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Review of energy potential of the wood biomass of orchards and vineyards in the Czech Republic

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Abstract

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The most important sources of biomass energy are currently coming from agricultural activity. A sizeable portion in production areas is waste wood after the winter cut of orchards and vineyards, which cover areas exceeding 30,000 ha in the Czech Republic. The most important are species like apples, peaches, apricots, plums, sweet cherries, sour cherries and grapevines. Average production of wood mass for individual species of fruit trees and grapevines ranges from 1,540 kg/ha up to 6,762 kg/ha, i.e. 1.5 t/ha to 6.8 t/ha. The calorific value for these species ranges from 14.70 to 16.39 MJ/kg, with moisture between 6 and 8%. The results show that the total measured energy potential of the fruit species-cultivated areas is 1,469.7 TJ for the whole Czech Republic.

Keywords: net calorific value; waste wood; wood production; total energetic potential

The importance of renewable energy in the world has been constantly increasing. The Czech Republic used, based on the Eurostat – SHARES methodology, approximately 15.1% of renewable energy sources out of all primary energy sources in 2015. These renewable energy sources covered only 14% of energy consumption; 6% of that for transport and 20% for heating. By the end of the year 2020, across the whole EU, it is planned to achieve 20% share of energy from renewable sources, according to Eurostat (2017). In the Czech Republic, it is supposed to increase up to 13% (this percentage has already been over exceeded).

Biomass is a source of energy that can be used according to the specific conditions either independently or in conjunction with coal. This trend applied more recently, is called "cofiring" and is used mostly in large heating plants (Mann, Spath 2001).

In terms of the use of biomass, it can significantly contribute to the diversification of resources more evenly dispersed in a particular area and thereby ensure greater stability in energy supply (Bentsen, Felby 2012). Hamelinck et al. (2005) states that due to the large amount of phytomass energy needed for obtaining the energy equivalents (compared to e.g. coal), it is not suitable for long distance transport. This implies the construction of new energy facilities, naturally dispersed within the sources of phytomass (Flores et al. 2010). A similar opinion had also Rosúa and Pasadas (2012), who analysed the potential of biomass in Andalusia. According to them, that wood material has the potential to replace up to 51% of the energy used for heating in the region.

Bilandzija et al. (2012) states, that the use of biomass energy has got an increasing importance in

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ensuring renewable energy sources, in enhancing energy self-sufficiency in the regions, in reducing greenhouse gas emissions, in maintaining cultural landscapes by bigger use of biomass waste, in creating of new jobs and in stabilizing the rural area.

The most important sources of biomass energy are currently coming from agricultural activity (Van Dam et al. 2007). The most used are primarily by-products, which are mostly straws of cereals and oilseed rape. A sizeable portion is waste timber after the cut perennial crops in production areas (González-García et al. 2014). These are the orchards and grapevines mostly, but the wood waste from maintenance of ornamental surfaces has been growing significantly as well (Radojevic et al. 2007).

For example, Souček et al. (2007) dealt with the problem of waste wood production from vineyards. The results of his work show that the total production of wood in the given year was affected by the set of factors as variety, rootstock, habitat conditions, nutrition, plant health and wine thickness. The production of wood mass obtained at the annual winter cut is then between 0.37–0.65 kg per tree. With regard to the richness of plantations in conditions of the Czech Republic, which ranges from 2.2–3 × 0.8–1.3, the average hectare yield of vineyards can be 1.8–2.8 Mg/ha. Walg (2007) reports the production of vineyards immediately after the cut in 3.0–4.0 Mg/ha (at fresh condition) and after drying approximately 2.0–2.8 Mg/ha.

Žufánek(1998) dealt with the evaluation of wood production at the plantations of kernels and yellow plums. The results of the measurements show that the average production is at 2.11 Mg/ha. Velázquez-Martí and Cazco-Logroño (2017) also evaluated the production of plum tree wood, which is 2.34 ± 0.97 kg per tree, which means around 2.0 ± 0.8 Mg/ha each year. High dispersion in this measure can be caused by pruning style, area per tree, irrigation, light, temperature and others.

