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FUEL PROPERTIES OF OAK, POPLAR AND PINE LOGGING RESIDUES

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Abstract:

The growing global energy demand and concerns about the negative effects of growing greenhouse gas (GHG) emissions from fossil fuels call for alternative energy sources. One such renewable resource is logging residues that remain in the forest after harvesting. Exploring the possibilities of utilizing the biomass of logging residues for energy requires analysis and knowledge of its properties. In this research work the properties (percentage of bark, ash, volatiles, fixed carbon, carbon, hydrogen, oxygen, nitrogen and calorific value) of the various constituents of the biomass of oak (Quercus frainetto), poplar (Populus alba) and pine (Pinus nigra) logging residues were determined. Bark and ash content increased with decreasing diameter of branches. Ash content was higher in bark than in wood of branches in all species. Ash content of the all thick and thin branches was in oak 2,53% and 3,81%, in poplar 1,12% and 1,58% and in pine 0,79% and 1,16%, respectively. Ash content of twigs was in oak 4,14% and in pine 2,27%. Nitrogen content of branches varied from 0,105% to 0,312% and it was higher in oak and in thin branches. N content of twigs was 1,173% in oak and 0,76% in pine. Oak branches and oak and pine twigs had ash and nitrogen content higher than that required by the EN ISO 17225-2 standard for domestic pellets and they should not be used for energy, at least for pellets production. Volatile mater, fixed carbon, carbon and hydrogen content were in the range given by other researchers. Heating value ranged between 18,27MJ/kg to 21,0% and it was higher in pine than in oak and poplar, and higher in twigs and thin branches.

Key words: *forest biomass; logging residues; oak; poplar; pine; energy properties.*

INTRODUCTION

The growing global energy demand and concerns about the negative effects of growing greenhouse gas (GHG) emissions from fossil fuels call for alternative energy sources, which are low cost, renewable and non-polluting. One such renewable resource is biomass, especially forest biomass (European Commission 2005, Smeets and Faaij 2007, Ladanai and Vinterbäck 2009, Becker et al. 2011).

In recent years, the use of residues that remain in the forests after logging has attracted great interest as an energy source (Lehtikangas 2001, Gan and Smith 2006, Gan and Smith 2007, Nurmi 2007, Eker et al. 2009, Hu and Heitman 2008, Malinen et al. 2010, Giuntoli et al. 2015, Filippou et al. 2015, Roser et al. 2008, Philippou 2014).

The biomass consists of tops, branches, bark, foliage or needles and stumps. Forest residues may also include small trees that break during logging, dead trees and low-value trees or trees of non-market forest species (Roser et al. 2008, Philippou 2014).

In the past, logging residues were not exploited mainly because their harvest and transport was technically difficult and uneconomic. Currently new harvesting technologies and transportation systems have been developed and in conjunction with the increase in petroleum prices enable their extraction from the forest (Kauriinoja 2010, Svanaes and Jungmeier 2010, Filippou and Philippou 2014). Also, new and more efficient technologies enable conversion of biomass into energy in small units (mainly gasification) or conversion into compressed forms (wood pellets) that can be installed in or near the forests (Filippou and Philippou 2014). These further limit transportation costs and give opportunities for local employment and rural development. Thus, logging residues from final harvest are expected to play an important role in meeting renewable energy goals in many countries (Gan and Smith 2006, Nurmi 1993). Their utilization for

energy could create business opportunities and employments in local populations, generate profit from residual material and provide energy self-sufficiency for rural communities (Aguilar 2014).

Compared with the usual stem wood, biomass of logging residues differ in chemical composition % of cellulose, hemicelluloses, lignin, extracts and inorganic elements (Nordin 1994, Nurmi 1993, Nurmi 1997, Zeng 2014). There also exists variability in chemical composition between the various constituents of forest biomass (Philippou 1982, Werkelin et al. 2005, Wang and Dibdiakova. 2014). Moisture content, ash content, volatile content, elemental composition and calorific value are the main material properties that affect the material behavior during conversion into energy as well the overall energy outcome (Obernberger et al. 2006, Vassilev et al. 2010).

