Fuel Properties of Woody Biomass from Pruning Operations in Fruit Orchards

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Biomass has become a major source of renewable energy. The basic fuel properties of woody biomass from orchards were evaluated on the following fruit tree wood obtained from pruning operations: ‘Reliance’ peach, ‘Burlat’ cherry, ‘Packham’s Triumph’ pear, ‘Early Geneva’ apple, hazel (Polish variety Halle), ‘Hargrand’ apricot, walnut, domestic plum (Polish variety Węgierka), and sour cherry (variety Ujfehertoi fürtos). The research included the wood and bark of the trunk, whole limbs, and branches. Gross calorific value for the majority tested biomass ranged from 19.2 to 21.3 MJ / kg, which is typical for wood and bark of broadleaf species. The low content of chlorine and sulfur in the analyzed samples would contribute to low corrosion in boilers and a low atmospheric pollution factor for generated sulfur oxides and hydrogen chloride. Properties of fuel biomass obtained from pruning operations were not noticeably different from the typical properties of solid biofuels derived from woody forest biomass. Based on these results, biomass from orchards can be a substitute for raw forest material suitable for energy use.

Keywords: Fuel properties; Pruned biomass; Biofuel; Bioenergy

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INTRODUCTION

As a result of a climate policy, led by the European Union, the “20-20-20” targets were accepted by the European Parliament in 2008. These targets include the following objectives: reduce the emissions of greenhouse gases by 20%, increase energy efficiency in the EU by 20%, and increase total consumption of renewable energy by 20% in the EU by 2020. These commitments seem to be difficult to implement in Poland because of the structure of the Polish energy sector and the dominant role of factories that still burn fossil fuels for energy production. Due to this situation, biomass has become a major source of renewable energy. A valuable source of renewable energy in Poland is the crops from agricultural production and wood residues. Use of these materials allows Poland to fulfill their international commitments to produce electricity and heat from renewable sources.

In Poland, there is a deficit of wood that can be used to produce energy. In 2010, the shortage of wood from the forest was estimated at 2.2 million m^3, and from all sectors of consumption at about 1.5 million m^3. The deficit of forestry wood in 2015 is estimated to be in the range from 7.7 million m^3 to 11.4 million m^3 (Ratajczak 2013). This is due to the limited forest resources in Poland, which cannot cover the growing needs of the wood industry. In contrast, the development program of renewable energy sources focuses primarily on the use of different kind of biomass. So far, the basic type of biomass used in large power plants in Poland are mainly waste material from the mechanical treatment of wood. A characteristic of this type of fuel is its high chemical purity. Agricultural biomass, which seems to have unlimited potential in many regions of Poland, causes many technological problems in the energy sector.

Considering global climate change, the European Parliament and the Council of Europe adopted Directive 2001/77/EC, which aimed to increase the energy production from renewable sources in electricity production. This document caused a lot of important changes in the energy production sector in Poland. An example could be the recently revised Regulation of the Ministry of Economy from 9 November 2012 (Dz.U.2012.1229). This detailed the scope of obligations to obtain and submit to the redemption of certificates of origin, the payment of a substitute fee, the purchase of electricity and heat produced from renewable energy sources, and the obligation to confirm the data on the amount of electricity produced from renewable energy sources.

Guided by the objective needs of the energy industry, unused sources of wood materials for use as potential fuel for power plants are being sought. One of the sources is woody biomass generated by pruning operations in the urban green areas and fruit orchards. Fruit tree pruning is an important element in the function of each orchard. The main purpose of these operations is to facilitate crown shaping for optimal fruit production and efficient harvesting. A properly formed crown is able to produce and bear a large fruit yield. After reaching the desired crown shape, trees are selectively pruned to maintain or improve a well-balanced and natural form and size. Pruning operations also ensure the formation of new shoots, which determine the appropriate level of yield. Both the formation of crowns in the first years after planting, as well as cuts in later periods have varying impacts on trees (Hołubowicz 1999).