The aim of the thesis is to determine the potential production of wood and its calorific value within the main fruit species and grapevine at production plantations under the conditions of the Czech Republic.

MATERIAL AND METHODS

Current data on the size of plantations of the fruit trees main species grown in the Czech Republic, stated in the annual Situation and outlook report for fruit and vine of the Ministry of agriculture of the Czech Republic published in 2016, were used for review analyses. This report says that the most commonly grown species, classified by the overall size of plantations, are apples (*Malus domestica*, 6,885 ha), pears (*Pyrus domestica*, 630 ha), peaches (*Prunus persica*, 342 ha), apricots (*Prunus armeniaca*, 766 ha), plums (*Prunus domestica*, 1,745 ha), sweet cherries (*Prunus avium*, 765 ha), sour cherries (*Prunus cerasus*, 1,245 ha) and grapevines (*Vitis vinifera,* 17,678 ha).

Input data for review analyses were determined on the production of waste wood mass of individual fruit species and on the net calorific value of wood mass. These data were obtained from fruit growing and viticulture services measurements, carried out in a two-year period between the year 2015 and 2016 under different conditions of the Czech Republic. Representative samples of wood mass based on various fruit species were collected immediately after the winter cut in fresh condition, with no leaves left, at each delivery point. For each type of fruit tree around 70 samples were collected representing different forms of cultivation, age and variety. Each of the evaluated samples included wood material from 30 trees or bushes, which was disintegrated by mobile chipper machine LASKI LS 51/D (Laski, Czech Republic) while still fresh. Wooden chips were then weighed on a precision laboratory scale APP 30C2 (Kern, Germany) with higher capacity to determine the average production of wood per one tree or bush. From these wooden chips homogeneous samples were then collected for laboratory analyses; the analyses comprised drying to a moisture content in the range between 6–8%, including the final value of moisture content in percentage, the determination of elemental composition with emphasis on the hydrogen content in percentage as well and the determination of the gross calorific value (GJ/t) followed by the net calorific value (GJ/t).

Determination of moisture. Determination of moisture content and dry mass in the tested samples was carried out according to standard laboratory procedures ISO 1928:1999. For the determination of dry mass content in all samples laboratory dryer MEMMERT Oven U (Memmert, Germany) and scale KERN ALS-K 250-4 (Kern, Germany) were used.

The determination of the energy value of wooden mass. A prerequisite for determining the gross

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Table 1. Average rate of basic structure of fruit wood (dry basis)

	Ash (%)	C (%)	H (%)	N (%)	S (%)	O (%)
Apple	1.43	47.98	6.54	0.85	0.17	43.03
Pear	3.97	46.98	6.17	0.70	0.20	41.98
Peach	2.18	47.30	6.67	0.56	0.19	43.10
Apricot	2.45	47.20	6.75	0.62	0.21	42.77
Plum	2.20	47.69	6.89	0.84	0.21	42.17
Sweet cherry	2.35	47.50	7.04	0.83	0.19	42.09
Sour cherry	2.59	48.11	7.16	0.71	0.18	41.25
Grapevine	2.86	45.55	6.73	0.61	0.23	44.02

calorific value of wood and net calorific value of wooden chips was an analysis of the elemental composition that was ensured by TOC/TN elemental analyser multi N/C 2100s (Analytik Jena AG, Germany) (Table 1).

Determination of the gross calorific value was performed according to the standard for solid biofuels CSN CEN/TS 14918 and DIN 51 900-3. For the determination of gross calorific value a calorimeter ANTON PARR 6400 was used and for accurate determination of mass of the incinerated sample was done using an analytical scale OHAUS Adventurer PRO AV264C. The obtained gross calorific values were in accordance with ISO 1928 converted into net calorific value according to the relation:

$$Q_i^r = Q_s^r - \gamma \times (W_t^r + 8.94 \times H_t^r) \quad (1)$$

where: Q_i^r – net calorific value of the evaluated sample (MJ/kg); Q_s^r – gross calorific value of the sample (MJ/kg); γ – ratio of evaporation of 1% H_2O (MJ/kg), at temperature 25°C, γ = 0.02442 MJ/kg; 8.94 – hydrogen to water conversion ratio (–); W_t^r – total water content in the sample (%); H_t^r – total hydrogen content in the sample (%)

Statistical evaluation. Analysis of variance was conducted and the results were tested and compared using the Tukey's multiple range test (α = 0.05). A statistical analysis was carried out using the software package Statistica 12.0 (StatSoft Inc., USA).