The ash content of biomass is known to vary between tree species and tree components (Hytonen and Nurmi 2015, Rhén 2004). High ash content can decrease the heating value of biomass. In addition, ash content and its composition affect the proper functioning of the burners and gassifiers (Bryers 1996, Raask 1969). The ash adheres to the heat transfer surfaces and cause corrosion. When burning the elements, mainly K, Na, S and Ca can melt, form sticky particles, adhere to the surfaces of the walls and create a burner malfunction (Raask 1969). The biofuel content of nitrogen N is responsible for the formation of NOx which have an environmental impact (Munalula and Meincken 2009). For biomass pellets, there is a need to have a low ash and nitrogen content in order to meet quality standards requirements (Filbakk et al. 2011, EN ISO 17225-2:2014).

Calorific value of biomass is a function of its chemical composition. Various researchers have determined the calorific value of various types of biomass from their elemental composition using proximity regression analysis models (Demirbas 2003, Friedl et al. 2005, Telmo et al. 2010, Singh et al. 2015). Several researchers (Nurmi 1997, Zeng et al. 2014, Philippou 1982, Obernberger et al. 2006, Harris 1984, Howard 1973, Howard 1988, Demirbas 1997) have measured the heating value of various tree species and various tree components and found significant differences both between species and between tree biomass components.

Proper utilization of logging residues for energy requires analysis and good knowledge of their properties. The aim of this work was to look at the branches of oak, poplar and pine that remain in the forest after harvesting and determine their properties that affect energy efficiency. The properties studied included percentage of bark, moisture, ash, volatiles, fixed carbon, carbon, hydrogen, oxygen, nitrogen and calorific value.

MATERIAL AND METHODS

Representative samples of oak (*Quercus frainetto*), poplar (*Populus alba*) and pine (*Pinus nigra*) branches with bark and foliage were taken from five trees of each species from a mixed forest in northern Greece during normal logging operations. For determining the % of bark in branches transverse discs of different diameters (from 2 to 9cm) were cut (Fig. 1). The percentage (%) of bark was calculated by measuring the diameter of the disc with the bark and after peeling the bark using the formula:

(1)

$$\text{bark } \% = \frac{d_1 - d_2}{d_1} \times 100$$

where: d_1=disk diameter with bark; $d_{2=}$ disk diameter without bark.

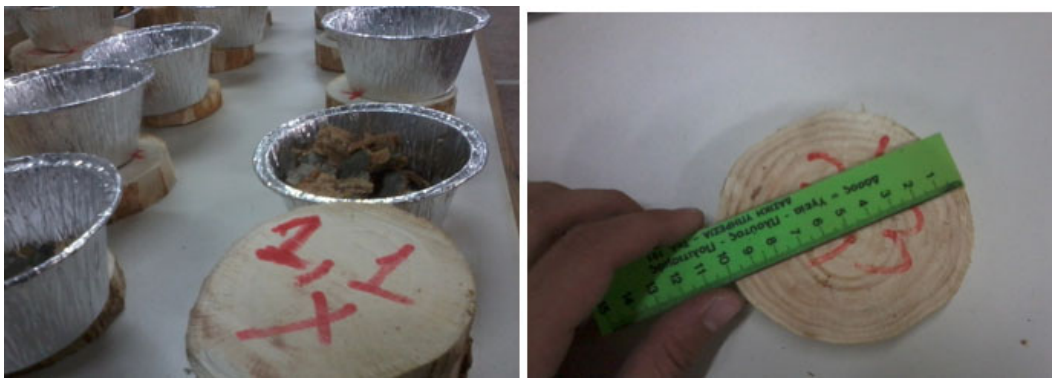


Fig. 1.
Disks of branches of various diameters for measuring % of bark.

The branch samples were in total 170 and had a diameter of 2cm to 9cm. Measurements were carried out in 4 discs (repetitions) of each branch. Regression analysis was used to find any relationships between branch diameter and bark percentage.

