The evaluation of energy from grapevine shoots used as biomass depending on the cultivar

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Abstract: The article examines the influence of physicochemical traits on yield depending on the variety and year of cultivation. Four common to Poland grape cultivars, i.e. 'Regent', 'Rondo', 'Seyval Blanc', and 'Solaris', were evaluated by analysing, among others, number of clusters per bush, their weight, number of berries, and the yield per hectare, number of woody shoots, weight of woody shoots, and the diameter of woody shoots. Energy and emission parameters were evaluated by conducting technical evaluation (lower heating value, ash content, volatile matters content, moisture content, fixed carbon) and elemental analysis (carbon, nitrogen, hydrogen, sulphur and oxygen contents) of one-year, two-year and three-year vine shoots. In addition, emission factors for CO, CO_2, NO_x, SO_2 and dust were estimated. The study showed that there was no significant differences between years under study (2020, 2021 and 2022) and energy and emission parameters. It was observed that the highest *LHV* (lower heating value) occurred in the 'Regent' cultivar while the lowest level in the 'Rondo' cultivar. As regards energy-emission parameters, a significant influence of cultivar ('Solaris', 'Rondo', 'Seyval Blanc' and 'Regent') was shown on the parameters studied except for nitrogen content and NOx emission index. The interaction of year and cultivar showed no significant differences except for the moisture content.

Keywords: biomass, crop, energy properties, shootings, vine

INTRODUCTION

Viticulture in Poland has developed in the conditions of the so-called cold climate. These conditions are significantly different from the traditional cultivation area of grapevine species. Characteristic growing conditions determine precise recommendations for the selection of appropriate fertilisation and cultivation, as well as the verification of results obtained against natural conditions (Lisek *et al.*, 2016).

In regions with a cool climate, extremely low temperatures are the most common constraint to grape production. Frost damage to buds, fruiting shoots and trunks increases production costs due to additional reclamation and replacement of damaged vines in the case of a yield drop (Zabadal *et al.*, 2007). Freezing injuries may be caused under extremely low negative temperatures in winter and spring, significantly impairing grapevine

development (Gonzalez Antivilo *et al.*, 2020). Grape genotypes with excellent tolerance to low temperatures are necessary for a successful wine industry in climate areas of low temperatures. Cold climate interspecific hybrid grapevines (CCIHG) have a genetic background including *Vitis aestivalis*, *V. labrusca*, *V. riparia*, *V. rupestris and V. vinifera* (Smiley and Cochran, 2016; Atucha, Tanzi and Lanzetta, 2018). The high fruit quality of *V. vinifera* with excellent winter hardiness found in wild *Vitis* species due to the development of CCIHG cultivars.

Recently, the interest in interspecific varieties has increased again around the world, mainly due to greater awareness among consumers and growers about organic farming and the environmental impact of phytochemicals (Jacquet *et al.*, 2020). Successful viticulture must meet expectations of both consumers and growers regarding high-quality wine, tolerance to insects and diseases (Lisek, 2004; Vool, Rätsep and Karp, 2015; Casanova-

Gascón *et al.*, 2019; Roca, 2019; Clark, 2020). In recent years, environmental issues have increasingly sparked political and social discussions. The European agricultural policy has introduced management and integrated agronomic practices in vineyards (Directive, 2009) while reducing the use of fungicides and pesticides by resorting to more disease-resistant varieties instead of conventional ones. Hybrid varieties are probably the most promising for low-cost, time-saving and low-input viticulture due to their pest and disease tolerance (Lisek, 2008; Lisek, 2009). Currently, the wine industry in many countries outside the European Union uses a high percentage of interspecific varieties with very good results. They also provide funding for special breeding programmes (Dobrowolska-Iwanek *et al.*, 2014). These varieties are desirable to combine the quality of traditional European varieties (*V. vinifera*) with diverse resistance characteristics typical of American varieties, such as *V. aestivalis*, *V. amurensis*, *V. berlandieri*, *V. labrusca* and *V. riparia*.

Currently, a promising market for hybrids has been created by the 'Regent' cultivar in Germany, where it is grown on more than 600 ha; a similar trend can be foreseen in Europe, especially in Italy (Fisher, 2000). Since soil, location and climate, and soil conditions play a key role in vine productivity and wine quality characteristics, the relationship between hybrids and the environment is essential when assessing the study area.

Unlike other orchard species, the vine requires intensive pruning in order to obtain the highest quality and production volume (Spinelli *et al.*, 2012). The recovery of plant biomass in the form of waste and residues from vine cutting and their possible use for energy production is one of the most important innovations in the agricultural sector (González-García *et al.*, 2014; Choudhury *et al.*, 2021; Garita-Cambronero *et al.*, 2021). Residues from agricultural production can become a potential source of biomass for renewable energy production, as they are available annually (Manzone *et al.*, 2016; Senila *et al.*, 2020). Total wood production in a given year depends on many factors, i.e. habitat conditions, rootstock, cultivar, planting density and type of fertilisers, health (Rosúa and Pasadas, 2012).

Vine pruning residue should be removed before any other treatment is undertaken (Dam van *et al.*, 2007; Spinelli *et al.*, 2012; González-García *et al.*, 2014; Burg *et al.*, 2017; Garita-Cambronero *et al.*, 2021). In commercial vineyards, the residue is stored outside the vineyard and burned or mulched on site (Souček, Burg and Kroulik, 2007; González-García *et al.*, 2014). Both solutions pose problems in terms of time, environmental impact and economy. Mulching is very dangerous in terms of spreading disease, but it helps to maintain organic matter, nutrients and moisture in the soil (Blasi di, Tanzi and Lanzetta, 1997). In addition to being labour-intensive, incineration is cheap (Mendívil *et al.*, 2013). At the same time, it is characterised by an increased amount of dust emitted to the atmosphere (Spinelli *et al.*, 2012; Spinelli *et al.*, 2014). It should be noted that vineyard pruning residues have qualitative characteristics compared to other lignocellulosic raw materials, which most likely affects the choice and efficiency of processing technology (Scarlat, Blujdea and Dallemand, 2011), as well as the potential for co-firing (Magagnotti *et al.*, 2009).