RESULTS AND DISCUSSION

In the Czech Republic, orchards and vineyards cover areas exceeding approximately 30,000 hectares. Information about the acreage of orchards and vineyards were determined from the statistical survey conducted by the Ministry of Agriculture of the Czech Republic in 2016 (Buchtová 2016; Bublíková 2016).

During the annual interventions in these areas there is a considerable amount of waste wood. In the years 2015 and 2016 the measurement survey was carried out in terms of viticulture and orchards in the Czech Republic. The data of the production for each fruit species were analysed and are shown in Table 2.

Table 2. Average production of fresh wood from the orchards and vineyards (2015–2016)

Crop	Planting distance (m)	Number of trees/ha	Wood production		Growing areas (ha)	Total wood production (kg)
			(kg/tree)	(kg/ha)		
Apple	3.5 × 1.2	2,381	2.84	6,762	6,885	$46,556 \times 10^3$
Pear	4.0 × 1.2	2,083	2.69	5,603	630	$3,530 \times 10^3$
Peach	5.0 × 2.0	1,000	1.54	1,540	342	526×10^3
Apricot	4.5 × 2.5	889	1.81	1,609	766	$1,232 \times 10^3$
Plum	4.0 × 2.0	1,250	2.12	2,650	1,745	$4,624 \times 10^3$
Sweet cherry	4.5 × 1.5	1,481	1.75	2,592	765	$1,982 \times 10^3$
Sour cherry	4.5 × 2.0	1,111	1.82	2,022	1,245	$2,517 \times 10^3$
Grapevine	2.3 × 1.0	4,348	0.72	3,130	17,678	$55,342 \times 10^3$
Total in the Czech Republic				25,908	30,056	$116,312 \times 10^3$

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Problems with evaluation of wood waste production from orchards were discussed by e.g. Rosúa and Pasadas (2012), who indicated the average production for wood fruit species app. 2.5 kg per tree, which represents about 1,000 kg/ha. Likewise, Boschiero et al. (2016) discloses the production value from fruit trees wood mass in the value of 1,030 kg/ha.

Problems with production of vineyards wastage in Spain was discussed again by Rosúa and Pasadas (2012). From their work, it results that the production of fresh vineyards wastage is around 0.5 kg per tree, which is 934 kg/ha. Corona and Nicoletti (2010) reported the value of 2,240 kg/ha. Pruning residues from production in Italy ranged between 0.45 kg and 1.34 kg (1,850–5,360 kg/ha) per plant (Manzone et al. 2016). The yield from different varieties varied from 944 kg/ha up to 5,467 kg/ha. Also, Michálek et al. (2013) evaluated the differences in the production of vineyards, depending on the buckle in the planting, which ranged from 1,600 to 2,500 kg/ha.

If summing up the partial values of wood mass production of individual species, the available data about the total possible production of wood mass for the whole country (Czech Republic) state the value of $116,312 \times 10^3$ kg. Similar value was described in the work of Rosúa and Pasadas (2012) studying the conditions of Andalusia (total potential $1,165,046 \times 10^3$ kg), or Bilandzija et al. (2012) studying the conditions of Croatia (total potential of 4,217 TJ).

Following the methodology process, the analyses of the elemental composition were performed while focusing on the determination of hydrogen content, followed with calorimeter tests that determined the gross calorific value. From these values, average net calorific value was determined in accordance with CSN ISO 1928. An overview of these average values for each type of fruit/fruit species is shown in Table 3. These determined values were evaluated using the analysis of variance (ANOVA) and mutually compared by the Tukey´s test at the significance level $\alpha = 0.05$.