For the determination of other properties, the branches were cut into three parts: thick branches (diameter >5cm), thin branches (diameter of 2 - ≤5cm) and twigs (branches with a diameter <2cm including the needles or leaves). Samples of thick and thin branches were debarked in order wood and bark to be tested separately. The samples were air-dried and milled first in a common hammer mill and then in a Willey mill to obtain particles having a size <0,420mm (40 mesh). Ash content (% dry weight), the percentage of volatiles and the fixed carbon, and the elemental analysis (C, H, N) were determined accordance with CEN/TS 14775 (2005), CEN/TS 15148 (2005) and CEN/TS 15104 (2005) standards, respectively. The higher heating value (MJ/Kg dry) were determined in accordance with CEN/TS 14918 (2005) standard. Three samples of each material were used for the measurements of each property.

RESULTS AND DISCUSION

Percentage (%) bark

Table 1 shows the average bark percentages of all branches measured as well as the average percentage in each of the two class sizes of branches of oak, poplar and pine. Bark % was much higher in oak than in pine and poplar and increased with decreasing branch diameter. The differences in the percentage of bark between species was more evident when it was calculated at the same branch diameter (d = 5cm) for the three species. Table 2 and Fig. 2 give the regression analysis models of the effect of branch diameter on bark percentage.

Table 1

Bark percentage (%) of branches

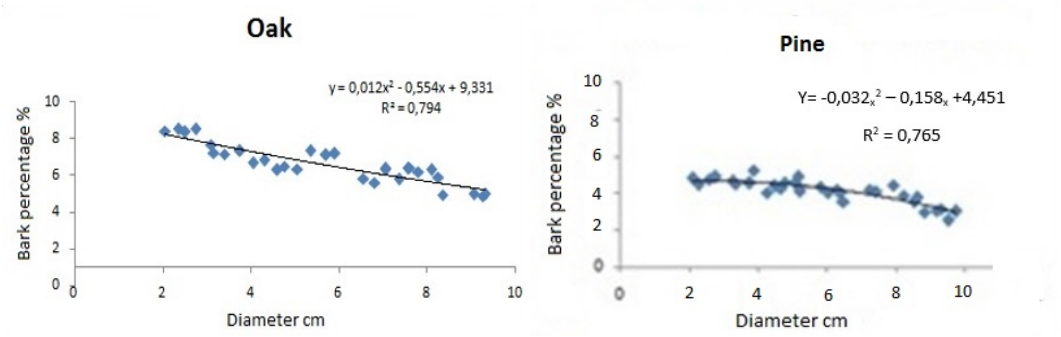
Species	Branches						
	d=2-9cm		d=2-5cm		d=>5cm		d=5cm
	đ* a/a**	% bark	đ a/a	% bark	đ a/a	% bark	% bark++
Oak	5,86* 32**	6,89 (1,32)+	4,02 16	7,85 (1,01)	7,97 16	5,85 (0,52)	7,30
Poplar	5,93 35	3,98 (0,79)	3,92 19	4,46 (0,54)	8,02 16	3,04 (0,39)	4,19
Pine	5,91 32	4,09 (0,71)	4,05 17	4,52 (0,83)	7,97 15	3,61 (0,55)	4,49

* Average diameter, **No of samples, +standard deviation, ++ calculated

Table 2

Correlation models with the best fit between branch diameter and percentage of bark

Species	Mondel	R^2
Oak	$y = -0,055x^2 + 0,189x + 8,065$	0,794
Poplar	$y = -0,006x^2 - 0,233x + 5,618$	0,773
Pine	$y = -0,032x^2 + 0,158x + 4,451$	0,765



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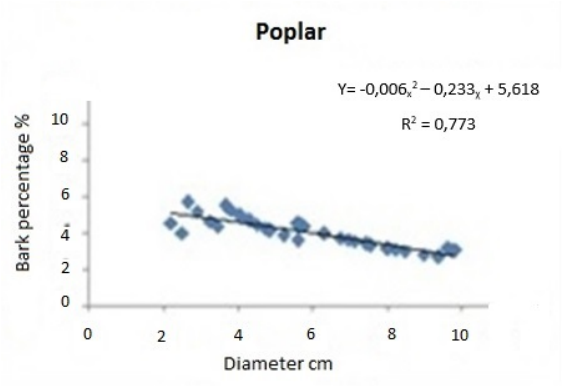

Fig. 2.
Correlation between bark percentage and branch diameter in oak, poplar and pine. Proximate analysis.