Biofuel properties are affected by many characteristics of the biomass, such as large species diversity, the significant heterogeneity of the plant material, diverse habitats, as well as the type and nature of crop basal area. Therefore, it has become important to conduct research to determine the suitability of such material for energy production. The results of the study on the fuel properties of woody biomass from the pruning operation in urban green areas are described in a previous work (Cichy *et al.* 2012). The present publication expands on this the topic, describing the fuel properties of woody biomass derived from the pruning operation in gardens and orchards in Poland. In young orchards, the amount of woody raw materials harvested from pruning in winter ranges between 0.5 t/ha and 0.6 t/ha, while in the six-year-old orchards, depending on the type of orchard, it is already in the range from 1.9 t/ha to 5 t/ha (Werner 2012). According to data from the Central Statistical Office, the total area of fruit tree plantations in 2014 in Poland amounted to 341,800 ha (GUS 2015). In Poland almost 200,000 hectares of apple orchards are cultivated (Dyjakon *et al.* 2016). As a result of apple tree pruning, the average generated amount of woody biomass is calculated as 3.5 Mg/ha·year. Using estimating methods to calculate the potential amount of biomass from pruning operations, a minimum of 93,000 m^3 of woody biomass could be obtained per year (Kowalczyk-Juśko 2010). Most of the biomass is ground and scattered as mulch in orchards, effectively inhibiting the growth of weeds, increasing the long-term humidity and uniform temperature of soil, and then burned directly in private domestic installation.

The main aim of this study was to investigate the basic fuel properties of the wood materials obtained from pruning operations in fruit orchards. The secondary aim was the assessment of the suitability of pruned biomass for production of solid biofuels as an alternative to forest raw material.

EXPERIMENTAL

Materials

The present study included the wood and bark of the trunk and the entire limbs and branches from pruning operations in fruit orchards. The choice of the following species was aimed at common Polish orchard trees: ‘Reliance’ peach, ‘Burlat’ cherry, ‘Packham’s Triumph’ pear, ‘Early Geneva’ apple, hazel (Polish variety Halle), ‘Hargrand’ apricot, walnut, domestic plum (Polish variety Węgierka), and sour cherry (variety Ujfehertoi fürtos).

Materials were obtained during pruning operations in the spring (beginning of March 2013) from the PRZYBRODA Agricultural Experimental Farm, University of Life Sciences (Poznań, Poland). The samples for analysis were taken as wood pieces in the form of discs from the cross-section of the trunk and limb or cross-sectional slices of the branches. The first step was dividing the woody biomass from the bark, then samples were air-dried until they acquired a dry condition. Then they were cut into smaller segments, which were disintegrated in a knife mill or impact mill into particles of the desired size.

Methods

In samples of 1.0 mm grain size, moisture (EN ISO 18134-2 (2015)) and ash contents (EN ISO 18122 (2016)) were determined.

In samples of < 0.2 mm grain sizes, the elementary composition was determined (EN ISO 16948 (2015), EN ISO 16994 (2015)), using the elementary analyzer Flash 1112 of Thermo Electron Corporation (Milano, Italy). The determination was performed in three replications, using weighed portions of samples in the mass range 3 to 4 mg each. For the multi-stage calibration of the instrument, material standards with different contents of C, H, N, and S were applied.

The heat of combustion and calorific values were determined according to the standard EN 14918 (2010), using the calorimeter KL-12 Mn of Precyzja Bit Company (Bydgoszcz, Poland).

The chlorine content was determined according to instructions in the standard EN ISO 16994 (2015) by the potentiometric titration method.

Trace elements of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) were visible *via* atomic emission spectrometry with excitation in an inductively coupled plasma using a simultaneous ICP OES spectrometer iCAP 6500 Duo of Thermo Scientific (Cambridge, UK). Mercury (Hg) was determined by atomic absorption spectrometry by an amalgamation technique using a mercury content analyzer MA-2 by Nippon Instruments Corporation (Tokyo, Japan).

RESULTS AND DISCUSSION

The results of the lignocellulosic raw materials analysis are shown in Tables 1 through 4. Table 5 presents the typical values for fuel properties for broad-leaf wood and coniferous wood (EN ISO 17225-1 (2014)) in comparison with coal (Deimling *et al.* 2000).

The ash content of the fuel is of high importance when choosing the appropriate combustion and gas cleaning technologies. Furthermore, fly ash formation, ash deposit formation, and logistics concerning ash storage and ash disposal or utilization need to be considered. Fuels with low ash content are therefore preferable.