In terms of statistical evaluation of moisture data, the same results were obtained for pear, apricot and plum. The highest moisture content was then determined for the wood mass of apple and grapevine (7.21 to 7.33%). However, overall, the moisture samples fluctuated within a relatively narrow range of values from 6.14 to 7.33%. The hydrogen content required for calculating the calorific value according to formula 1 ranged from 6.17 to 7.16% in the measured samples.

For evaluation of the energy potential of waste wood material the most important is the net calorific value. From the statistical analysis (Table 3) follows that the species of apple, peach, apricot, plums, sweet cherry and sour cherry gave comparable values. The net calorific value for these species ranged from 14.70 to 15.46 MJ/kg. Higher net calorific values, compared with these species, were determined for pear (15.69 MJ/kg) and grapevine (16.39 MJ/kg). Bilandzija et al. (2012), and Rosúa and Pasadas (2012) report the values of gross calorific value for wood mass from different types of fruit in the range of 15.60 to 17.73 MJ/kg. Likewise, Zivkovic et. al. (2013) reports a net calorific value of orchard wood from 14.5 to 19.4 MJ/kg, and similarly Boschiero et al. (2016) 19.03 MJ/kg.

Walg (2007), for example, studied the net calorific value of grapevine wood and he set the value

Table 3. Average values of pruned wood of different horticultural species (dry basis)

Type of fruit wood	The average value of evaluated content			
	moisture (%)	hydrogen content (%)	gross calorific value (MJ/kg)	net calorific value (MJ/kg)
Apple	7.21 ± 0.035^{d}	6.54 ± 0.102^{b}	17.22 ± 0.106^{bc}	15.46 ± 0.255^{cd}
Pear	6.15 ± 0.025^{a}	6.17 ± 0.038^{d}	17.34 ± 0.046^{c}	15.69 ± 0.146^{d}
Peach	6.91 ± 0.038^{c}	6.67 ± 0.032^{ab}	17.12 ± 0.082^{b}	15.33 ± 0.157^{bcd}
Apricot	6.27 ± 0.025^{a}	6.75 ± 0.040^{a}	16.89 ± 0.068^{a}	15.10 ± 0.124^{abc}
Plum	6.14 ± 0.031^{a}	6.89 ± 0.020^{e}	16.83 ± 0.032^{a}	15.01 ± 0.162^{abc}
Sweet cherry	6.61 ± 0.075^{b}	7.04 ± 0.025^{c}	16.57 ± 0.045^{d}	14.70 ± 0.217^{abc}
Sour cherry	6.75 ± 0.085^{bc}	7.16 ± 0.036^{c}	16.76 ± 0.035^{a}	14.85 ± 0.144^{ab}
Grapevine	7.33 ± 0.107^{d}	6.73 ± 0.060^{a}	18.20 ± 0.025^{e}	16.39 ± 0.184^{e}

values followed by the same letter in a column are not significantly different according to the Tukey's test ($\alpha = 0,05$)

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Table 4. Energy potential of wood mass af different fruit species in the Czech Republic

Type of fruit wood mass	Total production (kg)		Net calorific value (MJ/kg)	Energetic potential (MJ)
	fresh wood	dry wood		
Apple	$46,556 \times 10^3$	$27,933 \times 10^3$	15.46	$431,844 \times 10^3$
Pear	$3,530 \times 10^3$	$2,118 \times 10^3$	15.69	$33,231 \times 10^3$
Peach	526×10^3	315×10^3	15.33	$4,828 \times 10^3$
Apricot	$1,232 \times 10^3$	739×10^3	15.10	$11,159 \times 10^3$
Plums	$4,624 \times 10^3$	$2,774 \times 10^3$	15.01	$41,637 \times 10^3$
Sweet cherry	$1,982 \times 10^3$	$1,189 \times 10^3$	14.70	$17,478 \times 10^3$
Sour cherry	$2,517 \times 10^3$	$1,510 \times 10^3$	14.85	$22,424 \times 10^3$
Grapevine	$55,342 \times 10^3$	$33,205 \times 10^3$	16.39	$907,055 \times 10^3$
Total	$116,312 \times 10^3$	$69,787 \times 10^3$		$1,469,656 \times 10^3$

of 12.6 MJ/kg at the moisture level of 20%. Overall, the evaluation results of net calorific value coincide with the data of Pastorek et al. (2004), Rosúa and Pasadas (2012) and Clermidy (2012). According to these authors, the net calorific value of the dry mass of plant containing lignocellulose raw materials varies little and moves between 17.5 to 19.0 MJ/kg. Souček et al. (2010), very similarly, determined the net calorific value in the range between 14.39 to 16.66 MJ/kg.

