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ANALYSIS OF THE YIELD POTENTIAL OF VINEYARD CHIPS FOR ENERGY, COMPOSTING AND RAW MATERIAL USE

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This article focuses on the issue of the utilization of the woody matter generated by vineyard maintenance. This material is generated by regular winter pruning and the disposal of old growth during replanting. In view of current environmental trends, it is not possible to dispose of this material by inappropriate burning on the land as in the past. Instead, it is desirable to use this wood as raw material for further use. In the operating conditions, the authors have determined the yield of the wood mass in the maintenance and disposal of stands of selected varieties. The average wood yield ranged 1,8 – 2,8 t·ha^{-1}. The lowest yield was recorded for the variety Riesling walrus. The most profitable varieties were St. Lawrence and Sauvignon. The authors determined the energy and time requirements for disintegration into graft form. The measurements were carried out using a PEZZOLATO 110 Mb chipper driven by a HONDA GX 120 four-stroke petrol engine. During the chipping process it was determined the time required for chipping, weight of the obtained chip, fuel consumption, RPM of the chipping, content of water and mean particle length. From the values of the monitored parameters, the performance of the chipper, the specific energy consumed and the specific gravity were further calculated. The mean chip length was 4,4 – 9,24 mm. The output of the equipment was in the range of 0.5 - 1 m^3·h^{-1}. The specific energy consumption for chipping ranged from 144,6 – 259,8 MJ·t^{-1}. The wood chips produced from the woody matter generated during vineyard maintenance have potential for energy and material recovery. Given the area and age structure of vineyards, it can be assumed that 24 - 38 thousand tonnes per year will be available in the Czech Republic in the long term. At EU level, the amount of material can be expected to be between 4,2 and 6,7 million tonnes annually.

Keywords: *vineyards, chipping, waste biomass, vineyard waste, wood chips, bioenergy, organic matter*

INTRODUCTION

In the past, wood from vineyard maintenance was considered waste. It was burned at the edge of the vineyard without further use. Today, this practice is not environmentally acceptable. Wood from the vines has become a potentially valuable raw material for further use. For example, it can be used for the production of biofuels (Senila, et al.,2022) (Senila, et al., 2020), biochar (Pinto, et al., 2021), in the production of composts, (Burg, et al., 2014) mulches (Burg, et al., 2022) or other raw materials (Karaoğlu, et al., 2010).

Regular pruning of vines is one of the characteristic work operations carried out in vineyards in winter and pre-spring seasons. The main importance of pruning lies in the reduction of the above-ground parts of the vine (often up to 80% of the woody matter is removed), which is essential for its future growth, quantity and quality of the grapes harvested. From a labour point of view, hand pruning is a very demanding operation (Allegro, et al., 2023).

Measurements show that, on average, a worker makes 15 - 20 cuts per bush, which, depending on the clip, corresponds to 6 000 – 8 000 cuts per shift (65 000 – 90 000 cuts·ha^{-1}).

Variety and rootstock, together with other factors, affect the growth potential of the shrub and influence the overall wood production.

Another significant amount of wood is produced by regular regeneration, which is usually preceded by the removal of old vines (Salata, et al., 2022). The minimum life span of a vineyard is 15 years. However, the real life span is much higher and is commonly 25 - 30 years or more. This situation is also illustrated by the results of a survey by the Ministry of Agriculture of the Czech Republic, according to which the proportion of fertile vineyards under 30 years is 39% and that of vineyards from 30 to 50 years is 21%. The rest is made up of young plantings (Bublíková, et al., 2022). It follows that approximately 3 - 6 % of the productive vineyard area can be considered for renewal annually. From this point of view, vine plantations appear to be a promising resource in the future.

Wood chips are a universally usable raw material. Many authors have addressed the issue of its production and use. The theoretical aspect of the issue was addressed, for example, by (Souček, Jasinskas, 2017), who determined the dependence of mechanical properties on water content. Other authors (Stolarski, et al., 2023; Pedišius, et al., 2021) have addressed the problem of determining the quality of wood chips on the equipment used and material properties.

The aim of the research was to determine the real yield potential of vineyard waste and the difficulty of its processing into wood chips suitable for energy and raw material use.

RESEARCH METHODS

Determination of vineyard waste yield

Determination of the yield of vineyard waste was carried out in the production vineyards in the village of Rakvice, located in the Morava wine-growing region, subregion Velké Pavlovice.

The yield of the mass obtained during winter pruning and vineyard liquidation was determined. Yields were determined in vineyards with a planting age of 5 years, with high wire (VV), 4 350 individuals per 1 ha. The name, cultivation row spacing x space within the rows, type of wire line and type of the varieties are given in Tables 1 and 2.

