354.17 ±37.62^{CD}
p-value	0.5804	0.0001	0.0001	0.0001

Explanations: *SD* = standard deviation, *p*-value = the probability of obtaining test results at least as extreme as the result actually observed, under the assumption that the null hypothesis is correct, A, B, C at values = significant differences between the types of washers used at $\alpha = 0.05$.
Source: own study.

This regularity is also confirmed by Szewczuk and Gudarowska's (2011) study, which is a study of the effect of rootstock on the growth yield of four peach cultivars, which showed no significant differences in terms of the number of shoots and the type of rootstock used. Also conclusions were reached by Hetman and Monder (2003) studying two cultivars of large-flowered roses.

Another analysis was carried out to check the differences between the diameter of the shoots and the rootstocks used. The parameters for evaluating the diameter of woody shoots showed that their thickness ranged from 7.7 to 8.7 mm (Tab. 1). Analysing the trait, significant differences were noted between the combination used and shoot diameter. Shrubs grafted on 125 AA rootstock had significantly thickest shoots, while shoots on 101-14 rootstock had significantly thinnest shoots. The group of thin woody shoots included those derived from rootstocks 161-49 and 5 BB, while thick shoots were SO4 and SORI. The control shrubs had medium-thick shoots compared to the evaluated rootstocks. A study by Bielicki and Pąśko (2013) showed that the type of rootstock used has a strong influence on the strength of apricot growth, and thus on shoot quality. All rounded cultivars showed the strongest growth on Pumiselect clone and alder seedlings, and the weakest on Wangenheim's Hungarian seedlings.

In the conducted study, the mass of lignified shoots was evaluated to indicate significant relationships between the type of rootstock and the evaluated parameter. The analysis showed that the mass of woody shoots ranged from 0.039 to 0.067 kg and differed significantly depending on the evaluated combination (Tab. 1). Shrubs grafted on rootstock 125 AA had significantly the heaviest shoots, and the relationship was similar in the case of the mass of lignified shoots per entrustment of 1.0 ha, where the value of this parameter was 4,956.33 Mg·ha^{-1}. Shrubs grafted on rootstock 161-49 had shoots with significantly the lowest mass among the evaluated combinations. The control shrubs and those grafted on SORI and SO4 rootstock had shoots whose mass was ≥0.045 kg per bush i.e. above 3,330.0 Mg·ha^{-1}. Gorzelany and Matlok (2013) and Królikowski and Matlok (2021) came to similar conclusions, in their research and field measurements. Their data show that the average residue biomass obtained from one hectare after pivoting treatment of various fruit tree rootstocks, i.e. apple, cherry, pear and plum, recorded an increasing trend during the period they studied. The highest residues mass was obtained from Colt cherry rootstocks and amounted to 7,326.1 kg·ha^{-1}, while the lowest amount of 3,877.5 kg·ha^{-1} was obtained from M26 apple rootstocks. In other studies (Manzone *et al.*, 2016), the amount of pruning residue in the vineyard during the study period ranged from 1.85 to 5.36 Mg·ha^{-1}.

Analysing the obtained data from the technical and elemental analysis, all the studied traits showed a statistically significant difference between the used rootstocks in grapevine cultivation. The heat of combustion for the tested shoots, depending on the rootstock used, ranged from 15.69 MJ·kg^{-1} with 101-14 rootstock to 18.04 MJ·kg^{-1} for 161-49 rootstock (Tab. 2). Similar values to those for SO4, 5 BB and 161-49 rootstocks were shown for shoots from between-rows of 'Chardonnay' and 'Merloti Glera' cultivars (Mencarelli, Cavalli and Greco, 2022).

The carbon content of the raw materials tested was highest for SO4 rootstock and lowest for 125 AA rootstock with a difference of 4.2%. The highest hydrogen content was shown for shoots from vines grown on 101-14 rootstock. The lowest content of H with a 1% difference was shown for shoots from SORI rootstock. For nitrogen, the difference between the tested materials was only 0.13%, and similarities could be seen for this trait for many rootstocks. Sulphur content was also at a low level. Its content was recorded in the range of 0.04% for SO4 rootstock shoots to 0.44%, for 125 AA rootstock, hence the difference was 0.4%. In the case of assessing oxygen content, differences of 2.5% were found, where the rootstock showing the highest content in shoots was 101-14 (Tab. 2). The obtained results of elemental analysis showed that carbon, nitrogen and oxygen contents were similar for shoots of grape cultivars Savignon Blanc, Pinot Noir, Muscat Ottonel, or Feteasca Alba as in the study of Senila *et al.* (2020) and hydrogen content was on average 1% lower, and sulphur by 0.3% higher. Research by Nunes *et al.* (2021b) showed higher carbon content in vine shoots by an average of 5%, lower hydrogen content by 1% and similar nitrogen and oxygen content.