Table 1. Fuel Properties of Woody Biomass from Pruning Operations in Fruit Orchards

Material	Ash	Gross Calorific Value	Net Calorific Value
	$\%_d$	MJ/kg_d	MJ/kg_d
Reliance Peach			
Wood	0.4 ± 0.08	20.0 ± 0.20	18.6 ± 0.23
Bark	5.4 ± 0.10	21.3 ± 0.18	20.0 ± 0.21
Branches	2.0 ± 0.08	20.1 ± 0.19	18.8 ± 0.19
‘Burlat’ Cherry			
Wood	0.6 ± 0.04	19.4 ± 0.22	17.9 ± 0.25
Bark	5.3 ± 0.14	20.3 ± 0.11	18.8 ± 0.26
Branches	1.5 ± 0.08	20.0 ± 0.13	18.6 ± 0.13
‘Packham’s Triumph’ Pear			
Wood	0.5 ± 0.05	19.7 ± 0.14	18.3 ± 0.27
Bark	5.9 ± 0.18	19.6 ± 0.10	18.2 ± 0.15
Branches	3.8 ± 0.08	19.2 ± 0.15	17.8 ± 0.15
‘Early Geneva’ Apple			
Wood	0.6 ± 0.04	19.6 ± 0.19	18.1 ± 0.25
Bark	10.7 ± 0.44	17.5 ± 0.07	16.2 ± 0.14
Branches	1.9 ± 0.22	19.2 ± 0.22	17.9 ± 0.22
Hazel			
Wood	1.1 ± 0.08	19.6 ± 0.12	18.2 ± 0.17
Bark	8.8 ± 0.10	18.6 ± 0.08	17.3 ± 0.14
Branches	2.5 ± 0.14	19.6 ± 0.17	18.2 ± 0.17
‘Hargrand’ Apricot			
Wood	0.8 ± 0.08	19.7 ± 0.09	18.3 ± 0.15
Bark	5.4 ± 0.21	20.9 ± 0.22	19.5 ± 0.25
Branches	3.0 ± 0.08	20.5 ± 0.22	19.1 ± 0.22
Walnut			
Wood	0.9 ± 0.02	19.6 ± 0.18	18.2 ± 0.22
Bark	13.1 ± 0.10	16.9 ± 0.09	15.6 ± 0.14
Branches	2.9 ± 0.15	19.3 ± 0.11	17.9 ± 0.11
Polish Domestic Plum			
Wood	0.3 ± 0.03	19.6 ± 0.12	18.2 ± 0.17
Bark	6.4 ± 0.14	19.0 ± 0.15	17.7 ± 0.18
Branches	1.5 ± 0.08	19.6 ± 0.18	18.2 ± 0.18
Ujfehertoi fürtos Sour Cherry			
Wood	0.5 ± 0.07	19.4 ± 0.15	18.0 ± 0.19
Bark	5.0 ± 0.12	19.2 ± 0.07	17.9 ± 0.14
Branches	1.7 ± 0.06	19.7 ± 0.08	18.3 ± 0.08
d – dry			

The ash content in wood ranged from 0.3% (plum) to 1.1% (hazel). For branches, the minimum ash content was 1.5% (plum and sour cherry) and maximum ash content was 3.8% (pear). It was higher than the typical value for wood (0.3%) according to EN ISO 17225-1 (2014). These results corresponded to current literature. According to Prosiński (1984), the ash content is in the range from 0.3% to 1.0%, while Krzysik (1974) reports the range from 0.3% to 1.2%. According to Fengel and Wegener (1984), the mineral content in wood from the temperate region is in the range from 0.1% to 1.0%. The ash content in the bark ranged from 5.0% in cherry to 13.1% in walnut. The mineral content in bark impacts its differential chemical composition of the individual species of tree. Fengel and Wegener (1984) reported that bark has higher levels of ash (up to tenfold) than wood, while Prosiński (1984) describes that there is a maximum of 5% ash content in bark.