Table 1. Wood yield from winter pruning of the vineyard

Variety	Label	Row spacing x space within the rows (m)	Type of wire line, number of cane
Grüner Veltliner [A)]	VZ	2,3 x 1,0	VV, 1
Sauvignon [A)]	SVG	2,3 x 1,0	VV, 1
Neuburg [A)]	NB	2,3 x 1,0	VV, 1
Riesling[A)]	VR	2,3 x 1,0	VV, 1
Müller Thurgau [A)]	MT	2,3 x 1,0	VV, 2
Muškát Moravský [B)]	MM	2,3 x 1,0	VV, 2
André [A)]	AN	2,3 x 1,0	VV, 1
Frankovka [A)]	FR	2,3 x 1,0	VV, 1
Blue Portugal [A)]	PM	2,3 x 1,0	VV, 1
St. Lawrence [A)]	SV	2,3 x 1,0	VV, 1

Note: [A)] rootstock SO4, [B)] rootstock TELEKI 5C

Table 2. Wood yield at vineyard liquidation.

Variety	label	Growth age (year)	Type of wire line, number of cane
Muscat Ottonel[C)]	MO	33	SV[E)], 2
Neuburg [D)]	NB	25	VV, 1
Frankovka[C)]	FR	30	VV, 1

Note: [C)] rootstock Kober 125 AA, [D)] rootstock Kober 5 BB, [E)] middle wire

Yield was determined by weighing the harvested material by weight on a metrologically certified scale. The average yield of vineyard waste per bush was determined as the total weight of harvested material divided by the number of bushes. The water content of the harvested material was determined according to (ISO 18134-3:2015).

Figure 1. Vineyards before grubbing.

Determination of chipping parameters.

Vineyard waste varieties Müller Thurgau, Blue Portugal, St. Lawrence were grafted about three weeks after cutting and vineyard waste of the varieties Veltliner, Riesling and Sauvignon immediately after cutting. With regard to the water content observed, this delay was not significant and the moisture content of the grafted materials was comparable. The vineyard waste was chipped using a mobile PEZZOLATO 110 Mb chipper powered by a four-stroke HONDA GX 120 petrol engine of 9 kW (Pezzolato, Envine, Italy). The machine is equipped with a double-leg disc chipper, a non-stress system to ensure uniform material feed and to prevent a drop in chipper speed. The dimensions of the insertion hole are 110 x 115 mm, the cross diameter of the wood to be processed, as stated by the manufacturer, is 5 - 100 mm. The shredding speed was 1 950 min^{-1}. The diameter of the processed vineyard waste ranged from 10 to 35 mm.

During chipping, the vineyard waste was manually fed into the chipper. To improve the supply of material to the working unit, the chipper was equipped with a pair of hydraulically driven feed rollers.

In order to increase the objectivity of the measured data, emphasis was placed on the sharpness of the knives, counter-blades and the speed setting of the working gear during chipping. The machine is equipped with a digital tachometer and the machine control allows the speed to be precisely adjusted. During the chipping process it was determined:

- Time required for chipping by reading the time on a precision stopwatch.
- The weight of the obtained chip by gravimetric weighing on a metrologically verified scale (measured by mass using a KERN FTC 60K2 strain gauge (KERN&SOHN, Balingen,Germany) with a measuring range of 60 ± 0.002 kg and a digital online output).
- Fuel consumption by means of a graduated cylinder (measuring cylinder SIMAX, s.r.o., Sázava,Czech Republic) The full tank method was used to calculate consumption.
- RPM of the chipping unit using a tachometer
- Content of all water by laboratory according to ISO 18134-3:2015
- Mean particle length by sieve analysis according to ISO 9276-1
- From the values of the monitored parameters, the performance of the chipper, the specific energy consumed and the specific gravity (about EN 15150:2011) were further calculated.

The measurements took place in one cycle divided into three repetitions Analysis of variance (significance level α = 0.05) was used to assess the significance of differences between the trial variants evaluated. The Tukey-HSD test was used as a post hoc testing method at the significance level of α = 0.05. The above statistical evaluation methods were applied using Unistat 10 computer software for MS Excel.

RESEARCH RESULTS AND DISCUSSION

Determination of vineyard waste production

The results of the measurements showed that there are significant differences in the production of vineyard waste during winter cutting. The results obtained from measurements over 2 years show that production ranges from 0,37 – 0,65 $kg \cdot bush^{-1}$ (Table 3).