Shoots from 125 AA rootstock were characterised by obtaining the highest ash content, while SO4 was characterised by the lowest ash content with a difference of about 2.2% (Tab. 2). The obtained ash content values for the SO4 rootstock were the same as for the shoots of the Cabernet Sauvignon variety (Corbin *et al.*, 2015), while for the other rootstocks lower ash contents of about 1.5% were re-

Table 2. Comparison of technical and elemental analysis results for grape shoots depending on the rootstock used in grape cultivation

Parameter		Value depending on the rootstock						Control	*p*-value
		101-14	125 AA	161-49	5 BB	SO4	SORI		
HHV MJ·kg^{-1}	mean	15.69^{C}	16.40^{B}	18.04^{A}	17.91^{A}	17.93^{A}	16.90^{B}	16.49^{B}	0.0001
	±*SD*	0.07	0.11	0.09	0.08	0.10	0.07	0.06	
C %	mean	38.64^{E}	38.97^{E}	40.44^{C}	41.44^{B}	43.20^{A}	41.77^{B}	39.93^{D}	0.0001
	±*SD*	0.09	0.14	0.17	0.12	0.24	0.08	0.15	
H %	mean	8.14^{B}	7.75^{B}	7.83^{B}	7.68^{B}	7.56^{A}	7.14^{C}	7.82^{B}	0.0001
	±*SD*	0.03	0.23	0.04	0.02	0.06	0.02	0.10	
N %	mean	0.66^{BC}	0.68^{ABC}	0.62^{C}	0.65^{C}	0.72^{AB}	0.75^{A}	0.69^{ABC}	0.0006
	±*SD*	0.00	0.03	0.01	0.03	0.02	0.03	0.04	
S %	mean	0.43^{B}	0.44^{A}	0.37^{E}	0.34^{F}	0.04^{G}	0.38^{D}	0.41^{C}	0.0001
	±*SD*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
O %	mean	48.92^{A}	47.96^{B}	47.28^{C}	46.58^{D}	45.48^{E}	46.28^{D}	47.98^{B}	0.0001
	±*SD*	0.19	0.28	0.18	0.14	0.33	0.08	0.37	
M %	mean	20.89^{A}	18.90^{B}	16.48^{D}	14.18^{E}	9.44^{G}	12.76^{F}	17.42^{C}	0.0001
	±*SD*	0.03	0.06	0.07	0.06	0.06	0.07	0.10	
A %	mean	3.20^{CDE}	4.19^{A}	3.46^{BC}	3.30^{CD}	2.99^{E}	3.68^{B}	3.17^{DE}	0.0001
	±*SD*	0.12	0.10	0.06	0.10	0.10	0.04	0.16	
V %	mean	59.44^{E}	60.90^{D}	63.20^{C}	64.90^{B}	68.32^{A}	65.20^{B}	61.87^{D}	0.0001
	±*SD*	0.24	0.34	0.45	0.97	0.14	0.16	0.40	
FC %	mean	16.47^{DE}	16.01^{E}	16.86^{CDE}	17.62^{BC}	19.25^{A}	18.36^{AB}	17.54^{BCD}	0.0001
	±*SD*	0.32	0.29	0.44	0.85	0.04	0.25	0.18	

Explanations: *HHV* = higher 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.
Source: own study.

corded for the 'Savignon Blanc', 'Pinot Noir', 'Muscat Ottonel', or 'Feteasca Alba' cultivars (Senila *et al.*, 2020).The content of volatile parts ranged from 59.44% for the 101-14 rootstock, to 68.32% for the SO4 rootstock. It can be noted that for this trait, the difference between the extreme results was more than 8.8%. The lowest content for bound carbon was recorded for shoots from cultivation on 125 AA rootstock, while cultivation on SO4 rootstock showed the highest estimated value in shoots. Considering the content of bound carbon, the choice of the appropriate rootstock in cultivation may cause a difference in shoots of about 3.2%. Comparing the obtained TGA results with the studies of Nunes *et al.* (2021a) and Nunes *et al.* (2021b) it was noted that the obtained results for the content of volatile parts are 10% lower for the tested materials, and bound carbon at a similar level.