Table 3 gives ash, volatile mater (VC) and fixed carbon (FC) content of all branches, twigs and of wood and bark of thick (d=>5cm) and thin (d=2-5cm) branches of oak, poplar and pine.

Ash content

Ash content varied between the various parts of branches and between the species from 0, 38% in the wood of thick branches of pine to 8,01% in the bark of thin branches of oak. It was multiple higher in bark than in wood of branches and higher in thin than in thick branches. It is obvious that ash content increases with decreasing branch diameter (see also Table 1 and Fig. 2). Twigs in oak and pine had lower ash content than bark but higher than the all branches. The ash content of the all thick and thin branches was in oak 2,53% and 3,81%, in poplar 1,12% and 1,58% and in pine 0,79% and 1,16%, respectively. Werkelin et al. (2007) found big differences in ash content between wood and bark in branches of spruce, pine, poplar and birch. Dzurenda (2013) found 0,37% and 5,73% ash in wood and bark of poplar branches, respectively. Zeng et al. (2014) also found significant differences in ash content between different parts of Masson pine trees. Dibdiakova et al. (2015) measured ash content of different parts of scots pine tree and found that branch base has ash content of 0.48% and the branch twigs about 1.56%.The EN ISO 17225-2 (2014) standard for domestic pellets requires ash content less than 0,7% for A1 class, less than 1,2% for A2 class and less than 2% for B class pellets. Oak branches and pine twigs do not meet the above standard requirements and they should not be used alone for pellet production.

Table 3

Proximate analysis of logging residues

Property	Thick branch			Thin branch			Twigs	p-value1
	All*	Wood	Bark	All*	Wood	Bark		
Oak								
Ash (%)	2,53 ±0,045	1,2 ±0,035	6,96 ±0,065	3,81 ±0,645	1,33 ±0,425	8,01 ±0,495	4,14 ±0,690	+
VC (%)	79,96d ±0,187	80,32d ± 0,520	75,72a ± 0,177	78,84 c ± 0,386	80,83d ± 0,435	75,26a ± 0,859	76,95b ± 0,501	+
F C (%)	17,51 b ±0,310	18,58 d ± 0,433	17,33 a ± 0,463	17,35 b ± 0,455	17,85 b ± 0,196	16,72 a ± 0,337	18,20 c ± 0,503	+
Poplar								
Ash (%)	1,12 ±0,004	0,88 ±0,022	3,57 ±0,462	1,58 ±0,042	0,89 ±0,014	4,84 ±0,575	-	+
VC (%)	81,78 c ±0,570	81,37 c ± 0,342	79,52 b ± 0,404	80,89 c ± 0,412	81,88 d ± 0,345	78,64 a ± 0,5046	-	+
F C (%)	17,10 b ±0,391	17,75 c ± 0,255	16,95 b ± 0,279	17,43 b ± 0,156	17,43 b ± 0,243	16,52 a ± 0,326	-	+
Pine								
Ash (%)	%0,79 ±0,01	0.38 ±0,03	2,68 ±0,04	1,16 ±0,04	0,42 ±0,02	3,06 ±0,020	2,27 ±0,06	+
VC (%)	77,42 c ±0,332	81,24 e ± 0,120	73,23 a ±0,455	77,92 d ± 0,630	80,2 e ± 0,105	72,80 b ± 0,390	76,79 c ± 0,191	+
F C (%)	21,78 d ±0,280	18,38a ± 0,399	24,09 e ± 0,275	20,92c ± 0,387	19,53b ± 0,236	24,15 e ± 0,391	20,92c ± 0,211	+

*All branch (wood and bark at average diameter from Table 1) 1Oneway NOVA variance test (p=0,05%). In each column, figures followed by different letters (S) indicate significant difference by Duncan's multiple range test (P<0.05).