Table 3. Yield of vineyard waste in winter pruning

Variety	Label	2021		2022	
		Average wood yield per bush ($kg \cdot pc^{-1}$)	**Average wood yield per area ($t \cdot ha^{-1}$)**	**Average wood yield per bush ($kg \cdot pc^{-1}$)**	**Average wood yield per area ($t \cdot ha^{-1}$)**
Grüner Veltliner A)	VZ	0,44	1,91	0,5	2,18
Sauvignon A)	SVG	0,59	2,57	0,52	2,26
Neuburg A)	NB	0,41	1,78	0,62	2,70
Riesling A)	VR	0,37	1,61	0,39	1,70
Müller Thurgau A)	MT	0,60	2,61	0,53	2,30
Muškát Moravský B)	MM	-	-	0,61	2,65
André A)	AN	0,40	1,74	0,42	1,83
Frankovka A)	FR	0,38	1,65	0,65	2,83
Blue Portugal A)	PM	0,48	2,09	0,50	2,18
St. Lawrence A)	SV	0,55	2,39	0,60	2,61
Averadge		**0,47**	**2,04**	**0,53**	**2,32**

Table 3 shows the evaluation of the significance of differences between the evaluated varieties and experimental years by analysis of variance (significance level α = 0.05). Tukey's test (HSD) was used as a post-testing method at the significance level α = 0.05. Statistical evaluation is presented in Tables 4, 5 and 6.

Table 4. Analysis of variance

Source of variability	Sum of squares	Degrees of freedom	Mean square	Stat. F	Significance
Main effects	0,201	10	0,020	4,193	0,0014
Variety	0,161	9	0,018	3,735	0,0037*
Year	0,029	1	0,029	6,028	0,0208*
Explained Error	0,201 0,129	10 27	0,020 0,005	4,193	0,0014
Total	0,330	37	0,009		

Note: * indicates statistically significant difference

The results of the statistical analysis show that there is a statistically significant difference in the production of vineyard waste between the evaluated varieties. The results also showed that its quantity can vary from year to year. From a practical point of view, the total production of vineyard waste can be influenced by the cultivation system and agrotechnical measures such as the type of management, the method of pruning, the implementation of green works, fertilisation, etc.

Table 5. Tukey - HSD post-testing method (evaluated by variety)

Group	n. of case	average	RV	AN	VZ	MP	NB	FR	SVG
RV	4	0,3775							
AN	4	0,4050							
VZ	4	0,4675							
MP	4	0,4850							
NB	4	0,5125							
FR	4	0,5150							
SVG	4	0,5550							
MT	4	0,5625	*						
SV	4	0,5700	*						
MM	2	0,6050	*						

Note: * Significantly different pairs (α = 0.05)

The results of Tukey's test show a significantly lower production of vineyard waste in the variety Riesling Walnut (RV). This variety is characterised by medium growth intensity and the production of thin, upright canes. From a statistical point of view, there are no significant differences in the production of the other varieties evaluated.

Table 6. Tukey - HSD post-testing method (evaluated by year)

Group	n. of case	average	2021	2022
2021	18	0,4661		*
2022	**20**	**0,5310**	*	

Note: * Significantly different pairs (α = 0.05)

The woody material used for vineyard clearance consists mainly of vine clusters (Fig. 1). Depending on the type of line, their length is approximately 0,5-2,0 m, diameter 0,04 - 0,08 m. The weight of the stems found during the vine clearance in 2022 is given in table 7.

Table 7. The weight of the stems found during the vine clearance in 2022

Variety	**Length of trunk (m)**	Average wood yield per bush ($kg.pc^{-1}$)	Average wood yield per area ($t.ha^{-1}$)
Muškát Ottonel	0,6	2,4	6,78
Neuburské	0,8 – 1,0	1,5	3,95
Frankovka	1,8	4,9	13,80

The results show that the weight of the cane trunks ranges from 1,5 to 4,9 kg. Depending on the planting rotation and the number of bushes per hectare of planting area, the quantity of wood mass can be a maximum of 16-22 t. However, in practice, this quantity must be reduced by around 30 - 40 %, often more (previously removed dead bushes).

On the basis of refined calculations, it can be assumed that in the Czech Republic approximately 3 900 - 10 800 t of waste wood is produced annually during regular vineyard renewal.

Vineyard waste chipping

Field experimental measurements were carried out from February to March at the sites Rakvice, Velké Bílovice and Karlštejn. The vineyard waste of the varieties Blue Portugal (MP), St. Lawrence (SV), Müller Thurgau (MT), Veltliner (VZ), Riesling (RV) and Sauvignon (SG) was used for grafting. The different varieties differ in their bush habit and produce different amounts of vineyard waste. In addition, they differ in character, especially in the transverse diameter of the canes and the hardness of the wood.