Figure 1 shows the dependence of bound carbon on the heat of combustion (Tab. 3).

The heat of combustion of solid biofuel can also be affected by other parameters, such as the fixed carbon and volatile content of the fuel. By analysing the data in Figure 1, it can be concluded that the level of fixed carbon content in a solid fuel is directly related to its heat of combustion. As a rule, solid fuels with higher levels of fixed carbon content tend to have higher heat of combustion. This is due to the fact that bound carbon is the primary source of heat released during the fuel combustion process. Studies have also shown that the heat of combustion increases with increasing volatile content. It should be remembered that the higher the content of volatile parts in the fuel, the easier ignition and faster combustion. Hence, the fuel with the highest energy quality in terms of the evaluated parameters can be determined by shoots obtained from cultivation on SO4 rootstock (Fig. 1).

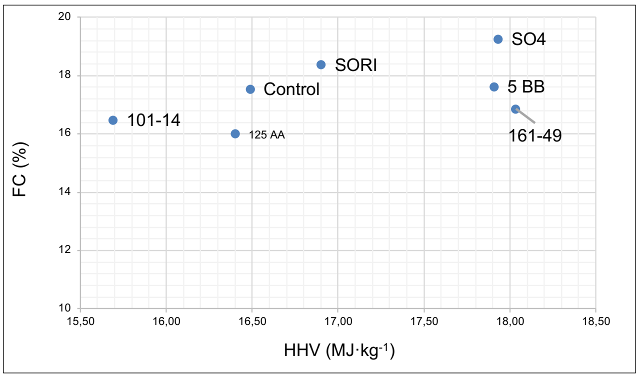

Fig. 1. Dependence of bound carbon on heat of combustion; *FC* = fixed carbon index, *HHV* = higher heating value, 101-14, 125 AA, 161-49, 5 BB, SO4, SORI = rootstoks; source: own study

When analysing the data on the results of exhaust composition estimation, the effect of rootstock on all estimated traits was also noted (Tab. 3). The oxygen demand of the exhaust (V_{O_2}) was on a similar level, as the difference between the extreme values for growing on SO4 rootstock (0.91 Nm^3·kg^{-1}) and on 125 AA rootstock (0.83 Nm^3·kg^{-1}) was 8.8%. The stoichiometric volume of dry air (V_{oa}) was in the range from 3.95 to 4.34 Nm^3·kg^{-1}, indicating the 125 AA rootstock to be the one that generates the lowest air demand during combustion. Cultivation on the rootstock SO4 showed the highest CO_2, N_2 and total dry flue gas stoichiometric volume (V_{ogu}). Shoots from the 101-14 rootstock cultivation had the highest parameters for generated flue gases like SO_2, water content (V_{H_2O}) and total flue gas volume (V_{oga}). The lowest V_{oga} was shown for shoots from vine cultivation on SO4 rootstock, and the lowest total dry stoichiometric

Table 3. Exhaust composition for grape shoots depending on the rootstock used in grape cultivation