Volatile and Fixed Carbon content

Volatile matter (VC) in oak ranged between 75,26% in the bark of thick branches and 80,83% in the wood of thin branches, in poplar between 78,64% in the bark of thin branches and 81,88% in wood of thick branches and in pine between 72,80% in the bark of thin branches and 81,24% in the wood of thick branches. VC of wood and bark was higher in poplar in all tree parts. In all species, VC of wood was higher than in bark. Fixed carbon (FC) ranged in oak between 16,72% in the bark of thin branches and 18,58% in wood of thick branches, in poplar between 16,52% in the bark of thin branches and 17,75% in the wood of thick branches and in pine between 18,38% in the wood of thick branches and 24,15% in bark of thin branches. FC in all parts of pine was higher in bark than in wood while in oak and poplar it was higher in wood. In a study (Telmo et al. 2010) of proximate analysis of 13 wood species, VC varied among the species between 74,7% and 87,1% and FC between 12,4% and 22,5%. In the same study VC and FC of oak wood was 81,7% and 18,0%, of pine 85,8% and 14,1% and of poplar 87,1% and 12,4%, respectively.

Ultimate analysis

Table 4 gives the carbon, hydrogen, oxygen and nitrogen content of the all branches, twigs and of wood and bark of thick (d=>5cm) and thin (d=2-5cm) branches of oak, poplar and pine.

Table 4

Ultimate analysis of logging residues

Sample	Thick branches			Thin branches			Twigs	p-value[1]
	All	wood	bark	All	wood	bark		
Oak								
C(%)	46,23^{b} ± 0,519	46,92^{b} ± ,285	45,12^{a} ±0,254	46,90^{b} ± 0,577	46,50^{b} ± 0,345	45,22^{a} ± 0,143	48,85^{c} ± 0, 238	+
H(%)	6,06^{b} ± 0,102	6,35^{c} ± ,051	6,34^{c} ± 0,051	6,09^{b} ± 0,015	6,27^{c} ± 0,090	5,78^{b} ± 0,119	6,22^{b} ± 0,040	+
O(%)	47,71	46,7	48,5	47	47,2	49	45	
N(%)	0,29^{b} ± 0,020	0,21^{a} ± ,010	0,217^{a} ± 0,010	0,312^{b} ± 0,040	0,216^{a} ± 0,020	0,414^{c} ± 0,010	1,173^{d} ± 0,060	+
Poplar								
C(%)	45,015^{d} ± 0,095	44,02^{b} ± ,111	43,67^{a} ± 0,202	45,13^{d} ± 0,230	45,29^{d} ± 0,147	44,82^{c} ± 0,286	-	+
H(%)	6,15^{d} ± 0,121	6,16^{d} ±0,150	5,46^{a} ± 0,089	5,96^{c} ± 0,075	6,11^{d} ± 0,065	5,75^{b} ± 0,081	-	+
O(%)	48,8	49,8	50,9	48,9	48,6	49,4	-	
N(%)	0,105^{a} ± 0,005	0,195^{c} ± ,004	0,215^{d} ± 0,008	0,207^{c} ± 0,007	0,12^{b} ± 0,005	0,403^{e} ± 0,004	-	+
Pine								
C (%)	50,62^{c} ± 0,325	49,97^{b} ±0,117	50,73^{c} ± 0,340	49,94^{b} ± 0,272	49,02^{a} ± 0,125	49,75^{b} ± 0,310	50,00^{b} ± 0,48	+
H (%)	6,29^{b} ± 0,075	6,85^{c} ± ,020	6,10^{a} ± 0,045	6,54^{b} ± 0,144	6,64^{c} ± 0,123	6,36^{b} ± 0,110	6,58^{d} ± 0,04	+
O (%)	43,1	43,2	43,2	43,5	44,3	43,89	43,41	
N (%)	0,13^{b} ± 0,011	0,07^{a} ±0,005	0,595^{d} ± 0,042	0,2^{c} ± 0,020	0,13^{b} ± 0,026	0,41^{d} ± 0,020	0,76^{e} ±0,02	+