In their work, Corona and Nicoletti (2010) showed that in the Agrigento district, Italy, the production of biomass, which includes pruned shoots, is 2.69 $Mg \cdot ha^{-1} \cdot y^{-1}$. The research discussed in this paper is innovative, because the evaluation of "PIWI" (from the German "pilzwiderstandsfähige Rebsorten" – vine varieties resistant to fungal diseases) varieties in terms of energy potential and biomass residues is little known compared to the varieties commonly cultivated in the world, such as *V. vinifera* (Souček *et al.*, 2007; Scarlat, Blujdea and Dallemand, 2011; Mendívil *et al.*, 2013; González-García *et al.*, 2014).

The aim of the work was to indicate differences in the number of shoots generated and energy and emission parameters of biomass depending on the grape cultivar and the year of research as a potential biofuel.

MATERIALS AND METHODS

The experimental material consisted of one-year-old woody shoots (beds) collected in the spring (March) of 2020, 2021 and 2022 from common to Poland grape cultivars: 'Regent', 'Rondo', 'Seyval Blanc' and 'Solaris'. To verify the validity of results, a preliminary analysis of normal distribution was carried out using Shapiro–Wilk test. The significant effect of lignified shoots of four vines on dry biomass was verified by Tukey's test and one-way ANOVA. Inference was carried out at the significance level of $\alpha = 0.05$. Multivariate techniques, i.e. cluster analysis, were used to graphically represent the biomass studied.

Figure 1 shows the statistical methods used for the four grape varieties, the three years of the study and the energy potential. A detailed description of the plant material sampling methodology is also presented. Table 1 presents weather conditions in the place of cultivation of the vines tested.

The average air temperature for the growing season in 2021 was lower than the long-term average. A similar trend was observed in April, May and August. In the remaining period of the study, the opposite situation was observed, i.e. the average air temperature was higher than the long-term average.

It was observed that in 2021 the total precipitation from April to October was higher than the long-term average. In the other years, the opposite relationship was shown. The wettest month in the entire study period was August 2021, and the driest October 2021.

The tests were carried out in accordance with the procedure included in the individual standards listed in Figure 2. Individual parameters for the grinded material were determined using dedicated analysers. It included the determination of the lower heat value (LECO AC 600), and technical analysis (LECO TGA 701) and elemental analysis (LECO CHNS 628) for solid fuels. On the basis of the data obtained, in the next stage, the emission assessment was performed using the detailed indicator method described in Figure 2.

RESULTS AND DISCUSSION

The grape varieties analysed are characterised by generating large amounts of wood waste each year. The grape shoots obtained by pruning are characterised by both the large number of woody shoots on the vine and the weight (Tab. 2). On a per hectare basis, a waste product is obtained that should be managed and the quantities indicate a high potential for the utilisation of the raw material.
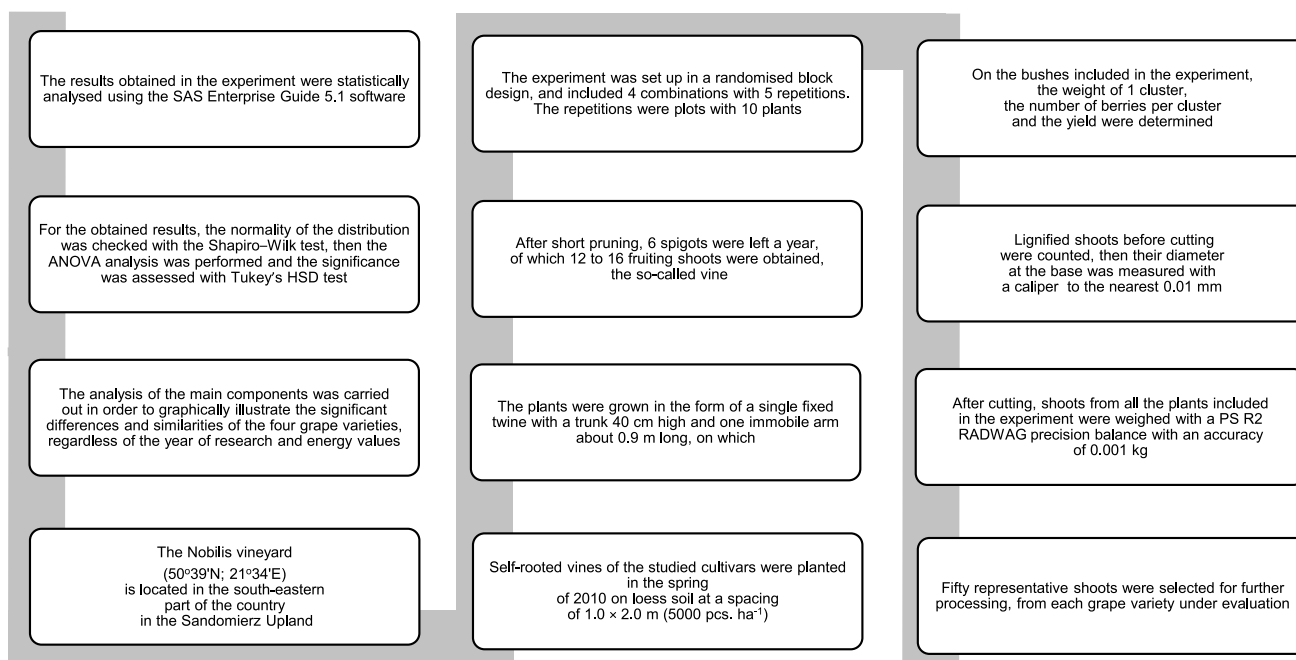
Fig. 1. Summary of statistical methods used and sampling of raw materials tested; source: own study

Table 1. Average monthly air temperatures and total precipitation according to the Agrometeorological Station in Pęchów in April–October 2020–2022 (Horti ProCam)

Period	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr–Oct
Air temperature (°C)								average
2020	9.5	11.9	18.6	19.3	20.5	15.3	9.9	15.0
2021	6.7	13.0	20.0	22.2	17.3	13.7	9.2	13.6
2022	8.7	16.2	21.4	20.7	22.2	13.3	11.7	16.3
Mean (1988–2008)	8.8	14.2	16.9	19.1	18.4	13.4	8.6	14.2
Total precipitation (mm)								sum
2020	11.0	54.6	64.2	44.0	43.8	58.2	78.2	354.0
2021	43.2	47.4	64.1	105.3	215.1	67.5	7.1	549.7
2022	39.5	12.0	16.0	101.8	93.6	47.2	33.8	300.9
Mean (1988–2008)	45.7	57.0	68.7	82.4	58.7	57.0	37.9	361.7

Source: own elaboration.