The resulting values of the parameters monitored are shown in Table 8.

Table 8. Results of the values obtained by measurement and calculation

parameter	**Unit**	**MT**	**VZ**	**RV**	**SVG**	**SV**	MP
water content	%	40,60	40,02	41,97	39,73	41,04	40,82
weight of chipped material	$kg\cdot m^{-3}$	436	458	452	660	472	442
Mean particle length	mm	8,92	4,38	9,24	4,40	4,32	8,58
Machine performance	$kg\cdot h^{-1}$	290	270	330	370	470	230
Specific energy consumption	$MJ\cdot t^{-1}$	185,3	259,8	229,4	177,0	144,6	170,6

In terms of quality and quantity of chips, fresh, wet and wide wood is the most suitable. In terms of anatomical structure, it is soft, straight, without knots, and comes from the branches or trunk of the tree. However, it is difficult to achieve these conditions with vineyard waste after vineyard pruning because it is a heterogeneous material.

The values shown in Table 8 show that the performance of the chipper in chipping vineyard waste with an average total water content of 40,7 % ranged 230 – 470 kg·h^{-1} (0,52 – 0,99 m^{3}·h^{-1}). The results of the statistical evaluation (Tables 9 and 10) show the statistical significance of the influence of the characteristics of the input material on the performance of the chipper according to the different varieties.

Table 9. Analysis of variance – performance of chipper

Source of variability	Sum of squares	Degrees of freedom	Mean square	Stat. F	Significance
Main effects	73067,667	5	14613,533	1169,083	**0,0000**
Performance	73067,667	5	14613,533	1169,083	**0,0000***
Explained Error	73067,667 75,000	5 6	14613,533 12,500	1169,083	**0,0000**
Total	**73142,667**	**11**	**6649,333**		

Note: * indicates statistically significant difference

Table 10. Tukey - HSD post-testing method (evaluated by variety)

Variety	average	MP	VZ	MT	RV	SVG	SV
MP	0,3775		**	**	**	**	**
VZ	0,4050	**		**	**	**	**
MT	0,4675	**	**		**	**	**
RV	0,4850	**	**	**		**	**
SVG	0,5125	**	**	**	**		**
SV	0,5150	**	**	**	**	**	

Note: * Significantly different pairs (α = 0.05); **

The best performance was achieved with the St. Lawrence and Sauvignon varieties, which produce sufficiently long, strong, straight canes. This allows smooth grafting with good filling of the machine's insertion opening. These two varieties are characterised by their higher wood volume (660 kg·m^{-3} and 472 kg·m^{-3} respectively). The higher wood hardness of these two varieties is evidenced by the experience of hand-cutters, who confirm the reduced performance and higher hand effort involved in cutting these two varieties. From the results it can be concluded that the harder vineyard waste is more suitable for chipping than the tough vineyard waste of the other varieties. This may also explain to some extent the lower chipping performance of the other varieties.

Although the character of vineyard waste is not only influenced by the varietal characteristics, but also by the growing system and agronomic measures such as the type of management, the method of cutting and the implementation of green work or fertilisation, the effect of vineyard waste by variety on performance is most pronounced.

The energy intensity of chipping, expressed in terms of specific fuel consumption, also depends on the characteristics of the vineyard waste. The resulting values presented in table 12 show that the specific energy consumption for chipping ranged 144,6 - 259,8 MJ·t^{-1}. The lowest values were measured for vineyard waste of the St. Lawrence and Blue Portugal varieties, while the highest values were measured for vineyard waste of the Riesling and Grüner Veltliner varieties.

The energy consumed during the chipping process depends significantly on the degree of disintegration, the physical properties of the chipped material (density) and the type of working gear. Other factors influencing the quality of work and the performance of chippers are the properties of the chipped wood such as moisture content, flexibility, strength, hardness.

This is illustrated by the results of the statistical evaluation of specific energy consumption carried out using analysis of variance and post-testing methods (table 11 and 12).