Exhaust component		Value ($Nm^3\ kg^{-1}$) depending on the rootstock						Control	*p*-value
		101-14	125 AA	161-49	5 BB	SO4	SORI		
V_{O_2}	mean	0.84^{DE}	0.83^{E}	0.87^{BC}	0.88^{B}	0.91^{A}	0.86^{BCD}	0.85^{CDE}	0.0001
	±*SD*	0.00	0.02	0.00	0.00	0.01	0.00	0.01	
V_{oa}	mean	3.99^{DE}	3.95^{E}	4.12^{BC}	4.19^{B}	4.34^{A}	4.09^{BCD}	4.05^{CDE}	0.0001
	±*SD*	0.01	0.07	0.01	0.02	0.05	0.01	0.04	
V_{CO_2}	mean	0.72^{E}	0.73^{E}	0.76^{C}	0.77^{B}	0.81^{A}	0.78^{B}	0.75^{D}	0.0001
	±*SD*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
V_{SO_2}	mean	0.0030^{B}	0.0031^{A}	0.0026^{E}	0.0024^{F}	0.0003^{G}	0.0027^{D}	0.0029^{C}	0.0001
	±*SD*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
V_{H_2O}	mean	181.72^{A}	141.56^{B}	107.91^{C}	89.47^{D}	71.53^{D}	166.20^{A}	125.69^{BC}	0.0001
	±*SD*	5.84	4.44	6.89	6.85	6.28	7.14	7.88	
V_{N_2}	mean	3.68^{C}	3.67^{C}	3.75^{BC}	3.83^{B}	4.01^{A}	3.83^{B}	3.75^{BC}	0.0001
	±*SD*	0.01	0.08	0.00	0.02	0.05	0.03	0.06	
V_{oga}	mean	186.13^{A}	145.96^{C}	112.41^{C}	94.08^{D}	76.35^{D}	170.81^{A}	130.19^{BC}	0.0001
	±*SD*	5.83	4.39	6.89	6.83	6.23	7.16	7.92	
V_{ogu}	mean	4.41^{C}	4.40^{C}	4.51^{BC}	4.61^{B}	4.82^{A}	4.61^{B}	4.50^{BC}	0.0001
	±*SD*	0.01	0.08	0.01	0.02	0.06	0.03	0.06	

Explanations: V_{O_2} = the theoretical oxygen demand, V_{oa} = stoichiometric volume of dry air required to burn 1 kg of biomass, V_{CO_2} = the carbon dioxide content, V_{SO_2} = the content of sulphur dioxide, V_{H_2O} = the water vapour content of the exhaust gas, V_{N_2} = 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, the others as in Tab. 1.
Source: own study.

exhaust (V_{oga}) for shoots from 125 AA rootstock. Analysis of the data indicates that the total volume of exhaust gases for the crops studied showed a variation of up to 58%. With this in mind, the desire to use the shoots as biofuel brings with it the need to evaluate the volume of emitted gases from the combustion process. In order to reduce exhaust gas emissions, it would be advisable in such a case to recommend cultivation on SO4 rootstock. Comparing the obtained data with the literature, it was found that the obtained data for the cultivation of 'Regent' grapevines on different rootstocks in terms of theoretical air demand coincides for pure grape talks Malaťák *et al.* (2022) and from growing on 101-14 rootstock with *Miscanthus gigantheus* vs. on 125 AA rootstock as in *Phalaris arundinacea* L. (Malaťák *et al.*, 2020). Making a comparison of the theoretic all amount of dry flue gases, the tested materials showed an average of 1.0 $Nm^3 \cdot kg^{-1}$ higher content than *Camelina sativa*, *Miscanthus gigantheus*, *Sorghum bicolor*, or pure grapes talks (Malaťák *et al.*, 2020; Malaťák *et al.*, 2022). Similar values were recorded for pure white grape pomace, as well as pure red grape pomace (Malaťák *et al.*, 2022).

Figure 2 shows the main component analysis of energy (a) and biomass (b) parameters. Cutting off the analysis at the 0.75 level of the scale, we observe that both dendrograms distinguish three clusters. Energy parameters that the first cluster consists of 101-14 and SORI, the next cluster consists of the 125 AA and control group and the 161-49 subgroup, and the last cluster is 5 BB and SO4. Compared to the parameters of green biomass, no clusters overlap with the division included in the energy parameters. The first cluster consists of 125 AA, the next one of SORI, and the last largest one consists of the remaining types of revision. In this case, the analysis of principal components can only indicate similarities in rootstock types within individual clusters divided into energy and green mass parameters.