The number of clusters per bush ranged from 19.8 to 23.5 and differed significantly among the varieties. There were no significant differences in the evaluation of the parameter between the 'Rondo', 'Seyval Blanc' and 'Regent' cultivars. In turn, no significant differences were shown between the years of the study and the interaction of cultivar and the year of study.

The weight of one cluster ranged from 119.7 to 202.5 g and differed significantly between the varieties evaluated. Bushes of the 'Rondo' and 'Seyval Blanc' cultivars had clusters that did not differ significantly among themselves, while the statistical analysis carried out showed significant differences with the other varieties. Significant differences in weight per cluster were shown between the first and last years of the study, and interactions were also found between the year of the study and the cultivar. While evaluating the performance of 19 hybrids and 'Pinot Gris'

cultivars in north-eastern Italy, Pacifico et al. (2013) showed that grape weight differed significantly among the varieties evaluated, ranging from 103.0 to 217.0 g.

The number of berries per cluster ranged from 96.7 to 152.8 and differed significantly among all the grape varieties evaluated. Indeed, clusters of the 'Seyval Blanc' cultivar had the most berries per cluster. Significant differences in the evaluation of the parameter under study were also shown by all years of the study. The highest values of the parameter were shown in 2022, while the lowest in 2020. The correlation between the cultivar and the year of the study was significant.

The grape yield of the varieties ranged from 12.3 to 21.4 Mg·ha^{-1}. There were no significant differences in yield weight between the 'Regent', 'Seyval Blanc' and 'Solaris' cultivars, while they differed significantly from the 'Rondo' cultivar.
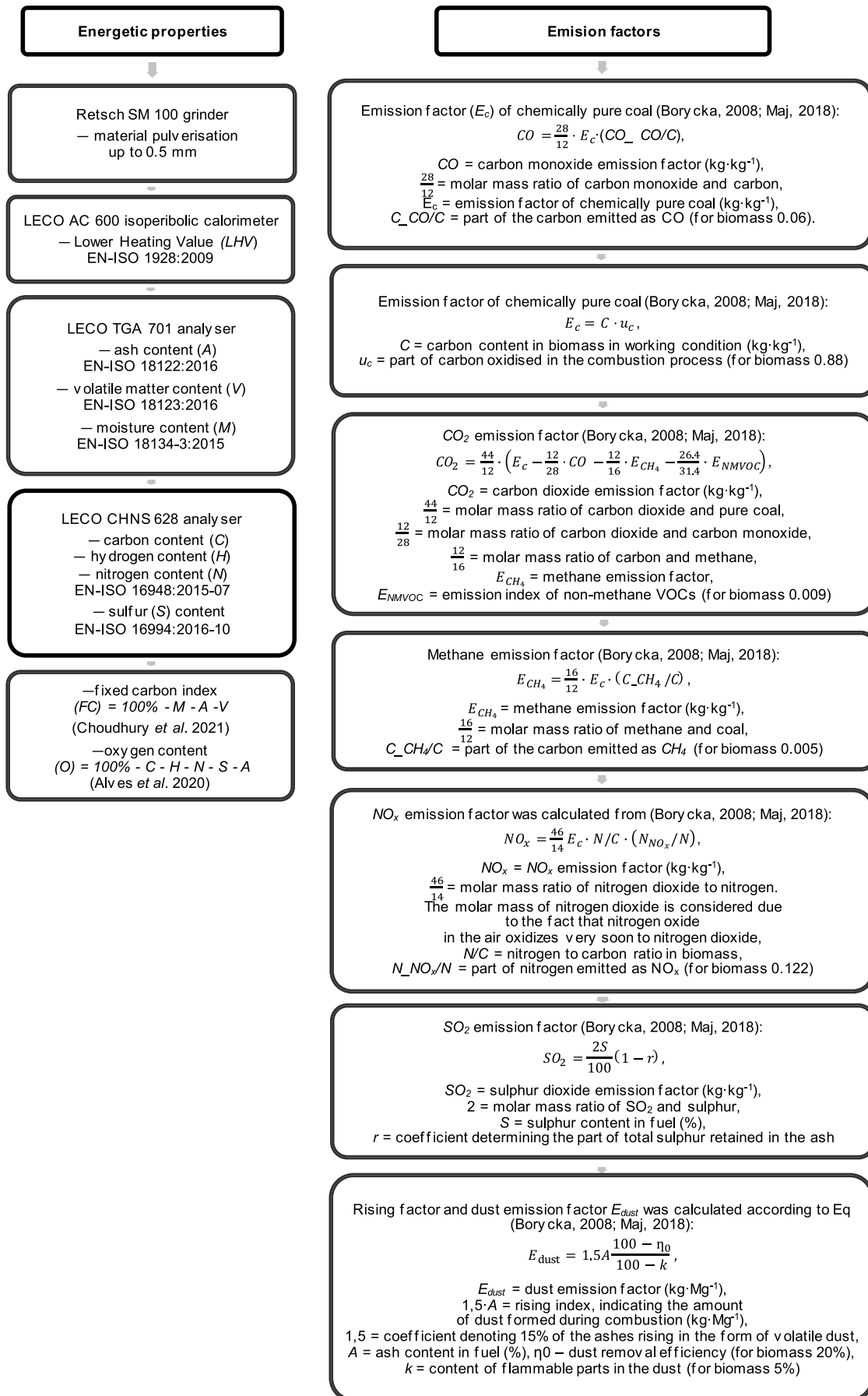
| **Energetic properties** | **Emision factors** |

Energetic properties

Retsch SM 100 grinder
— material pulverisation
up to 0.5 mm

LECO AC 600 isoperibolic calorimeter
— Lower Heating Value *(LHV)*
EN-ISO 1928:2009

LECO TGA 701 analyser
— ash content (*A*)
EN-ISO 18122:2016
— volatile matter content (*V*)
EN-ISO 18123:2016
— moisture content (*M*)
EN-ISO 18134-3:2015

LECO CHNS 628 analyser
— carbon content (*C*)
— hydrogen content (*H*)
— nitrogen content (*N*)
EN-ISO 16948:2015-07
— sulfur (*S*) content
EN-ISO 16994:2016-10

—fixed carbon index
(FC) = 100% - M - A -V
(Choudhury *et al.* 2021)
—oxygen content
(O) = 100% - C - H - N - S - A
(Alves *et al.* 2020)

Emision factors

Emission factor (E_c) of chemically pure coal (Borycka, 2008; Maj, 2018):
$$CO = \frac{28}{12} \cdot E_c \cdot (CO\_\ CO/C),$$
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/C = part of the carbon emitted as CO (for biomass 0.06).