*All branch (wood and bark at average diameter from Table 1), [1]Oneway NOVA variance test (p=0,05%). In each column, figures followed by different letters (^{S}) indicate significant difference by Duncan's multiple range test (P<0.05).

Carbon content varied in oak between 45,12% in the bark of thick branches and 48,85% in twigs; in poplar between 43,67% in the bark of thick branches and 45,29% in the wood of thin branches and in pine between 49,02% in the wood of thin branches and 50,62% in bark of thick branches. There were no difference between thick and thin in all branches in oak and poplar, while in pine thick branches had higher carbon content. Branch wood had higher C % than bark in oak and poplar and lower in pine.

Hydrogen content varied in oak between 5,78% in twigs and 6,35% in the wood of thick branches; in poplar between 5,46% in the bark of thick branches and 6,16%, in the wood of thick branches and in pine between 6,10% in the bark of thick branches and 6,85%, in wood of thick branches. There no difference between thick and thin whole branches in oak and pine, while in poplar thick branches had higher hydrogen content. Hydrogen content was higher in Pine than oak and poplar branches and higher in oak than in poplar

branches. Ragland and Aerts (1991) noticed that the C content of softwood species varies between 50 and 53%, and that of hardwood species between 47 and 50% mainly due to the varying lignin and extractives content. They also give 52,25% and 54.9% C in oak and pine bark, respectively. Nurmi (1993) gives for trembling aspen >5mm branch wood 46,84% C and 5,96% H, and for branch bark 48,05% C and 5,77% H. He also gives for scots pine branch wood 53,53% C and 6,03% H and 54,99% C and for branch bark 54,99% C and 6,7% H. Wilen et. al. (1996) give for scots pine logging residues, 51,3% C and 6,1% H.

Oxygen content was determined by subtracting C, H, N and ash content from the whole mass (100%). In oak O% varied from 45% in twigs to 48,5% in the bark of thick branches. In poplar oxygen content varied from 48,6% in the wood of thin branches to 50,9% in the bark of thick branches and in pine it varies from 43,1% in thick branches to 44,3% in the wood of thin branches. Oxygen content was higher in oak and poplar than in pine. Oxygen content was lower than carbon content in all pine biomass components, while in oak and poplar it was higher

Nitrogen content was higher in oak and it varied from 0,216% in wood of thin branches to 1,173% in twigs. In poplar and pine N content varied from 0,105% in thick branches and 0,403% in bark of thin branches to 0,07 in wood of thick branches and 0,76 in twigs, respectively. In all cases, bark had 2-3 times higher nitrogen content than wood. Dzurenda (2013) give 0,36%, 0,65% and 0,46% N content for populous branch wood, branch bark and branch chip. Alakangas (2005) give 0,3% N content for scots pine whole trees and 0,4% for pine logging residues. Oak and pine twigs have higher N content than EN ISO 17225-2 (2014) standard for domestic pellets requires and should not be used alone for pellet production.

Heating value

Table 5 shows the heating value of the various branch components of oak, poplar and pine Heating value is given in two types, as higher heating value (HHV) and as higher heating value of ash free material (HHVf). The later was calculated after subtraction of ash from the weight of the HHV determination biomass samples. The higher heating value (HHV) of oak ranged from 18,72MJ/Kg in bark of thick branches to 19,52MJ/kg in the wood of thin branches. In poplar the higher heating value (HHV) ranged from 18,02MJ/kg in the bark of thick branches to 18,28MJ/kg in the wood of thin branches and in pine ranged from 20,75MJ/kg in wood of thin branches to 21,0MJ/kg in the bark of thick branches. In oak HHV was higher in wood than in bark, but in pine it was higher in bark. The ash free higher heating value (HHVf) ranged in oak from 19,38MJ/kg in wood of thick branches to 20,80MJ/kg in bark of thin branches, in poplar from 18,43MJ/kg in the wood of thick branches to 19,19MJ/kg in the bark of thin branches and in pine from 20,84MJ/kg in wood of thin branches to 21,60MJ/kg in bark of thin branches. HHVf increased proportionally with the removal of ash and was higher in bark than in wood in all species.

