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Energetic properties of green chips made of branches of wood species *Populus x euroamericana* clone *Pannonia* grown on plantations

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Abstract: *Energetic properties of green chips made of branches of wood species Populus x euroamericana clone Pannonia grown on plantations*. This paper presents the results of determining the energy properties of green wood chips *Populus x euroamericana* clone: *Pannonia* such as: the share of bark in chips, elementary chemical composition of the combustible of wood chips, ash content in the dry matter of biofuel and the lower heating value of biofuel in dry state.Green wood chips made from branches of trees grown on plantation: *Populus x euroamericana* clone: *Pannonia* consist of juvenile wood and juvenile bark. The share of juvenile bark in analyzed green wood chips is $X_B = 33.42 \pm 3.76\%$.The combustible of green wood chips does not differ from the chemical composition of the combustible of firewood of *Populus tremuloides* except for the presence of nitrogen - endothermic flammable component. Nitorgen content in the combustible of green wood chips is N^{daf} = 0.46 %, which is 2.5 times higher than the nitrogen content in the combustible of firewood of *Populus tremuloides*. This fact is reflected, from an environmental aspect, in an increase in the production of emissions - fuel nitrogen oxides NOx. The ash content from green wood chips produced from branches of fast growing tree species: *Populus x euroamericana* clone: *Pannonia*, determined by the weighted average ash content from juvenile wood, bark and the share of bark in wood chips is $A^d = 2.17\%$, which is 3-4 times higher than the value of the ash content from wood of deciduous trees. Lower heating value of wood chips in dry state is Qn = 17568 kJ.kg $^{-1}$. This value, compared to calorific value of wood from deciduous trees referred to in EN 14961 Solid biofuels - Fuel specifications and classes, is lower by 6%.

Keywords: biofuel, wood chips, *Populus x euroamericana* clone *Pannonia*, ash, lower heating value, short rotation coppice.

INTRODUCTION

The wood of broadleaves in dry state is, according to the European Norm *EN 14 961 Solid fuels*, a bio-fuel characterized by an average lower heating value $Q^d_n = 18{,}9$ MJ.kg^{-1} and low content of ash $A^d = 0{,}3$ %, which belongs to the renewable sources of energy.

In the last three decades, in order to increase production of wood biomass for energy purposes, numerous plantations of short rotation coppices were established, with a production of wood biomass reaches at minimum 10 t per 1 ha per year. According to the research papers by: *Varga – Godó (2002), Trenčiansky – Lieskovský – Oravec (2007), Jandačka – Malcho – Mikulík (2007), Malaťák – Vaculík (2008), Čížková – Čížek – Bajajová (2010), Varga – Bartko (2010), Liebhart (2010), Otepka – Habán (2011)* the most suitable short rotation coppices grown at plantations for energy purposes in the Central and Eastern Europe are *Robinia psedoacacia L.*, various clones of *Populus*, *Salix alba L.* and various clones of *Salix viminalis*.

Depending on a way of the establishment of an energy plantation, and the growth period of the short rotation coppice, according to *Simanov (1995)* a possible division of the plantations may be proposed as following: plantations with a harvest cycle up to 5 years from planting (mini rotation), plantations with a harvest cycle between 5 and 10 years from planting (midi rotation), and plantations with a harvest cycle between 10 and 20 years from planting (maxi rotation). The objective of production of wood biomass from plantations with a harvest cycle between 10 and 20 years from planting is production of a fibrous material for pulp and paper industry, or of a raw material for production of a chipboard, or a branch wood to consequently produce the green chips for energy purposes.

In this article several results of experimental research are presented which were undertaken with the objective to assess energy properties of the green wood chips produced from *Populus x euroamericana* clone *Pannonia* produced from branches of twenty years old short rotation coppice. The research focused on the following energy properties: share of bark in the wood chips, elementary chemical composition of the combustibles of the wood chips, ash content per unit of dry mass of the biofuel and lower heating value of the biofuel in dry state.

MATERIALS AND METHODS

A samples of juvenile wood and juvenile bark were taken from the green wood chips produced from branches of eighteen years old short rotation coppice *Populus x euroamericana* clone *Pannonia* planted for energy purposes in the Southwestern part of Slovakia, in the area of the municipality Horná Seč.

The share of wood and bark in the green wood chips of the analyzed short rotation coppice was determined by a laboratory method, according to the Slovak Technical Norm, *STN 48 0058:2004*, sorts of wood – chips and sawdust from broadleaves. The Share of bark in the wood chips was assessed according to the formula:

$$X_B = \frac{m_B}{m_{CH}}.100 \qquad [\%] \tag{1}$$

where:

m_B – mass of bark in the sample from the wood chips [g],
m_{CH} – mass of the sample of the wood chips [g].