Emission factor of chemically pure coal (Borycka, 2008; Maj, 2018):
$$E_c = C \cdot u_c,$$
C = carbon content in biomass in working condition (kg·kg⁻¹),
u_c = part of carbon oxidised in the combustion process (for biomass 0.88)

CO_2 emission factor (Borycka, 2008; Maj, 2018):
$$CO_2 = \frac{44}{12} \cdot \left(E_c - \frac{12}{28} \cdot CO - \frac{12}{16} \cdot E_{CH_4} - \frac{26.4}{31.4} \cdot E_{NMVOC} \right),$$
CO_2 = carbon dioxide emission factor (kg·kg⁻¹),
$\frac{44}{12}$ = molar mass ratio of carbon dioxide and pure coal,
$\frac{12}{28}$ = molar mass ratio of carbon dioxide and carbon monoxide,
$\frac{12}{16}$ = molar mass ratio of carbon and methane,
E_{CH_4} = methane emission factor,
E_{NMVOC} = emission index of non-methane VOCs (for biomass 0.009)

Methane emission factor (Borycka, 2008; Maj, 2018):
$$E_{CH_4} = \frac{16}{12} \cdot E_c \cdot (C\_CH_4 /C),$$
E_{CH_4} = methane emission factor (kg·kg⁻¹),
$\frac{16}{12}$ = molar mass ratio of methane and coal,
C_CH_4/C = part of the carbon emitted as CH_4 (for biomass 0.005)

NO_x emission factor was calculated from (Borycka, 2008; Maj, 2018):
$$NO_x = \frac{46}{14} E_c \cdot N/C \cdot \left(N_{NO_x}/N \right),$$
NO_x = NO_x emission factor (kg·kg⁻¹),
$\frac{46}{14}$ = 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,
N_NO_x/N = part of nitrogen emitted as NO_x (for biomass 0.122)

SO_2 emission factor (Borycka, 2008; Maj, 2018):
$$SO_2 = \frac{2S}{100}(1 - r),$$
SO_2 = sulphur dioxide emission factor (kg·kg⁻¹),
2 = molar mass ratio of SO_2 and sulphur,
S = sulphur content in fuel (%),
r = coefficient determining the part of total sulphur retained in the ash

Rising factor and dust emission factor E_{dust} was calculated according to Eq
(Borycka, 2008; Maj, 2018):
$$E_{dust} = 1.5A\frac{100 - \eta_0}{100 - k},$$
E_{dust} = dust emission factor (kg·Mg⁻¹),
1,5·A = rising index, indicating the amount
of dust formed during combustion (kg·Mg⁻¹),
1,5 = coefficient denoting 15% of the ashes rising in the form of volatile dust,
A = ash content in fuel (%), η0 — dust removal efficiency (for biomass 20%),
k = content of flammable parts in the dust (for biomass 5%)

Fig. 2. Methods and apparatuses used for the energy and carbon analysis of the raw materials studied; source: own study

Table 2. Yield and quality parameters and biomass (vine shoots residues) of four grape varieties in 2020–2022

Factor		Average number of cluster	Number of berries per cluster	Cluster weight (g)	Yield (Mg·ha⁻¹)	Number of lignified shoots (pcs)	Mass of lignified shoots (kg·ha⁻¹)	Diameter of lignified shoots (mm)
		pcs						
Vine variety (A)	'Regent'	20.6 ±1.2[B]	96.7 ±11.4 [D]	119.7 ±7.2[C]	12.3 ±0.9[B]	15.5 ±0.5[A]	3250.0 ±100.0[C]	8.1 ±0.1[B]
	'Rondo'	19.8 ±1.5[B]	106.7 ±6.6 [C]	202.5 ±11.4[A]	20.1 ±1.5[A]	14.2 ±0.8[B]	4433.3 ±256.6[A]	8.5 ±0.2[AB]
	'Seyval Blanc'	20.0 ±1.2[B]	152.8 ±14.7 [A]	200.8 ±12.1[A]	20.1 ±1.6[A]	12.5 ±0.5[C]	3883.3 ±256.6[B]	8.9 ±0.1[A]
	'Solaris'	23.5 ±1.6[A]	127.8 ±16.5 [B]	181.8 ±18.5[B]	21.4 ±3.0[A]	14.0 ±0.5[B]	3533.3 ±202.1[C]	8.2 ±0.2[AB]
p-value		**0.0010**	**0.0012**	**0.0011**	**0.0014**	**0.0031**	**0.0021**	**0.0118**
Study year (B)	2020	20.9 ±1.4[A]	110.1 ±20.2 [C]	170.1 ±38.2[B]	17.8 ±4.1[B]	14.0 ±1.6[A]	3737.5 ±619.6[A]	8.3 ±0.3[A]
	2021	20.7 ±2.0[A]	120.1 ±23.6 [B]	176.4 ±36.3[AB]	18.2 ±3.8[B]	14.1 ±1.4[A]	3800.0 ±549.2[A]	8.5 ±0.4[A]
	2022	21.4 ±2.5[A]	132.8 ±27.3 [A]	182.1 ±36.4[A]	19.5 ±4.5[A]	14.0 ±0.9[A]	3787.5 ±460.8[A]	8.5 ±0.4[A]
p-value		0.3772	**0.0001**	**0.0318**	**0.0031**	0.9109	0.7658	0.4995
Interaction (A×B)	p-value	0.0529	**0.0216**	**0.0273**	**0.0001**	0.1105	**0.0101**	0.9226

Explanation: mean values marked with the same letters do not differ significantly at $\alpha = 0.05$.
Explanations: LHV = lower heating value, S = sulphur content, N = nitrogen content, C = carbon content, H = hydrogen content, M = moisture content, O = oxygen content, A = ash content, V = volatile matter content, FC = fixed carbon, N/C = molar ratio of nitrogen and carbon, H/C = molar ratio of hydrogen and carbon, O/C = molar ratio of oxygen and carbon, WeC = emission factor of chemically pure coal, $WECO$ = emission factor of carbon oxide, $WNOx$ = emission factor of nitrogen oxides, $WECO_2$ = emission factor of carbon dioxide, $WESO_2$ = emission factor of sulphur dioxide, WE_{dust} = emission factor of dust.
Source: own study.