The most important thermo-physical parameter of the fuel is its heat of combustion (gross calorific value) and net calorific value. These values determine the possibility and profitability of wood material as a fuel. The net calorific value is calculated from the heat of combustion set in a calorimeter bomb, elemental composition, and moisture content. The gross calorific value of the studied materials averaged 19.6 MJ/kg for deciduous wood and oscillated between 16.9 MJ/kg in walnut and 21.3 MJ/kg in peach bark. The average value for branches was 19.7 MJ/kg.

The obtained results were convergent with the recommended value of wood fuels (EN ISO 17225-1 (2014)). The typical net calorific (dry) value according to EN 14961-1 (2010) for biofuels produced from woody biomass ranges between 18.9 MJ/kg for wood and 19.0 MJ/kg for the bark of deciduous trees. In the studied biomass materials, the highest net calorific value was 20.0 MJ/kg in bark of peach and the lowest was 15.6 MJ/kg in bark of walnut.

During the combustion of natural plant materials, chemical compounds containing elementary elements (carbon, hydrogen, oxygen, nitrogen, and sulfur) are oxidized, resulting in heat generation. Knowledge of the elemental composition of fuels allows an accurate assessment of their calorific value and allows the estimation of risks associated with the emission of toxic combustion products.

The carbon content in the hardwood material was 49.5% in wood apple and 51.7% in peach; in the bark from 45.7% (walnut) to 55.0% (peach); and branches from 48.6% for apple to 51.5% for apricot. The values obtained were similar to the typical carbon content of deciduous species (from 49.0% to 52.0%). The hydrogen content in the bark, wood, and branches in most of the tested materials ranged from 5.8% to 6.5%, and was comparable to that of wood biomass (from 5.8% to 6.3%). Major differences between the tested materials (wood: from 0.3% to 0.5%, bark: from 0.2% to 1.6%, branches: from 0.5% to 1.1%) and the values for solid wood biofuels (0.1% in wood, from 0.3% to 0.5% in the bark) were observed for the nitrogen content, which was higher in the experimental material. Nitrogen is one of the five most important macro elements that affects the growth, development, and yield of a plant. It stimulates growth of the underground and above-ground plants. Extending the growing season also affects the consumption of other nutrients, such as potassium and phosphorus (Lewandowski 2012). Higher levels of nitrogen content in the analyzed raw materials was probably related to the fertilization process of woody plants. The results of the elemental composition analysis of C and H in most timber corresponded with the data in previous literature. Krzysik (1974) gives the average composition of wood for carbon (50%) and hydrogen (6.1%), while Prosinski (1984) reports 49.5% and 6.3%, respectively.

To evaluate the quality of biofuels, it is important to know the content of sulfur and chlorine. The high content of these elements is causing corrosion and contamination of boilers and increased emissions of SO_x, Cl_2, and HCl. Chlorine noticeably condenses as salt on the surface of the boilers and furnaces, or reacts with the generated ash. The main effect of chlorine and sulfur is high temperature corrosion and slagging (Obernberger *et al*. 2004; Król *et al*. 2010). In all of the studied materials, the sulfur content was below the level of quantification for the elemental analysis apparatus (< 0.01%). According to the standard EN ISO 17225-1 (2014), the typical sulfur content of the solid biofuels from woody biomass is a maximum of 0.02% in the wood and 0.3% in the bark of deciduous trees. In the classification standard EN ISO 17225-1 (2014), the average chlorine content in solid biofuels is 0.01% in wood and 0.03% in bark. The obtained results confirmed this order of magnitude. The only analysis of the walnut bark (0.074%) showed a higher chlorine content. At this stage, it was difficult to determine the origin of the unusually higher chlorine content.

Table 2. Ultimate Analysis of Woody Biomass from Pruning Operations in Fruit Orchards