Elementary analysis of the combustibles of samples of the juvenile wood and the juvenile bark was undertaken in the central forestry laboratory of the *National Forestry Institute* in city Zvolen. The contents of carbon C^{daf} [%], hydrogen H^{daf} [%] and nitrogen N^{daf} [%] in the combustibles of the samples of the juvenile wood and the juvenile bark were assessed in an analysing device NCS-FLASH EA 1112. The oxygen content in the combustibles of the samples was determined by a calculation made, with assumption of zero content of sulphur in the wood biomass and its combustibles $S^{daf} = 0$ (appearance in trace amounts), according to the following formula:

$$O^{daf} = 100 - C^{daf} - H^{daf} - N^{daf}, \quad [\%] \tag{2}$$

where:

C^{daf} – content of carbon in combustibles [%],
H^{daf} – content of hydrogen in combustibles [%],
N^{daf} – content of nitrogen in combustibles [%],

Chemical composition of the combustibles of the green wood chips comprised of combustibles of the juvenile wood and the juvenile bark was determined by a calculation, based on the share of wood and bark in the green wood chips, and measured content of the individual chemical components in the combustibles of wood and bark according to the following formulas:

$$
\begin{aligned}
C_{CH}^{daf} &= \left[\frac{100 - X_B}{100}\right].C_W^{daf} + \frac{X_B}{100}.C_B^{daf} \\
H_{CH}^{daf} &= \left[\frac{100 - X_B}{100}\right].H_W^{daf} + \frac{X_B}{100}.H_B^{daf} \\
N_{CH}^{daf} &= \left[\frac{100 - X_B}{100}\right].N_W^{daf} + \frac{X_B}{100}.N_B^{daf} \\
O_{CH}^{daf} &= \left[\frac{100 - X_B}{100}\right].O_W^{daf} + \frac{X_B}{100}.O_B^{daf}
\end{aligned}
\tag{3}
$$

where: $C_{CH}^{daf}, H_{CH}^{daf}, N_{CH}^{daf}, O_{CH}^{daf}$ – contents of carbon, hydrogen, nitrogen, oxygen in combustibles of wood chips [%],

$C_W^{daf}, H_W^{daf}, N_W^{daf}, O_W^{daf}$ – contents of carbon, hydrogen, nitrogen, oxygen in combustibles of wood [%],

$C_B^{daf}, H_B^{daf}, N_B^{daf}, O_B^{daf}$ – contents of carbon, hydrogen, nitrogen, oxygen in combustibles of bark [%],

X_K – share of bark in wood chips [%].

The ash content from biomass wood of the green wood chips of *Populus x euroamericana* clone *Pannonia* was assessed by a technical calculation, based on the share of bark in the green wood chips and the ash content from the juvenile wood and juvenile bark. Quantification of the ash content from the juvenile wood and juvenile bark was undertaken by laboratory method, according to the Slovak Technical Norm *STN ISO 1171 Solid fuels - assessment of ash*. The ash content from the sample of the juvenile wood and from sample of the juvenile bark is expressed by the following formula:

$$
\begin{aligned}
A_{\mathrm{W}}^{\mathrm{d}} &= \frac{m_{\mathrm{A\text{-}W}}^{\mathrm{d}}}{m_{\mathrm{W}}^{\mathrm{d}}}.100 \quad [\%] \\
A_{\mathrm{B}}^{\mathrm{d}} &= \frac{m_{\mathrm{A\text{-}B}}^{\mathrm{d}}}{m_{\mathrm{B}}^{\mathrm{d}}}.100 \quad [\%]
\end{aligned}
\tag{4}
$$

where:

m_{A-W}^{d} – mass of ash from a dry sample of a juvenile wood [g],

m_W^d – mass of a dry sample of a juvenile wood [g],

m_{A-B}^{d} – mass of ash from a dry sample of a juvenile bark [g],

m_B^d – mass of a dry sample of a juvenile bark [g].

Percentage of ash – inorganic residue after burn out of green wood chips is expressed by the formula:

$$
A_{CH}^{d} = \left[\frac{100 - X_B}{100}\right].A_W^d + \frac{X_B}{100}.A_B^d \qquad [\%] \tag{5}
$$

where:

$A_{\mathrm{W}}^{\mathrm{d}}$ – content of ash in a dry sample of a juvenile wood [%],

$A_{\mathrm{B}}^{\mathrm{d}}$ – content of ash on a dry sample of a juvenile bark [%],

X_B – share of bark in a sample of green wood chips [%].