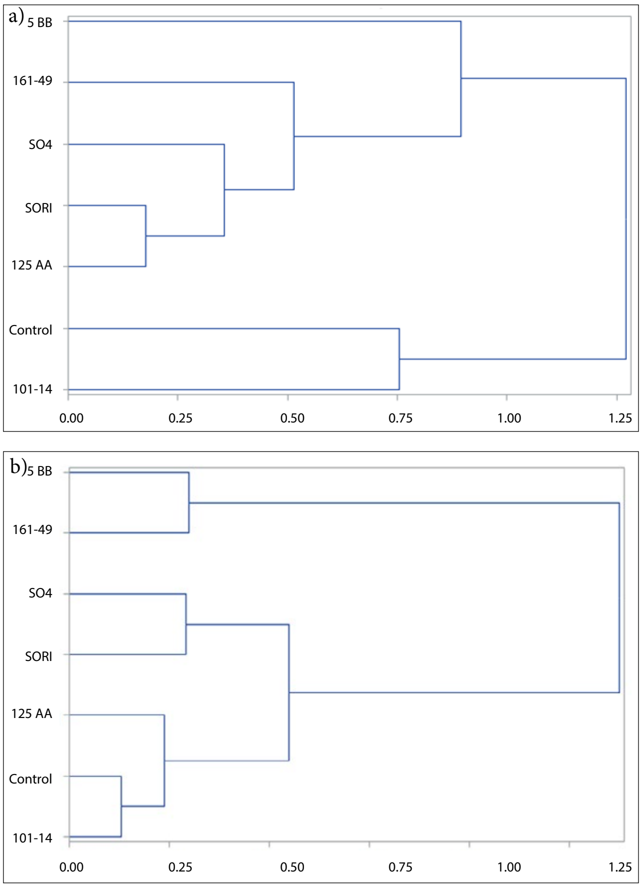

Fig. 2. Analysis of the main components of parameters: a) energetic, b) biomass; source: own study

CONCLUSIONS

1. There was no significant effect of the type of rootstock used on the number of lignified shoots of 'Regent' grapevines.
2. Biomass parameters determined by the diameter and mass of the lignified shoot in the vines grafted on 125 AA rootstock were characterised by significantly the highest value among the evaluated combinations. The analysed biomass parameters in shrubs on 101-14 and 161-49 rootstocks were significantly the lowest. The opposite trend was observed in the case of burning 161-49.
3. Biomass from control bushes expressed in average values, a tendency that was also confirmed in the first and elemental technical analysis.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

REFERENCES

Aniszewska, M. *et al.* (2015) "Nowoczesne rozwiązania konstrukcyjne maszyn do rozdrabniania biomasy w sadach i winnicach [Modern design solutions for biomass shredding machines in orchards and vineyards]," *Technika Rolnicza Ogrodnicza i Leśna*, 2/2015, pp. 21–23. Available at: https://tech-rol.eu/images/Archiwum_X/2019/05/trol_MA2_2015.pdf (Accessed: February 13, 2023).

Bielicki, P. and Pąśko, M. (2013) "Wpływ podkładki na jakość drzewek moreli produkowanych w szkółce ekologicznej [Effect of the rootstocks on the quality of apricot maiden trees produced in the organic nursery]," *Journal of Research and Applications in Agricultural Engineering*, 58(3), pp. 11–14. Available at: https://tech-rol.eu/images/Archiwum_X/2019/05/2013_3_2BP.pdf (Accessed: February 2, 2023).

Borkowska, H. and Lipiński, W. (2007) "Zawartość wybranych pierwiastków w biomasie kilku gatunków roślin energetycznych [Content of selected elements in biomass of several species of energy plants]," *Acta Agrophysica*, 10(2), pp. 287–292. Available at: http://www.old.acta-agrophysica.org/artykuly/acta_agrophysica/ActaAgr_152_2007_10_2_287.pdf (Accessed: February 13, 2023).

Corbin, K.R. *et al.* (2015) "Grapemarc as a source of carbohydrates for bioethanol: Chemicalcomposition, pre-treatment and saccharification," *Bioresource Technology*, 193, pp. 76–83. Available at: https://doi.org/10.1016/j.biortech.2015.06.030.

Directive (2008) "Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)," *Official Journal*, L L312/3.

Filipiak, T. and Maciejczak, M. (2017) "Zrównoważona uprawa winorośli i produkcja winogron jako szanse na dostosowanie do zmian klimatu badane w projekcie Vitismart [Sustainable viticulture and grape production as an opportunity for adaptation to climate change researched within the Vitismart project]," *Wieś Jutra*, 4(193), pp. 1–3.

Gaworski, M. and Malinowski, K. (2011) "Analiza transformacji gospodarstwa ogrodniczego uwzględnieniem aspektów technicznych [Analysis of horticultural farm transformation including some technical aspects]," *Inżyniera Rolnicza*, 11(134), pp. 42–48.