Material	Ultimate Analysis				Chlorine
	C	H	N	S	Cl
	$\%_d$	$\%_d$	$\%_d$	$\%_d$	$\%_d$
'Reliance' Peach					
Wood	51.7 ± 0.43	6.5 ± 0.57	0.4 ± 0.05	< 0.01	0.010 ± 0.004
Bark	55.0 ± 0.62	6.3 ± 0.56	1.2 ± 0.15	< 0.01	0.010 ± 0.005
Branches	51.1 ± 0.23	6.3 ± 0.12	0.9 ± 0.03	< 0.01	0.017 ± 0.003
'Burlat' Cherry					
Wood	50.9 ± 0.45	6.6 ± 0.58	0.4 ± 0.07	< 0.01	0.005 ± 0.003
Bark	52.1 ± 0.48	6.6 ± 0.57	0.9 ± 0.17	< 0.01	0.012 ± 0.011
Branches	50.8 ± 0.43	6.4 ± 0.08	0.5 ± 0.01	< 0.01	0.007 ± 0.002
'Packham's Triumph' Pear					
Wood	49.7 ± 0.45	6.5 ± 0.56	0.4 ± 0.06	< 0.01	0.009 ± 0.006
Bark	51.0 ± 0.44	6.1 ± 0.54	1.0 ± 0.17	< 0.01	0.008 ± 0.003
Branches	49.0 ± 0.26	6.3 ± 0.06	0.8 ± 0.01	< 0.01	0.007 ± 0.002
'Early Geneva' Apple					
Wood	49.5 ± 1.79	6.5 ± 0.78	0.4 ± 0.06	< 0.01	0.016 ± 0.013
Bark	46.5 ± 0.48	6.0 ± 0.55	1.1 ± 0.15	< 0.01	0.005 ± 0.004
Branches	48.6 ± 0.25	6.2 ± 0.10	0.5 ± 0.02	< 0.01	0.015 ± 0.004
Hazel					
Wood	50.0 ± 0.41	6.3 ± 0.55	0.5 ± 0.10	< 0.01	0.020 ± 0.003
Bark	49.1 ± 0.42	6.1 ± 0.54	1.2 ± 0.18	< 0.01	0.036 ± 0.009
Branches	49.8 ± 0.25	6.4 ± 0.06	0.8 ± 0.02	< 0.01	0.036 ± 0.011
'Hargrand' Apricot					
Wood	50.2 ± 0.76	6.3 ± 0.58	0.5 ± 0.07	< 0.01	0.008 ± 0.005
Bark	52.3 ± 0.44	6.4 ± 0.56	1.6 ± 0.21	< 0.01	0.001 ± 0.002
Branches	51.5 ± 0.36	6.5 ± 0.07	1.1 ± 0.03	< 0.01	0.011 ± 0.003
Walnut					
Wood	49.9 ± 0.43	6.4 ± 0.56	0.3 ± 0.05	< 0.01	0.012 ± 0.005
Bark	45.7 ± 0.64	5.8 ± 0.51	0.9 ± 0.13	< 0.01	0.074 ± 0.015
Branches	49.4 ± 0.22	6.4 ± 0.07	0.5 ± 0.02	< 0.01	0.031 ± 0.012
Polish Domestic Plum					
Wood	49.7 ± 0.67	6.4 ± 0.56	0.4 ± 0.05	< 0.01	0.007 ± 0.004
Bark	49.6 ± 0.41	6.1 ± 0.54	1.2 ± 0.17	< 0.01	0.009 ± 0.005
Branches	50.4 ± 0.49	6.5 ± 0.06	0.8 ± 0.02	< 0.01	0.007 ± 0.002
Ujfehertoi fürtos Sour Cherry					
Wood	49.6 ± 0.71	6.5 ± 0.58	0.3 ± 0.05	< 0.01	0.006 ± 0.005
Bark	50.2 ± 0.53	6.3 ± 0.55	0.7 ± 0.12	< 0.01	0.011 ± 0.003
Branches	49.5 ± 0.34	6.3 ± 0.07	0.6 ± 0.01	< 0.01	0.015 ± 0.004
d – dry					

Trace elements are components of the ash. These elements have an effect on the ash melting, the deposit formation, fly ash, and aerosol emission, as well as high-temperature corrosion (in combination with Cl and S). During the combustion, a fraction of the ash-forming compounds in the fuel is volatilized and released to the gas phase. The formation of this fraction is dependent on the chemical composition of the fuel, the atmosphere, the temperature, and the combustion technology (Obernberger *et al*. 2006).