Significant differences were shown between the years of study with the yield of the varieties evaluated being the highest in 2022. A significant correlation was observed between the cultivar and the year of study. A study by Gąstoł (2015), evaluating the yield of the 13 most promising varieties suitable for wine production in cold climates, shown that the least productive varieties yielded an average of 5.0 Mg·ha⁻¹, and the most productive varieties 8.9 Mg·ha⁻¹. The highest yields of white grapes were harvested from the cultivars of 'Seyval Blanc' (2.80 kg per vine) and 'Hibernal' (2.35). 'Frontenac' outperformed other red varieties (2.64 kg per vine). Cultivars with moderate yields were 'Aurora', 'Muscat Odeskij' and 'Sibera' (white grapes) and 'Swenson Red' (red grapes). The high productivity of the 'Seyval Blanc' cultivar in the study by Gąstoł (2015) confirmed earlier reports by Lisek (2005) and Lisek (2010). In addition, the cultivation results for the 'Regent' cultivar were higher, which were described by Ochmian et al. (2013) in Pomerania, Poland. The yields obtained were higher than those reported by Pacifico et al. (2013) (4.1–11.7 kg per vine) in north-eastern Italy. The present study did not confirm the high productivity of 'Regent' compared to the other varieties evaluated. However, differences resulted not only from different climatic and soil conditions, but also from different viticulture systems. The number of fruiting shoots differed significantly in the grape varieties evaluated. Vines of the 'Regent' cultivar had the statistically significant largest number of shoots, while 'Seyval Blanc' had the smallest number. The weight of shoots from the vines of the cultivars ranged from 3.250 to 4.433 Mg·ha⁻¹ and differed significantly. Bushes of the 'Rondo' cultivar had the highest weight, while 'Regent' and 'Solaris' had the lowest weight. The diameter of fruit-bearing shoots in shrubs of the 'Seyval Blanc' cultivar was significantly larger than in 'Regent'. There was no significant effect of year on the biomass parameters evaluated. Significant correlations between the year of study and cultivar were shown in the weight of lignified shoots, while in other cases no significant correlation was found. The study by Lisek et al. (2016), which evaluated the growth, yield and health of 'Solaris' and 'Regent' grapevines, showed that Solaris vines produced on average more than twice the weight of woody shoots than 'Regent' in 2009–2015. This was not confirmed by the present study.

Table 3 shows energy and emission parameters for the grapevine shoots studied. Significant differences in the level of LHV between the grapevine varieties were shown. It was observed that the highest level of LHV was in the 'Regent' cultivar, while significantly the lowest level in 'Rondo'. There was no significant effect of the year of testing on the evaluated parameter. The presented research showed that the analysed vine shoots are characterised by different energy values. Test years (2020, 2021 and 2022) showed no significant effect on the energy-emission parameters analysed. There was a significant impact of the cultivars ('Solaris', 'Rondo', 'Seyval Blanc' and 'Regent') on the parameters studied except N, N/C and $WNOx$. The correlation between the year and cultivar showed no significant differences except for the moisture level (Tab. 3). The parameters obtained for heat of combustion were consistent with other types of plant biomass, e.g. wheat straw (Montero et al., 2016); sugarcane leaves (Jutakridsada et al., 2016), rice straw (Uzun et al., 2017), or sorghum (Zhang et al., 2017). Significantly higher combustion heat values were observed for vine shoots of 'Tempranillo', 'Mazuelo', 'Viura' and 'Malvasía' (Mendivil et al., 2015; Miranda

Table 3. Energy-emission analysis of woody shoots of selected grape varieties

Parameter	Unit	Year of research			Year	Cultivar	Year × cultivar
		2020	2021	2022	*p*-value		
LHV	MJ·kg^{-1}	16.0 ±0.4	16.6 ±0.3	16.3 ±0.3	0.4897	0.0004	0.9874
S	%	0.07 ±0.0	0.07 ±0.0	0.07 ±0.01	0.3433	0.0001	0.9999
N	%	0.5 ±0.0	0.5 ±0.0	0.5 ±0.03	0.3041	0.7728	0.9999
C	%	48.7 ±0.4	48.9 ±0.3	48.8 ±0.3	0.4479	0.0001	0.9898
H	%	5.9 ±0.3	6.1 ±0.3	6.0 ±0.3	0.1549	0.0021	0.9998
M	%	7.0 ±0.3	7.3 ±0.3	7.1 ±0.3	0.0907	0.0001	0.0001
O	%	40.9 ±0.3	41.1 ±0.3	41.0 ±0.3	0.4425	0.0038	0.9999
A	%	3.9 ±0.3	4.0 ±0.3	4.0 ±0.3	0.4401	0.0001	0.9115
V	%	70.7 ±0.3	71.1 ±0.3	70.8 ±0.3	0.1438	0.0001	0.9947
FC	%	18.4 ±0.3	18.4 ±0.3	18.4 ±0.3	0.1945	0.0001	0.9999
N/C	-	0.01 ±0.0	0.01 ±0.0	0.01 ±0.0	0.3095	0.4241	0.9999
H/C	-	1.4 ±0.1	1.5 ±0.1	1.5 ±0.1	0.1622	0.0011	0.9997
O/C	-	0.6 ±0.01	0.6 ±0.0	0.6 ±0.0	0.9977	0.0001	0.9999
WeC	MJ·kg^{-1}	429.0 ±3.3	430.7 ±3.0	429.7 ±3.1	0.0409	0.0001	0.9898
WECO	MJ·kg^{-1}	60.1 ±0.5	60.3 ±0.4	60.2 ±0.4	0.4479	0.0001	0.9898
WNOx	MJ·kg^{-1}	1.8 ±0.1	1.9 ±0.1	1.8 ±0.1	0.3041	0.7728	0.9999
WECO$_2$	MJ·kg^{-1}	1470.7 ±11.5	1471.3 ±11.4	1470.9 ±11.4	0.8956	0.0001	0.9999
WESO$_2$	MJ·kg^{-1}	0.1 ±0.01	0.1 ±0.0	0.14 ±0.01	0.3433	0.0001	0.9999
We$_{dust}$	MJ·kg^{-1}	4.9 ±0.3	5.1 ±0.4	5.01 ±0.4	0.4401	0.0001	0.9115

* Significant difference on the level $p < 0.05$.
Source: own study.

et al., 2015) and, at the same time, ash, nitrogen, carbon and hydrogen content was at similar levels.