Gonçalves, C. *et al.* (2011) "Organic particulate emissions from field burning of garden and agriculture residues," *Atmospheric Research*, 101(3), pp. 666–680. Available at: https://doi.org/10.1016/j.atmosres.2011.04.017.

Gorzelany, J. and Matłok, N. (2013) "Analiza energetyczna biomasy odpadowej z produkcji drzewek owocowych na terenie województwa podkarpackiego [Energy analysis of waste biomass from production of fruit trees on the territory of podkarpackie voivodeship]," *Inżynieria Rolnicza*, 3(146), pp. 77–83.

Gudarowska, E. and Szewczuk, A. (2011) "Wpływ podkładki i geokompozytu sorbującego wodę na wzrost i owocowanie jabłoni [The influence of rootstock and water-absorbing geo-composite on the growth and yielding of apple trees]," *Infrastruktura i Ekologia Terenów Wiejskich*, 5, pp. 83–94. Available at: http://www.infraeco.pl/en/art/a_16321.htm?plik=1004 (Accessed: February 23, 2023).

Harris, J.L. (2018) *Effect of rootstock of vegetative growth yield and fruit composition of Norton grapevines*. PhD Thesis. Columbia, MI, USA: University of Missouri.

Hetman, J. and Monder, M.J. (2003) "Wpływ jakości podkładki i zrazów na wyniki okulizacji dwóch odmian róż z grupy wielokwiatowych [The influence of quality of the rootstocks and scions on results of budding two rose cultivars from the floribundas group]," *Acta Scientiarum Polonorum Hortorum Cultus*, 2(2), pp. 33–41.

Izajasz-Parchańska, M., Cioch, M. and Tuszyński, T. (2014) "Monitoring parametrów dojrzałości technologicznej winogron na terenie Małopolskiej winnicy Srebrna Góra, w sezonie wegetacyjnym 2012 [Monitoring parameters of technological maturity of grapes in Malopolska Silver Mountain Vineyard in the growing season 2012]," *Acta Agrophysica*, 21(3), pp. 263–278.

Jagustyn, B., Bątorek-Giesa, N. and Wilk, B. (2011) "Ocena właściwości biomasy wykorzystywanej do celów energetycznych [Assessment of the properties of biomass used for energy purposes]," *Chemik*, 65(6), pp. 557–563.

Kapłan, M. and Baryła, P. (2006) "The effect of M.9 and M.26 rootstocks on the growth of maiden trees of 'Szampion' and 'Jonica' apple cultivars," *Acta Agrobotanica*, 59(2), pp. 223–230. Available at: https://pbsociety.org.pl/journals/index.php/aa/article/view/aa.2006.078/1509 (Accessed: February 10, 2023).

Klimek, K., Kapłan, M. and Maj, G. (2023) "The evaluation of energy from grapevine shoots used as biomass depending on the cultivar," *Journal of Water and Land Development*, 58, pp. 120–128. Available at: https://doi.org/10.24425/jwld.2023.146604.

KOWR (2023). *Rynek wina w liczbach za lata gospodarcze 2009/2010–2021/2022 [Wine market in numbers for the marketing years 2009/2010–2021/2022]*. Warszawa: Krajowy Ośrodek Wsparcia Rolnictwa. Available at: https://www.gov.pl/web/kowr/administrowanie-potencjalem-produkcyjnym-produktow-sektora-wina (Accessed: October 12, 2023).

Królikowski, K. and Matłok, N. (2021) "Wielkość biomasy odpadowej z produkcji szkółkarskiej i możliwości jej zagospodarowania [Biomass waste amount from nursery production and possibilities of its usage]," *Polish Journal for Sustainable Development*, 25(2), pp. 63–68. Available at: https://doi.org/10.15584/psjd.2021.25.2.7.

Lisek, J. (2008) "Climatic factors affecting development and yielding of grapevine in Central Poland," *Journal of Fruit and Ornamental Plant Research*, 16, pp. 285–293. Available at: http://www.inhort.pl/files/journal_pdf/journal_2008/full25%202008.pdf (Accessed: February 13, 2023).

Lisek, J. *et al.* (2016) "Growth, yielding and healthiness of grapevine cultivars 'Solaris' and 'Regent' in response to fertilizers and biostimulants," *Journal of Horticultural Research*, 24(2), pp. 49–60. Available at: https://doi.org/10.1515/johr-2016-0020.