Table 3. Content of Trace Elements (As, Cd, Hg, Ni) in Woody Biomass from Pruning Operations in Fruit Orchards

Material	As	Cd	Hg	Ni
	mg/kg$_d$	mg/kg$_d$	mg/kg$_d$	mg/kg$_d$
'Reliance' Peach				
Wood	< 0.010	0.05 ± 0.009	0.001 ± 0.0002	0.366 ± 0.052
Bark	< 0.010	0.117 ± 0.020	0.014 ± 0.0023	0.829 ± 0.117
Branches	< 0.010	0.195 ± 0.034	0.003 ± 0.0005	0.967 ± 0.137
'Burlat' Cherry				
Wood	< 0.010	0.01 ± 0.002	0.006 ± 0.001	0.303 ± 0.043
Bark	0.41 ± 0.082	< 0.010	0.006 ± 0.001	0.401 ± 0.057
Branches	< 0.010	< 0.010	0.004 ± 0.001	0.311 ± 0.044
'Packham's Triumph' Pear				
Wood	< 0.010	0.041 ± 0.007	0.002 ± 0.0003	0.401 ± 0.057
Bark	0.463 ± 0.092	0.067 ± 0.012	0.009 ± 0.001	0.736 ± 0.104
Branches	< 0.010	0.059 ± 0.010	0.006 ± 0.001	0.607 ± 0.086
'Early Geneva' Apple				
Wood	< 0.010	0.077 ± 0.013	0.005 ± 0.001	0.607 ± 0.086
Bark	0.612 ± 0.122	0.127 ± 0.022	0.006 ± 0.001	1.41 ± 0.200
Branches	< 0.010	0.065 ± 0.011	0.002 ± 0.0003	0.703 ± 0.099
Hazel				
Wood	< 0.010	< 0.010	0.002 ± 0.0003	0.194 ± 0.027
Bark	< 0.010	< 0.010	0.009 ± 0.001	0.846 ± 0.120
Branches	< 0.010	0.022 ± 0.004	0.005 ± 0.001	0.435 ± 0.062
'Hargrand' Apricot				
Wood	< 0.010	0.011 ± 0.002	0.002 ± 0.0003	0.388 ± 0.055
Bark	0.331 ± 0.066	< 0.010	0.012 ± 0.002	0.565 ± 0.080
Branches	< 0.010	0.031 ± 0.005	0.003 ± 0.0005	0.363 ± 0.051
Walnut				
Wood	< 0.010	< 0.010	< 0.001	0.531 ± 0.075
Bark	0.274 ± 0.055	< 0.010	0.005 ± 0.001	0.916 ± 0.130
Branches	< 0.010	< 0.010	0.006 ± 0.001	0.547 ± 0.077
Polish Domestic Plum				
Wood	< 0.010	0.035 ± 0.006	0.001 ± 0.0002	0.329 ± 0.047
Bark	< 0.010	0.052 ± 0.009	0.008 ± 0.001	1.52 ± 0.215
Branches	< 0.010	0.018 ± 0.003	0.003 ± 0.0005	0.525 ± 0.074
Ujfehertoi Fürtos Sour Cherry				
Wood	< 0.010	< 0.010	0.001 ± 0.0002	0.31 ± 0.044
Bark	0.261 ± 0.052	< 0.010	0.005 ± 0.001	0.553 ± 0.078
Branches	< 0.010	< 0.010	0.002 ± 0.0003	0.458 ± 0.065
d – dry				

Table 4. Content of Trace Elements (Cr, Cu, Pb, Zn) in Woody Biomass from Pruning Operations in Fruit Orchards