The multivariate correlation analysis showed that as the number of clusters per one bush increased, the parameters *H*, *S*, *FC*, *H/C* and *WESO$_2$* correlated negatively. Significantly positive correlations were observed between the weight of one cluster and berry, fruit yield per hectare, weight of lignified shoots per planting area, and *O*, *A*, *V* and *O/C*, while significantly negative correlations were observed for *C*, *FC*, *WeC*, *WECO* and *WECO$_2$*.

Significantly positive correlations were observed between berry weight and the number and weight of woody shoots collected from the cultivation area, and *We$_{dust}$*, while M showed a negative correlation. As the number of berries per cluster increased, *S*, *M* and *WESO$_2$* increased significantly. The weight of woody shoots significantly positively correlated with the level of the *H/C* parameter, while the diameter of woody shoots significantly positively correlated with *S* and *WESO$_2$* (Tab. 4). The study indicates that emission parameters significantly correlate with

Table 4. Multivariate correlation analysis for crop and energy traits

Parameter	Average number of cluster	Number of berries per cluster	Cluster weight (g)	Yield (Mg·ha^{-1})	Number of lignified shoots (pcs)	Mass of lignified shoots (kg·ha^{-1})	Diameter of lignified shoots (mm)
	pcs						
LHV	−0.1082*	0.0615*	−0.0970*	−0.1412*	0.1639*	−0.0864*	0.1257*
C	0.0364*	0.0724*	−0.6424	−0.5673	0.1855*	−0.7130	−0.0963*
H	−0.5419	−0.0359*	0.0511*	−0.1907*	−0.0452*	0.2564*	0.1730*
N	−0.100*3	0.0601*	0.1510*	0.0899*	−0.0372*	0.1638*	0.1195*
S	−0.5181	0.3378*	0.1462*	−0.1051*	−0.3180*	0.1740*	0.3772
M	0.0253*	0.6818*	0.0342*	0.0450*	−0.3981*	−0.3335	0.3139*
O	0.2033*	0.2484*	0.5196	0.5565	−0.2195*	0.3426	0.1868*
A	0.1711*	−0.2170*	0.4234	0.4592	0.1061*	0.4878	−0.0398*
V	0.2184*	0.0258*	0.5664	0.5807	0.0155*	0.5487	0.1919*

cont. Tab. 4

Parameter	Average number of cluster	Number of berries per cluster	Cluster weight (g)	Yield (Mg·ha^{-1})	Number of lignified shoots (pcs)	Mass of lignified shoots (kg·ha^{-1})	Diameter of lignified shoots (mm)
	pcs						
FC	−0.4600	−0.3268*	−0.6999	−0.8209	0.2899*	−0.4218	−0.2052*
H/C	−0.5461	−0.0435*	0.1569*	−0.0967*	−0.0711*	0.3708	0.1934*
N/C	−0.1067*	0.0496*	0.2375*	0.1662*	−0.0596*	0.2593*	0.1321*
O/C	0.0988*	0.1067*	0.6541*	0.6343	−0.2264*	0.5895	0.1643*
WeC	0.0364*	0.0724*	−0.6424*	−0.5673	0.1855*	−0.7130	−0.0963*
WECO	0.0364*	0.0724*	−0.6424*	−0.5673	0.1855*	−0.7130	−0.0963*
WNOx	−0.1003*	0.0601*	0.1510*	0.0899*	−0.0372*	0.1638*	0.1195*
WECO$_2$	0.0535*	0.0446*	−0.6757*	−0.5891	0.1768*	−0.7400	−0.1372*
WESO$_2$	−0.5181	0.3378	0.1462*	−0.1051*	−0.3180*	0.1740*	0.3772
We$_{dust}$	0.1711*	−0.2170*	0.4234*	0.4592	0.1061*	0.4878	−0.0398*

* Significant difference $p < 0.05$.
Explanations as in Tab. 3.
Source: own study.

plant yield. Fruit yield affects the lower carbon content in shoots, which translates into lower carbon dioxide emission during combustion, keeping in mind the closed cycle of the gas in the environment. The positive correlation of shoot diameter with SO_2 emissions is also noteworthy. In this case, one would aim to trim shoots at the optimal diameter, which could help reduce emission of the harmful gas from combustion. However, an increase in yield contributes to a reduction in SO_2 emission. Hence, with a high yield of vines, we are also able to reduce emission from the shoot burning process.

Principal component analysis of technical and elemental parameters for one-year vine shoot waste of the 'Rondo', 'Solaris', 'Seyval Blanc' and 'Regent' cultivars during the three-year study shows two clusters. The data analysis in Figure 1 shows cluster 1 consisting of the 'Rondo' cultivar, which has significantly the highest shoot weight per hectare, while cluster 2 consists of the 'Regent' cultivar and the sub-group of white-skinned cultivars of 'Solaris' and 'Seyval Blanc'. Considering the amount of biomass obtained from the cultivated area, potentially the 'Regent' cultivars can provide the largest amount of raw material for energy production with a fairly high yield potential (Fig. 3).
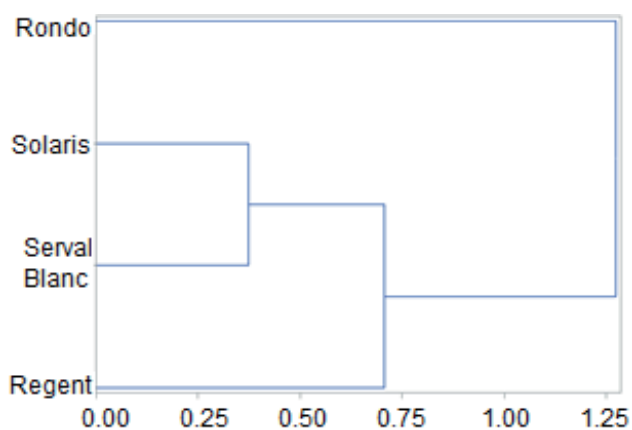