Malaťák, J. *et al.* (2020) "Evaluation of CO and NOx emissions in real-life operating conditions of herbaceous biomass briquettes combustion," *Acta Technologica Agriculturae*, 23, pp. 53–59. Available at: https://doi.org/10.2478/ata-2020-0009.

Malaťák, J. *et al.* (2022) "Reducing emissions from combustion of grape residues in mixtures with herbaceous biomass," *Materials*, 15, 7288. Available at: https://doi.org/10.3390/ma15207288.

Manzone, M. *et al.* (2016) "Biomass availability and quality produced by vineyard management during a period of 15 years," *Renewable Energy*, 99, pp. 465–471. Available at: https://doi.org/10.1016/j.renene.2016.07.031.

Mencarelli, A., Cavalli, R. and Greco, R. (2022) "Analysis of the main physical and chemical characteristics of the vine shoots of three vine varieties from Veneto (Italy)," *Journal of Agricultural Engineering*, 53(4). Available at: https://doi.org/10.4081/jae.2022.1396.

Mendivil, M.A. *et al.* (2015) "Energy potential of vine shoots in La Rioja (Spain) and their dependence on several viticultural factors," *Ciencia e Investigación Agraria*, 42(3), pp. 443–451. Available at: https://doi.org/10.4067/s0718-16202015000300012.

Myśliwiec, R. (2006) *Winorośl w ogrodzie [Vine in the garden]*. Warszawa: PWRiL.

Myśliwiec, R. (2013) *Uprawa winorośli [Viticulture]*. Kraków: PWRiL.

Nunes, L.J.R. *et al.* (2021a) "Energy recovery of agricultural residues: Incorporation of vine pruning in the production of biomass pellets with ENplus® certification," *Recycling*, 6(2), 28. Available at: https://doi.org/10.3390/recycling6020028.

Nunes, L.J.R. *et al.* (2021b) "Production of biochar from vine pruning: Waste recovery in the wine industry," *Agriculture*, 11(6), 489. Available at: https://doi.org/10.3390/agriculture11060489.

Olewnicki, D. (2018) "Uprawa winorośli w Polsce w świetle danych statystycznych [Viticulture in Poland in the light of statistical data]," *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, 20(5), pp. 139–145.

Provost, C., Cambell, A. and Dumont, F. (2021) "Rookstock impact yield, fruit compositions, nutrient deficiencies and winter survival of hybrid cultivars in eastern Canada," *Horticulturae*, 7(8), pp. 237. Available at: https://doi.org/10.3390/horticulturae7080237.

Reisch, B.I., Owens, C.L. and Cousins, P.S. (2012) "Grape" in M.L. Badenes and D.H. Byrne (eds.) *Fruit breeding. Handbook of plant breeding*, 8. New York, NY: Springer, pp. 225–262.

Rusnak, J. (2016) *Zakładanie i prowadzenie winnicy [Establishing and running a vineyard]*. Karniowic: Małopolski Ośrodek Doradztwa Rolniczego.

Sánchez-Gómez, R. *et al.* (2017) "Reuse of vine-shoots wastes for agricultural purposes," in C.M. Galanakis (ed.) *Handbook of grape processing by-products: Sustainable solutions*. Cambridge: Academic Press, pp. 79–104.

Senila, L. *et al.* (2020) "Vineshoots waste – new resources for bioethanol production," *Romanian Biotechnological Letters*, 25, pp. 1253–1259. Available at: https://doi.org/10.25083/rbl/25.1/1253.1259.

Spinelli, R. *et al.* (2012) "Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues," *Applied Energy*, 89(1), pp. 374–379. Available at: https://doi.org/10.1016/j.apenergy.2011.07.049.

Spinelli, R. *et al.* (2014) "An alternative to field burning of pruning residues in mountain vineyards," *Ecological Engineering*, 70, pp. 212–216. Available at: http://doi.org/10.1016/j.ecoleng.2014.05.023.

Szewczuk, A. and Gudarowska, E. (2011) *Wpływ podkładki na wzrost i plonowanie czterech odmian brzoskwiń. Przydatność podkładki karłowej Pumiselect w uprawie brzoskwini [The influence of the rootstock on the growth and yield of four peach cultivars. The usefulness of the Pumiselect dwarf rootstock in peach cultivation]*. Wrocław: Wyd. UPWr, pp. 72–102.