Material	Cr	Cu	Pb	Zn
	mg/kg$_d$	mg/kg$_d$	mg/kg$_d$	mg/kg$_d$
‘Reliance’ Peach				
Wood Bark Branches	0.318 ± 0.058 0.721 ± 0.131 0.535 ± 0.097	2.49 ± 0.32 408 ± 52 68.9 ± 8.72	0.15 ± 0.03 3.01 ± 0.63 0.653 ± 0.136	5.2 ± 0.5 12.1 ± 1.1 22.8 ± 2.0
‘Burlat’ Cherry				
Wood Bark Branches	0.480 ± 0.087 0.489 ± 0.089 0.657 ± 0.119	1.55 ± 0.20 170 ± 21.5 31.6 ± 4.00	0.086 ± 0.018 1.05 ± 0.219 0.09 ± 0.019	2.99 ± 0.3 5.46 ± 0.5 5.4 ± 0.5
‘Packham’s Triumph’ Pear				
Wood Bark Branches	0.522 ± 0.095 0.592 ± 0.108 1.16 ± 0.211	2.68 ± 0.34 110 ± 14 6.4 ± 0.81	0.147 ± 0.031 0.922 ± 0.192 0.375 ± 0.078	3.1 ± 0.3 27.6 ± 2.5 17.7 ± 1.6
‘Early Geneva’ Apple				
Wood Bark Branches	0.478 ± 0.087 0.619 ± 0.113 0.346 ± 0.063	2.4 ± 0.3 25.9 ± 3.3 8.85 ± 1.12	< 0.010 0.479 ± 0.100 0.217 ± 0.045	9.63 ± 0.9 13.6 ± 1.2 5.07 ± 0.5
Hazel				
Wood Bark Branches	0.266 ± 0.048 0.601 ± 0.109 0.504 ± 0.092	3.25 ± 0.41 7.23 ± 0.92 4.62 ± 0.58	0.457 ± 0.095 1.56 ± 0.325 0.9 ± 0.187	3.42 ± 0.3 10.3 ± 0.9 9.08 ± 0.8
‘Hargrand’ Apricot				
Wood Bark Branches	0.632 ± 0.115 0.709 ± 0.129 0.534 ± 0.097	2.72 ± 0.34 12.6 ± 1.6 7.87 ± 1.00	0.832 ± 0.173 1.33 ± 0.277 1.11 ± 0.231	6.68 ± 0.6 16.2 ± 1.5 14.8 ± 1.3
Walnut				
Wood Bark Branches	0.338 ± 0.061 0.562 ± 0.102 0.338 ± 0.061	1.2 ± 0.15 4.44 ± 0.56 2.32 ± 0.29	< 0.010 0.738 ± 0.154 0.185 ± 0.038	3.03 ± 0.3 17.7 ± 1.6 9.66 ± 0.9
Polish Domestic Plum				
Wood Bark Branches	0.367 ± 0.07 17.7 ± 3.22 0.426 ± 0.08	2.17 ± 0.27 15.8 ± 2.00 4.36 ± 0.55	0.118 ± 0.025 0.951 ± 0.198 0.121 ± 0.025	2.31 ± 0.2 11.2 ± 1.0 5.48 ± 0.5
Ujfehertoi Fürtos Sour Cherry				
Wood Bark Branches	0.480 ± 0.087 0.341 ± 0.062 0.484 ± 0.088	2.15 ± 0.27 73 ± 9.24 43.9 ± 5.56	0.025 ± 0.005 0.828 ± 0.172 0.378 ± 0.079	1.7 ± 0.2 5.09 ± 0.5 11.4 ± 1.0
d – dry				

The determined concentration of arsenic, cadmium, chromium, mercury, nickel, lead, and zinc in the test material (Tables 3 and 4) showed that the obtained results corresponded to the typical values for solid biofuels (EN ISO 17225-1 (2014)). The highest values of trace elements were determined: As – bark of apple (0.612 mg/kg), Cd – branches of peach (0.195 mg/kg), Cr - bark of plum (17.7 mg/kg), Hg - bark of peach (0.014 mg/kg), Ni – bark of plum (1.52 mg/kg), Pb - bark of peach (3.01 mg/kg), and Zn – bark of pear (27.6 mg/kg). The analysis of copper in wood was comparable to the typical value for solid biofuels, but in bark and branches, the content of this element was higher (Tables 4 and 5).

The maximum value of copper in bark and branches was determined for peach, 408.0 mg/kg and 68.9 mg/kg, respectively. It was probably related to the application of plant protection products. Copper compounds have long been used to protect the trees against fungi and diseases of bacterial and viral origin (Łabanowska-Bury 2012).

The available data concerning fuel properties of woody biomass obtained from pruning operations in fruit orchards is scarce. Measurements (ash, elemental analysis, net calorific value) of the studied biomass materials were comparable with results obtained by Bilandzija *et al.* (2012). The only exception was sulfur content, where the value was below 0.01%, whereas authors cited 0.2%. It should be noted that the indicated specifications may differ from each other due to different climatic zones, geographical location, or type of substrate on which the orchards grew.