Fig. 3. Comparative analysis covering waste shoots of vine varieties tested for energy production; source: own study

CONCLUSIONS

A study of grapevine shoots from a three-year crop shows no dependencies on the year of cultivation, while significant differences between the varieties tested. In addition, grapevine yield affects energy production and emission. The 'Regent' cultivar is characterised by a high yield, as well as a significant number of shoots from the cultivation area. Hence, the use of this cultivar is both advantageous from the point of view of the main purpose, i.e. yield of high fruit weight, and the additional point of view, i.e. yield of biomass from phytosanitary pruning of the crop. Nevertheless, despite the significant differences shown, the study shows that each of the varieties generates between 3.2–4.4 Mg·ha^{-1} of woody shoots. This can supplement the energy balance, for example, on the cultivation farm itself.

The research showed there was no significant differences between particular years (2020, 2021 and 2022) regarding energy-emission parameters. The correlation analysis showed that the lowest heating value significantly positively correlated with the number of berries per cluster, number of lignified shoots and diameter of lignified shoots, and negatively with the average number of clusters, cluster weight, yield and mass of lignified shoots. The analysis of emission parameters showed a negative correlation between CO_2 and cluster weight, yield, mass of lignified shoots and diameter of lignified shoots. The study has showed that the 'Regent' cultivar offers fairly high yield and can potentially provide the largest amount of raw material for energy production.

REFERENCES

Alves, J.L.F. *et al.* (2020) "Insights into the bioenergy potential of jackfruit wastes considering their physicochemical properties, bioenergy indicators, combustion behaviors, and emission characteristics," *Renewable Energy*, 155, pp. 1328–1338. Available at: https://doi.org/10.1016/j.renene.2020.04.025.

Atucha, A., Hedtcke, J. and Workmaster, B.A. (2018) "Evaluation of cold-climate interspecific hybrid wine grape cultivars for the

upper Midwest," *Journal of the American Pomological Society*, 72, pp. 80–93.

Blasi di, C., Tanzi, V. and Lanzetta, M.A. (1997) "Study on the production of agricultural residues in Italy," *Biomass Bioenergy*, 12, pp. 321–331. Available at: https://doi.org/10.1016/S0961-9534 (96)00073-6.

Borycka, B. (2008) *Towaroznawcze studium nad żywnościową i energetyczną użytecznością bogatobłonnikowych odpadów przemysłu owocowo-warzywnego [Commodity study on food and energy utilization of rich-food waste of the fruit and vegetables industry]* Politechnika Radomska, Monografie, 112. Radom: Uniwersytet Technologiczno-Humanistyczny w Radomiu.

Broome, J. and Warner, K. (2008) "Agro-environmental partnerships facilitate sustainable wine-grape production and assessment," *California Agriculture*, 62(4), pp. 133–141. Available at: https://webpages.scu.edu/ftp/kwarner/ageco-BroomeWarnerCalAg.pdf (Accessed: February 21, 2023).

Burg, P. *et al.* (2017) "Review of energy potential of the wood biomass of orchards and vineyards in the Czech Republic," *Research in Agricultural Engineering*, 63, S1–S7. Available at: https://doi.org/10.17221/30/2017-RAE.

Casanova-Gascón, J. *et al.* (2019) "Behavior of vine varieties resistant to fungal diseases in the Somontano Region," *Agronomy*, 9(11), 738. Available at: https://doi.org/10.3390/agronomy9110738.

Choudhury, N.D. *et al.* (2021) "Characterization and evaluation of energy properties of pellets produced from Coir pith, Saw dust and *Ipomoea carnea* and their blends," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, pp. 1–18. Available at: https://doi.org/10.1080/15567036.2020.1871446.

Clark, M.D. (2020) "Development of cold climate grapes in the Upper Midwestern US: The pioneering work of Elmer Swenson," in I. Goldman (ed.) *Plant Breeding Reviews*, 43, pp. 31–60. Hoboken, NJ, USA: Wiley.

Corona, G. and Nicoletti, G. (2010) "Renewable energy from the production residues of vineyards and wine: Evaluation of a business case," *New Medit*, 9, pp. 41–47.

Dam van, J. *et al.* (2007) "Biomass production potentials in Central and Eastern Europe under different scenarios," *Biomass Bioenergy*, 31, pp. 345–366. Available at: https://doi.org/10.1016/j.biombioe.2006.10.001.

Directive (2009) "Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (Text with EEA relevance)," *Official Journal*, L 309.

Dobrowolska-Iwanek, J. *et al.* (2014) "Wine of cool-climate areas in South Poland," *South African Journal of Enology and Viticulture*, 35(1), pp. 1–9. Available at: https://doi.org/10.21548/35-1-980.

EN-ISO 1928:2009. *Solid mineral fuels – Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value*. Brussels: European Committee for Standardization.

EN-ISO 16948:2015-07. *Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen*. Brussels: European Committee for Standardization.

EN-ISO 16994:2016. *Solid biofuels – Determination of total content of sulphur and chlorine*. Brussels: European Committee for Standardization.

EN-ISO 18122:2016-01. *Solid biofuels – Determination of ash content*. Brussels: European Committee for Standardization.

EN-ISO 18123:2016-01. *Solid fuels – Determination of volatile content by gravimetric method*. Brussels: European Committee for Standardization.

EN-ISO 18134-3:2015. *Solid biofuels – Determination of moisture content – Oven dry method – Part 3: Moisture in general analysis sample*. Brussels: European Committee for Standardization.

Fisher, K.H. (2000) "The development of interspecific grapevine hybrids in Ontario, Canada," in H. Willer, U. Meier (eds.) *Proceedings of the 6th International Congress on Organic Viticulture*. Basel: IFOAM, pp. 205–208. Available at: https://orgprints.org/id/eprint/548/1/willer-meier-2000-winecongress.pdf (Accessed: February 21, 2023).