Lower heating value of the green chips - analyzed clone of the wood biomass *Populus x euroamericana* is assessed by a technical calculation, according to formula by M. I. Mendelejev:

$$Q_n^d = \left[339.C_{CH}^{daf} + 1029{,}8.H_{CH}^{daf} - 108{,}8.O_{CH}^{daf}\right]\left[\frac{100 - A_{CH}^d}{100}\right] \quad \left[kJ.kg^{-1}\right] \qquad (6)$$

where:

C_{CH}^{daf} – content of carbon in combustibles of wood chips [%],

H_{CH}^{daf} – content of hydrogen in combustibles of wood chips [%],

O_{CH}^{daf} – content of oxygen in combustibles of wood chips [%],

A_{CH}^{d} – content of ash in a dry mass of the wood chips [%].

RESULTS

The share of bark in the samples of green wood chips of the analyzed clone of poplar is shown by the following table 1.

Tab. 1 Shares of bark in the wood chips of *Populus x euroamericana* clone *Pannonia*

Sample	sample 1	sample 2	sample 3	Average
Share of bark in wood chips [%	36.63	31.28	32.34	33.42 ± 3.76

The elementary chemical composition of the combustibles of the samples of juvenile wood and juvenile bark of *Populus x euroamericana* clone *Pannonia* and the ash content is shown in table 2.

Tab. 2 Elementary chemical composition of a juvenile wood and juvenile bark samples of *Populus x euroamericana* clone *Pannonia*

Populus x euroamericana* clone *Pannonia		**C^{daf} [%]**	**H^{daf} [%]**	**O^{daf} [%]**	**N^{daf} [%]**	**A^{d} [%]**
Wood	sample 1	49,69	5,99	42,94	0,38	0,31
	sample 2	51,35	6,07	43,08	0,33	0,44
	sample 3	50,40	5,52	43,85	0,37	0,37
	average	50,49	5,86	43,29	0,36	0,37
Bark	sample 1	48,79	5,58	44,91	0,62	6,34
	sample 2	47,36	5,96	46,43	0,66	5,17
	sample 3	46,98	5,41	46,63	0,67	5,68
	average	47,71	5,65	45,99	0.65	5,73

Content of the elements of combustibles and ash in the green wood chips of the analyzed clone of *Populus,* which was grown at plantations for energy purposes, assessed by an arithmetic mean, based on the shares of juvenile wood and juvenile bark in the wood chips, and the elementary chemical composition of the combustibles of samples of the juvenile wood and the juvenile bark, is shown in the table 3 below.

Tab.3 Shares of elementary combustible particles and ash in chips species *Populus x euroamericana* clone *Pannonia*

Wood species	Share of wood and bark in chips [%]		Chemical composition of the combustibles [%]				Ash [%]
			C^{daf}	H^{daf}	O^{daf}	N^{daf}	A^{d}
Populus x euroamericana clone *Pannonia*	Wood	66,58	50,49	5,86	43,29	0,36	0,37
	Bark	33,42	47,71	5,65	45,99	0.65	5,73
	Wood chips	**100**	**49,56**	**5,79**	**44,19**	**0,46**	**2,16**

The lower heating value of a dry mass of the biofuel - green wood chips, produced from the clone of *Populus x euroamericana* clone *Pannonia,* assessed by a formula by M. I. Mendelejev, based on the chemical composition of the combustibles of the wood chips and the ash content from a dry mass of the wood chips, is shown in the table 4 below.

Tab. 4 Lower heating value of the wood chips in dry state *of Populus x euroamericana* clone *Pannonia.*

Short rotation coppice	Lower heating value [$kJ.kg^{-1}$]
Populus x euroamericana clone *Pannonia*	17 568

DISCUSSION

The results of the experimental research have shown that the average share of bark in the green wood chips produced from a branch material of the short rotation coppice *Populus x euroamericana* clone *Pannonia* is X_K = 33,42 ± 3,76%. This value is 2,2 –3,7 times higher than the share of bark in the wood biomass of aged trees of *Populus tremuloides* - as assessed by the work of *Hnětkovský et al. (1983).*

The share of bark in the analyzed green wood chips is also 60 % higher than the share of bark in the wood chips of short rotation coppices grown for energy purposes of the following clones of *Populus*: *Max 5, Oxford, AF 2, Monviso*, with the period of harvest 4-6 years from planting in the geographical conditions of the Central Europe, as assessed by work of *Dzurenda-Zoliak (2011)*.