Table 5. Typical Values* of Solid Biomass Fuels in the Standard EN ISO 17225-1 (2014) and Typical Values of Coal (Deimling *et al*. 2000)

Parameter		Unit	Broadleaf Wood		Coniferous Wood		Coal
			Virgin Wood Materials	Virgin Bark Materials	Virgin Wood Materials	Virgin Bark Materials	
Ash		$\%_d$	0.30	1.5	0.30	1.5	1.0 to 15.0
Ultimate Analysis	C	$\%_d$	49.0	52.0	51.0	52.0	72.5 to 92.0
	H	$\%_d$	6.2	5.8	6.3	5.9	4.0 to 5.6
	N	$\%_d$	0.1	0.3	0.1	0.5	1.2 to 1.7
	S	$\%_d$	0.02	0.03	< 0.02	0.03	0.6 to 1.4
Chlorine		$\%_d$	0.01	0.02	0.01	0.02	0.1
Gross Calorific Value		MJ/kg_d	20.1	20.0	20.5	20.4	-
Net Calorific Value		MJ/kg_d	18.9	19.0	19.1	19.2	31.8 to 35.0
Trace Elements	As	mg/kg_d	< 1.0	< 4.0	< 1.0	< 4.0	-
	Cd	mg/kg_d	< 0.5	< 1.2	< 0.5	< 1.0	3.0
	Cr	mg/kg_d	< 10.0	< 30.0	< 10.0	< 10.0	220.0
	Cu	mg/kg_d	< 10.0	< 20.0	< 10.0	< 30.0	-
	Hg	mg/kg_d	< 0.05	< 0.05	< 0.05	< 0.1	-
	Ni	mg/kg_d	< 10.0	< 10.0	< 10.0	< 20.0	220.0
	Pb	mg/kg_d	< 10.0	< 30.0	< 10.0	< 30.0	260.0
	Zn	mg/kg_d	< 100.0	< 200.0	< 50.0	< 200.0	-

d – dry

CONCLUSIONS

1. Obtained results determining the fuel properties of woody biomass from pruning operations in Polish fruit orchards indicated the possibility of using this type of material as the carrier of renewable energy. Therefore, this woody material could be successfully employed as a high quality solid fuel.
2. The ash content in the studied materials ranged from 0.3% (plum) to 1.1% (hazel) in the wood part; from 1.5% (plum, cherry) to 3.8% (pear) in branches, and from 5.0% (cherry) to 13.1% (walnut) in bark, which corresponded to the literature data.
3. The carbon and hydrogen content in tested samples ranged from 45.7% (bark of walnut) to 55.0% (bark of peach), and from 5.8% (bark of walnut) to 6.6% (wood and bark of cherry), respectively.
4. The nitrogen content was higher in all tested samples (from 0.3% to 1.6%) in comparison to typical values for this element in woody biomass (from 0.1% in wood to 0.5% in bark). It was assumed that this involved the fertilization process of fruit plantations.
5. The results for the determination of trace elements (arsenic, cadmium, chromium, lead, mercury, nickel, and zinc) corresponded to typical values for solid biofuels obtained from woody biomass. A substantial difference was observed for the determination of copper content, in particular in the bark and branches of: peach (408 mg/kg, 68.9 mg/kg), cherry (170 mg/kg, 31.6 mg/kg), sour cherry (73 mg/kg, 43.9 mg/kg), and bark of pear (110 mg/kg). It was concluded that this was related to plant protection products being used by the growers.
6. Gross calorific value and net calorific value of the tested materials ranged from: 16.9 MJ/kg (bark of walnut) to 21.3 MJ/kg (bark of peach), and from 15.6 MJ/kg (bark of walnut) to 20.0 MJ/kg (bark of peach), respectively. Lower, deviating from others, values of gross calorific value and net calorific value for bark of apple (17.5 MJ/kg and 16.2 MJ/kg) and bark of walnut (16.9 MJ/kg and 15.6 MJ/kg) were related to high mineral content in the studied materials (bark of the apple, 10.7%; bark of walnut, 13.1%).

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