Garita-Cambronero, J. *et al.* (2021) "Biobutanol production from pruned vine shoots," *Renewable Energy*, 177, pp. 124–133.

Gąstoł, M. (2015) "Vineyard performance and fruit quality of some interspecific grapevine cultivars in cool climate conditions," *Folia Horticulturae*, 27(1), pp. 21–31. Available at: https://doi.org/10.1515/fhort-2015-0011.

Jacquet, F. *et al.* (2020) "Pesticide-free agriculture as a new paradigm for research," *Agronomy for Sustainable Development*, 42, 8. Available at: https://doi.org/10.1007/s13593-021-00742-8.

Jutakridsada, P. *et al.* (2016) "Comparison study of sugarcane leaves and corn stover as a potential energy source in pyrolysis process," *Energy Procedia*, 100, pp. 26–29. Available at: https://doi.org/10.1016/j.egypro.2016.10.142.

Lisek, J. (2004) "Odporność pąków trzydziestu odmian winorośli (*Vitis* sp.) na uszkodzenia mrozowe w warunkach centralnej Polski [Winter hardiness of thirty grape cultivar buds (*Vitis* sp.) under conditions of Central Poland]," *Zeszyty Problemowe Postępów Nauk Rolniczych*, 497, pp. 405–410.

Lisek, J. (2005) "Zdrowotność, plonowanie i rozmnażanie wybranych genotypów winorośli (*Vitis sp. L.*) w warunkach Polski [Health, yielding and propagation of selected vine genotypes (*Vitis sp.* L.) in Polish conditions]," *Zeszyty Naukowe Instytutu Sadownictwa i Kwiaciarstwa. Monografie i Rozprawy*. Skierniewice: ISiK.

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.

Lisek, J. (2009) "Frost damage of buds on one-year-old shoots of wine and table grapevine cultivars in Central Poland following the winter of 2008/2009," *Journal of Fruit and Ornamental Plant Research*, 17, pp. 149–161.

Lisek, J. (2010) "Yielding and healthiness of selected grape cultivars for processing in Central Poland," *Journal of Fruit and Ornamental Plant Research*, 18, pp. 265–272.

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). Available at: https://doi.org/10.1515/johr-2016-0020.

Magagnotti, N. *et al.* (2009) "Protocollo tecnico di utilizzazione delle potature di vigneti e oliveti [Technical protocol for the utilization of pruning residues from vineyards and olive groves]," *The forest-wood-energy chain: Results from the International Project Woodland Energy*. Florence, Italy: ARSIA di Regione Toscana, pp. 55–66.

Maj, G. (2018) "Emission factors and energy properties of agro and forest biomass in aspect of sustainability of energy sector," *Energies*, 11, 1516. Available at: https://doi.org/10.3390/en11061516.

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.

Mendívil, M.A. *et al.* (2013) "Chemical characterization of pruned vine shoots from La Rioja (Spain) for obtaining solid bio-fuels,"

Journal of Renewable and Sustainable Energy, 5, 033113. Available at: https://doi.org/10.1063/1.4808043.

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: revista latinoamericana de ciencias de la agricultura*, 42(3), pp. 443–451. Available at: https://doi.org/10.4067/s0718-16202015000300012.

Miranda, T. *et al.* (2015) "A review of pellets from different sources," *Materials*, 8, pp. 1413–1427. Available at: https://doi.org/10.3390/ma8041413.

Montero, G. *et al.* (2016) "Higher heating value determination of wheat straw from Baja California, Mexico," *Energy*, 109, pp. 612–619. Available at: https://doi.org/10.1016/j.energy.2016.05.011.

Ochmian, I. *et al.* (2013) "The impact of cutting and mulching grapevine Regent on yielding and fruit quality," *Folia Pomeranae Universitatis Technologiae Stetinensis*, 304(26), pp. 87–96.

Pacifico, D. *et al.* (2013) "Performance of interspecific grapevine varieties in north-east Italy," *Agricultural Sciences*, 4, pp. 91–101. Available at: https://doi.org/10.4236/as.2013.42015.

Roca, P. (2019) *Statistical report on world vitiviniculture*. Paris, France: OIV.

Rosúa, J.M. and Pasadas, M. (2012) "Biomass potential in Andalusia, from grapevines, olives, fruit trees and poplar, for providing heating in homes," *Renewable and Sustainable Energy Reviews*, 16, pp. 4190–4195. Available at: https://doi.org/10.1016/j.rser.2012.02.035.

Scarlat, N., Blujdea, V. and Dallemand, J.F. (2011) "Assessment of the availability of agricultural and forest residues for bioenergy production in Romania," *Biomass Bioenergy*, 35, pp. 1995–2005. Available at: https://doi.org/10.1016/j.biombioe.2011.01.057.

Senila, L. *et al.* (2020) "Sustainable biomass pellets production using vineyard wastes," *Agriculture*, 10, 501. Available at: https://doi.org/10.3390/agriculture10110501.

Smiley, L.A. and Cochran, D. (2016) *A review of cold climate grape cultivars*. Iowa State University Extension and Outreach. Available at: https://www.extension.iastate.edu/wine/wp-content/uploads/2021/09/HORT3040.pdf (Accessed: February 23, 2023).

Souček, J., Burg P. and Kroulík, M. (2007): "Dřevo z ovocných výsadeb jako potenciální zdroj energie [Wood from fruit woods as potentional resource of energy]," in *Mezinárodní konference Strom a květina – součást života*. Průhonice: VÚKOZ, pp. 181–183.

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: https://doi.org/10.1016/j.ecoleng.2014.05.023.

Uzun, H. *et al.* (2017) "Improved prediction of higher heating value of biomass using an artificial neural network model based on proximate analysis," *Bioresource Technology*, 234, pp. 122–130. Available at: https://doi.org/10.1016/j.biortech.2017.03.015.

Zabadal, T.J. *et al.* (2007) "Winter injury to grapevines and methods of protection," *Extension Bulletin*, E2930. East Lansing: Michigan State University.

Zhang, K. *et al.* (2017) "Fast analysis of high heating value and elemental compositions of sorghum biomass using near-infrared spectroscopy," *Energy*, 118, pp. 1353–1360. Available at: https://doi.org/10.1016/j.energy.2016.11.015.