Table 11. Analysis of variance – specific energy consumption

Source of variability	Sum of squares	Degrees of freedom	Mean square	Stat. F	Significance
Main effects	20,240	5	4,048	967,630	0,0000
Specific energy consumption	20,240	5	4,048	967,630	0,0000*
Explained Error	20,240 0,025	5 6	4,048 0,004	967,630	0,0000
Total	20,265	11	1,842		

Note: * indicates statistically significant difference

Table 12. Tukey - HSD post-testing method (evaluated by variety)

Variety	average	MP	VZ	MT	RV	SVG	SV
MP	4,520		**	**	**	**	**
VZ	5,330	**			**	**	**
MT	5,530	**			*	**	**
RV	5,795	**	**	*		**	**
SVG	7,710	**	**	**	**		**
SV	8,110	**	**	**	**	**	

Note: * Significantly different pairs (α = 0.05); **

The results of the granulometric analysis indicate the mean particle length. The length of the harder wood vineyard waste was 4,32 - 4,40 mm (St. Lawrence and Sauvignon varieties). Tough wood (Müller Thurgau, Blue Portugal, Riesling) had a mean particle length of 8,58 - 9,24 mm. The chips from these varieties also contained a higher proportion of longer pieces of bark and bark. The results of the tests presented in Tables 13 and 14 show that the influence of the varieties Müller Thurgau, Blue Portugal and Riesling on the size of the chips is conclusive.

Table 13. Analysis of variance – particle length

Source of variability	**Sum of squares**	**Degrees of freedom**	**Mean square**	**Stat. F**	**Significance**
Main effects	62,833	5	12,567	9195,039	0,0000
particle length	62,833	5	12,567	9195,039	0,0000*
Explained	62,833	5	12,567	9195,039	0,0000
Error	0,008	6	0,001		
Total	**62,841**	**11**	**5,713**		

Note: * indicates statistically significant difference

Table 14. Tukey - HSD post-testing method (evaluated by variety)

Variety	**average**	**MP**	**VZ**	**MT**	**RV**	**SVG**	**SV**
MP	4,325				**	**	**
VZ	4,350				**	**	**
MT	4,380				**	**	**
RV	8,575	**	**	**		**	**
SVG	8,915	**	**	**	**		**
SV	**9,245**	**	**	**	**	**	

Note: * Significantly different pairs (α = 0.05); **

The specific fuel consumption is an important indicator of energy intensity in woodchip production. The lowest values of specific fuel consumption were measured for the vineyard waste chips of the St. Lawrence (144,6 $MJ \cdot t^{-1}$) and Blue Portugal (170,6 $MJ \cdot t^{-1}$) varieties, while the highest values were measured for the vineyard waste chips of the Riesling (229,4 $MJ \cdot t^{-1}$) and Veltliner (259,8 $MJ \cdot t^{-1}$) varieties.

In the granulometric analysis, the tough wood of the Müller Thurgau, Blue Portugal and Riesling varieties had a mean particle length of 8,58 - 9,24 mm, while the vineyard waste chips of the hardwood varieties (St. Laurent and Sauvignon) had a mean particle length of 4,32 – 4,40 mm. The resulting chips are suitable for biofuel production (heating briquettes, direct combustion) and for raw material use (biochair, compost, mulch, etc.).

No information was found in the studied literature on the chipping of vineyard waste with a comparable machine. Compared to the data of the authors (Stolarski. et al., 2023, Soucek, Jasinskas, 2017), who were engaged in the production of wood chips, the energy consumption is slightly increased. However, the advantage for further processing is the smaller particle size and the use of waste raw materials (Burg, et al., 2024)

CONCLUSIONS

The aim of the analysis was to assess the effect of vineyard waste obtained from winter pruning of vines of different varieties on the performance of the chipper and the quality of the chips. The results confirm the influence of varietal characteristics on the performance of the chipper used in vineyard waste chipping. The highest performance of the chipper was obtained when chipping vineyard waste of the varieties St. Lawrence and Sauvignon, when the process was smooth with a good filling of the machine's insertion throat. These two varieties also have the highest bulk density (660 $kg \cdot m^{-3}$ and 470 $kg \cdot m^{-3}$ respectively).

Although the nature of vineyard waste is also influenced by the growing system and agrotechnical measures such as the type of management, the method of cutting and the implementation of green works or fertilisation, the varietal characteristics of vineyard waste are mainly determined by the hardness and toughness of the input material in terms of disintegration. These characteristics determine the performance and the specific energy consumed and the size of the resulting chips. The performance of the machine is also influenced by the length and the transverse diameter of the processed vineyard waste.

Taking into account the planting staples in the conditions of the Czech Republic, which range from 2,2 - 3 x 0,8 – 1,3, the average yield of vineyard waste can be 1,8 - 2,8 $t \cdot ha^{-1}$.

As of 31 December 2021, a total of 17 865 ha of vineyards were registered in the Czech Republic (Bublíková, L. et al., 2022). In view of the above, it can be assumed that the regular winter pruning in the Czech Republic generates approximately 24 000 - 38 000 t of fresh vineyard waste. When converted to the EU cultivation area (3,2 million ha), an annual production of approximately 4,2 – 6,7 million tonnes of wood can be assumed.

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