The average gross calorific value of the five vine varieties ranged from 17.92 MJ/kg up to 18.02 MJ/kg whereas the net calorific value ranged between 7.34 and 7.96 MJ/kg (Manzone et al. 2016). Spinelli et al. (2012) presents the gross calorific value of vineyard pruning residues of 18.7 MJ/kg, Muzikant et al. (2010) 16.3 MJ/kg and Fernández-Puratich et al. (2015) from 16.5 MJ/kg up to 18.7 MJ/kg.

Freppaz et al. (2004) and McCormick and Käberger (2007) dealt with the issue of energy use in other alternative energy sources. From the results of their work it is clear that the net calorific value of wood from fast-growing bushes is around 18.5 MJ/kg and in plant biomass it is at the level of 16 MJ/kg.

Trávníček et al (2015) and Muzikant et al. (2010) both state that for energetic purposes it is appropriate to use wood with a moisture content of up to 20% by weight, which is air-dry. Fresh wood has a moisture content of 30–50% (Mikulová et al. 2014). Also in the vineyard, Souček (2007) claims moisture between 40–50%, according to Muzikant et al. (2010) it is between 15–50% and according to Manzone et al. (2016) it is approximately 50%.

When drying fresh wood to the desired moisture content, its weight is reduced by 30–40% (Maga et al. 2008; Pelaez-Samaniego et al. 2013; Simpson 2013). Also, Sims (2002) states that reducing wood moisture from 50% to 20% represents a weight loss of 37.5%.

The data of the wood material production, weight reduction in moisture reduction and the calorific values determined from the calorimetric analyses were used to determine the energy potential of the individual fruit species. The results obtained are shown in Table 4.

The values show that the highest energy potential has the grapevine from vineyards. This is due to the overall size of plantations, average production of grape cane and the highest net calorific value. For the other fruit trees, the energy potential ranged from $4,828 \times 10^3$ MJ (peach) to $431,844 \times 10^3$ MJ (apple). The evaluation of the energy potential of waste wood mass from orchards and vineyards is discussed in the work of Bilandzija et al. (2012) as well. They calculated the total energy potential of biomass from orchards and vineyards shreds at the level of 4,217 TJ. This value covers the energy requirements of Croatia only by 1%. Rosúa and Pasadas (2012), provide conditions for Andalusia, where the values of the energy potential of waste orchard wood is about 18,495 TJ. This figure covers more than 50% demand of the region for heating.

CONCLUSION

The results of measurements carried out in the years 2015 and 2016 aimed at identifying and assessing the energy potential of waste wood material from orchards and vineyards in the Czech Republic. The following conclusions were made:

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– Average production of wood mass for individual species of fruit trees and grapevines ranges from 1,540 up to 6,762 kg/ha, i.e. 1.5 to 6.8 t/ha.
– Net calorific value of the wood mass ranges from 14.70 up to 16.39 MJ/kg and is comparable to the net calorific value of the spruce bark (15.47 MJ/kg), softwood (14.61 MJ/kg) or the net calorific value of brown coal (16.0 MJ/kg).
– Total energy potential of the cultivated areas used for measurements and evaluated fruit species is 1,469.6 TJ for the whole Czech Republic; this value corresponds to an equivalent expression over 91,799 × 10^3 kg of brown coal, or 43,814 × 10^3 m^3 of natural gas.
– In practice, it is also necessary to take into account the loss of energy in assessing the energy potential of waste wood, especially during transport, handling and drying.
– The energetic strategy of the Czech Republic for the area of bioenergy establishes the requirement to ensure biomass energy sources (RES) amounting to 13% by 2020, which represents 145,993.7 TJ. Based on the results of this research, the conclusion is that the waste wood material of orchards and vineyards may contribute up to 1.01% of this requirement.

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