Table 5

Heating values (MJ/kg) of logging residues

Property	Thick branch			Thin branch			Twigs	p-value[1]
	All*	Wood	Bark	All*	Wood	Bark		
Oak								
HHV[2]	19.26[d] ±0.050	19.15[c] ±0.110	18.72[a] ±0.090	19.31[b] ±0.060	19.52[d] ±0.085	19.13[a] ±0.090	19.3[b] ±0.122	+
HHVf[3]	19,76	19,38	20,12	20,07	19,78	20,80	20,13	
Poplar								
HHV	18.26[c] ±0.075	18.27[c] ± 0.080	18.02[c] ± 0.010	18.27[b] ± 0.020	18.28[b] ± 0.025	18.26[a] ± 0.035	-	+
HHVf	18,47	18,43	18,69	18,68	18,44	19,19	-	
Pine								
HHV	20.95[c] ±0.020	20.84[d] ± 0.015	21.00[d] ± 0.020	20.80[a] ±0.045	20.75[b] ± 0.025	20.84[a] ± 0.025	20.95[e] ±0.015	+
HHVf	21,20	20,92	21,58	20,94	20,84	21,60	21,44	

**All branch (wood and bark at average diameter from Table 1), [2]HHV= higher heat value, [3]HHVf= higher heating value free ash, [1]Oneway NOVA variance test (p=0,05%). In each column, figures followed by different letters ([S]) indicate significant difference by Duncan's multiple range test (P<0.05).*

On the average, heating value was higher in pine biomass than in oak and poplar and higher in oak than in poplar. Philippou (1982) found for the same tree species in oak 19,65MJ/kg and 18,79MJ/kg, in poplar 19,78MJ/kg and 19,62MJ/kg and in pine 20,35MJ/kg and 21,60MJ/kg for stem wood and stem bark, respectively. Agar (2014) making pellets from pine and logging residues found that the average caloric

content for the whole pine tree was 20,800MJ/kg and for the residues 21,600MJ/kg. Griu and Lunguleasa (2015) found 19,13MJ/kg for poplar stemwood.

CONLUSIONS

This study has shown that oak, poplar and pine residues left in the forest after harvesting differ in some properties that are important for energy use. Bark and ash content increased with decreasing diameter of branches. Ash content was higher in bark than in wood of branches in all species. Ash content of all thick and thin branches was in oak 2,53% and 3,81%, in poplar 1,12% and 1,58% and in pine 0,79% and 1,16%, respectively. Ash content of twigs was in oak 4,14% and in pine 2,27%. Nitrogen content of branches varied from 0,105% to 0,312% and it was higher in oak and in thin branches. N content of twigs was 1,173% in oak and 0,76% in pine. Oak branches and oak and pine twigs had ash and nitrogen content higher than that required by the EN ISO 17225-2 (2014) standard (Howard 1988) for domestic pellets and they should not be used for energy, at least for pellets production. Volatile mater, fixed carbon, carbon and hydrogen content were in the range given by other researchers. Heating value ranged between 18,27MJ/kg to 21,0% and it was higher in pine than in oak and poplar, and higher in twigs and thin branches.

From the above results we could conclude that branches of poplar and pine could be good material for domestic pellet production and other energy usages. Branches of oak and twigs should be left to provide nitrogen and minerals to the forest soil. Utilization of logging residues biomass could create business opportunities and employments in local populations, generate profit from residual material and provide energy self-sufficiency for rural communities.

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