When comparing the chemical composition of the combustibles of the green wood chips from the juvenile wood and juvenile bark of *Populus x euroamericana* clone *Pannonia* with chemical composition of the combustibles of fuel wood from *Populus tremuloides* we may come to the conclusion that the chemical compositions are about the same, except from the contain of nitrogen – endothermic component of the combustibles. The nitrogen content in the combustibles of the green wood chips, N = 0,46%, is some 2,5 times higher than the nitrogen content in the combustibles of the fuel wood of *Populus tremuloides*. This higher nitrogen content is caused by presence of albumin- and amino acids in cambium cells, and also by chlorophyll in the surface plexus of the juvenile bark, as assessed by works of *Dzurenda-Zoliak (2011a).* The higher nitrogen content is, from the environmental aspect, reflected in the increased production of emissions, in the form of fuel nitrogen oxides NOx.

The higher ash content in the bark of the analyzed clone of *Populus x euroamericana,* than the nitrogen content in the wood of the same clone, shown in the table 2, is in line with the previously undertaken research on this topic. As a novelty, an assessment of the nitrogen content from a dry mass of the green wood chips of *Populus x euroamericana* clone *Pannonia* with the period of harvest between 10 and 20 years from the plantation, may be considered. The nitrogen content was assessed as A^{d} = 2,16%. This value is 3 to 4 times higher than the

nitrogen content from the wood of broadleaved plants, as published by *Simanov (1995), Domanski et all. (2007), Dobrowolska et all. (2010).*

The lower heating value of the green wood chips in dry state of the analyzed clone of *Populus* was assessed as Qn = 17 568 kJ.kg^{-1}. This value, if compared with the lower heating value of broadleaves stated in the European Norm, *EN 14 961* is 6% lower. This difference is possibly caused by the increased share of an inorganic ash material in the green wood chips produced from a branch material of *Populus x euroamericana* clone *Pannonia* and by the increased content of nitrogen – endothermic component of the combustibles of biofuel.

CONCLUSION

Based on the experimental research above the following conclusions can be made: The green wood chips from a branch material of the short rotation coppice *Populus x euroamericana* clone *Pannonia* grown for energy purposes are consisting of a juvenile wood and a juvenile bark with the share of the juvenile bark in the value range of X_K = 33,42 ± 3,76%.

The combustible of the green wood chips of analysed wood species does not differ from the chemical composition of fuel wood from *Populus tremuloides* except for the nitrogen content – endothermic component of the combustibles. The nitrogen content in the combustibles of the green wood chips, N = 0,49 %, is about 2,7 times higher than the nitrogen content in the combustibles of the fuel wood of *Populus tremuloides*. This fact has negative impact on lower heating value, as well as on the production of emissions in the form of nitrogen oxides.

The ash content from green wood chips of the analyzed clone was assessed as A^d = 2,16%, which designates the biofuel into the group of lower ash biofuels, however this value is some 3 to 5 times higher than the ash content from the wood of broadleaved plants.

The lower heating values of the green wood chips from a branch material of the short rotation coppice *Populus x euroamericana* clone *Pannonia* in dry state was assessed as Qn = 17 568 kJ·kg^{-1}.

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Streszczenie: *Własności energetyczne zrębek z gałęzi drewna Populus x euroamericana clone Pannonia z zasadzeń plantacyjnych*. Praca prezentuje własności energetyczne zielonych zrębek *Populus x euroamericana* clone: *Pannonia* biorąc pod uwagę: zawartość kory, podstawowy skład chemiczny substancji palnych, zawartość popiołu oraz wartość opałową w stanie suchym. Zrębki wytworzono z gałęzi drzew plantacyjnych *Populus x euroamericana* clone: *Pannonia,* składały się z młodego drewna oraz kory. Zawartość kory w badanych zrębkach wynosiła X_B = 33.42 ± 3.76%. Skład substancji palnych w badanych zrębkach nie różnił się od składu *Populus tremuloides* za wyjątkiem obecności azotu – endotermicznej substancji palnej. Zawartość azotu w zrębkach opałowych wynosiła N^{daf} = 0.46 %, czyli 2.5 raza więcej niż w drewnie opałowym *Populus tremuloides*. Ten fakt powoduje zwiększoną emisję tlenków azotu. Zawartość popiołu badanego materiału wyniosła A^d = 2.17%, czyli 3-4 razy więcej niż zawartość popiołu w zrębkach z drewna liściastego. Wartość opałowa wyniosła Qn = 17568 kJ.kg $^{-1}$, co porównane z wartościami kalorymetrycznymi drzew liściastych normy EN 14961 Solid biofuels - Fuel specifications and classes, jest niższa o około 6%.

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