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ENERGY CHARACTERISTICS OF BIOFUELS – WOOD CHIPS FROM DENDROMASS OF PLANTATION GROWN BLACK LOCUST

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ABSTRACT

In the present paper, energetic properties of wood chips of the species *Robinia pseudoacacia* (clones *Ambigua*, *Debrecenyi 2*, *Göri*, *Matyasi*, *Nyirsegi*, *Rozaszin*, *Zalyi*) ere determined, relative humidity of chips during a harvest, bulk density, namely the share of bark in chips, chemical composition of combustibles of chips, ash content in dry mass of biofuel, and lower heating value. Green wood chips made of dendromass from plantations consist of juvenile wood and juvenile bark. The share of juvenile bark in green wood chips of the analyzed clones of *Robinia pseudoacacia* is $X_B = 22.97 \pm 1.95$ %.

The nitrogen content in green wood chips made of *Robinia pseudoacacia* trees grown on plantation is 8 times higher than the nitrogen content in the combustibles of fuelwood of *broad-leaved tree species*, which has negative impact on the production of emissions – concentration of nitrogen oxides NOx in combustion products. The share of inorganic substances determined by the form of ash content $A_d = 1.73$ % puts the analyzed biofuel into the category of low-ash fuels. The lower heating value of green wood chips of the individual *Robinia pseudoacacia* clones analyzed in dry state is Qn = 18.0 MJ.kg^{-1}.

Key words: bio-fuel, energy chips, *Robinia pseudoacacia*, humidity, bulk density, share of bark combustibles, ash, lower heating value.

INTRODUCTION

The wood of broad-leaved trees in dry state is, according to the European standard EN 14961 – 1:(2010) on solid biofuels, characterized by an average lower heating value (Qd n = 18.9 MJ.kg^{-1}), high share of volatile combustibles, and low ash content (Ad = 0.3 %).

In the last three decades, significant effort has been exerted in Central Europe to increase the production of wood biomass for energy purposes by establishing numerous plantations of short rotation coppices with the production of wood biomass reaching annually at least 10 t in dry state per 1 ha. According to *(Varga–Godó 2002; Trenčiansky–Lieskovský–Oravec 2007; Čižkova–Čižek–Bajajová 2010; Liebhart 2010; Picchio, et al. 2012)* the most suitable short rotation coppices grown for energy purposes on Central European plantations are *Robinia pseudoacacia*, various clones of *Populus*, *Salix alba*, and various *Salix viminalis* clones.

According to the method of the plantations establishment and the growing period of trees, the plantations of fast-growing trees are divided into plantations with harvest time under 5 years (mini rotation), 5–10 years (midi rotation), and 10–20 years (maxi rotation) *(Simanov 1995)*. The goal of the dendromass production on plantations with the 10–20-year harvest time is the production of fibre for cellulose, paper industry and plywood, feedstock for chipboards, and branches for chips for the energy sector.

Green wood chips made of dendromass from trees grown on plantations are a two-component biofuel consisting of juvenile wood and juvenile bark. The objective of the study was to determine the energetic properties of green wood chips made of *Robinia pseudoacacia*, clones *Ambigua*, *Debrecenyi 2*, *Göri*, *Matyasi*, *Nyirsegi*, *Rozaszin*, *Zalyi*. The following properties were investigated: relative chips humidity, bulk density, share of bark in wood chips, elementary chemical composition of the combustibles of wood chips, ash content in dry mass of the biofuel, lower heating value of the biofuel.

EXPERIMENTAL PART

Trees grown for green wood chips used to determine the energetic properties of individual clones: *Ambigua*, *Debrecenyi 2*, *Göri*, *Matyasi*, *Nyirsegi*, *Rozaszin*, *Zalyi* of wood species *Robinia pseudoacacia* were obtained from 12 year-old coppices grown on plantations by NFC Zvolen – research station Fiľakovské Kľačany located in Cerová vrchovina (fig. 1). Dendromass samples of individual analyzed clones were taken during autumn and winter – during dormancy. Chips from plants – dendromass of plantation coppices of fast grown wood were made at Finnish mobile mower type: JUNKARI HJ 10.

Figure 1: The locations of black locust plantations which from the sample of energetic chip were obtained.

Relative humidity of energy chips during the harvest was set according to EN 14774 – 2 Solid bio fuel. – Determination of humidity capacity. Values of relative humidity of individual samples were calculated using following formula:

$$W^r = \frac{m_w - m_0}{m_w}.100 \qquad [\%] \qquad (1)$$

where: m_w – sample weight before exsiccation [g].

m_0 – sample weight after exsiccation to a constant weight [g].

Bulk density of energy chips of *Robinia pseudoacacia* with humidity during collection time was set laboratory at the Technical University in Zvolen, Department of wood processing, in terms of EN 15103:2010. The calculation of the bulk density with volume compression of the sample which is in a measure bin after multiple shaking of energy chips is described by a formula:

$$\rho_{prms-w} = \frac{m_2 - m_1}{V} \quad [kg.m^{-3}] \qquad (2)$$

where: m_2 – weihgt of a meassure bin filled with joggled bio fuel [kg],

m_1 – weight of an empty meassure bin [kg],

V – volume of a meassure bin [m^3].

The share of bark in green wood chips of individual *Robinia pseudoacacia* clones was determined in a laboratory, according to the Slovak technical standard STN 48 0058:2004 Assortments of wood – Chips and sawdust of hardwood. The share of bark in the sample was calculated using the formula:

$$X_B = \frac{m_B}{m_{CH}}.100 \qquad [\%] \qquad (3)$$

where: m_B – weight of bark in the chips sample [g],

m_{CH} – weight of the chips sample [g].

Elemental analysis of combustibles of individual components of two-component biofuel: carbon C^{daf} [%], hydrogen H^{daf} [%] and nitrogen N^{daf} [%] in the dry mater of juvenile wood and juvenile bark of analysed clones was determined in the analyser NCS-FLASH EA 112. The oxygen content in the combustible of the samples was determined with the assumption of zero sulphur content (S^{daf} = 0 (appearance in trace amounts)) in the dendromass and its combustibles, according to the following formula:

$$O^{daf} = 100 - C^{daf} - H^{daf} - N^{daf} \ [\%] \qquad (4)$$

where: C^{daf} = carbon content in the combustible of the sample (%)

H^{daf} = hydrogen content in the combustible of the sample (%)

N^{daf} = nitrogen content in the combustible of the sample (%)

Chemical composition of the combustible – green wood chips consisting of juvenile wood and juvenile bark was determined by a calculation based on the share of wood and bark in chips and the measured content of the individual chemical elements of the combustibles in wood and bark according to the following formulae:

$$\begin{aligned} C_{CH}^{daf} &= \left(\frac{100 - X_B}{100}\right).C_W^{daf} + \frac{X_B}{100}.C_B^{daf} \\ H_{CH}^{daf} &= \left(\frac{100 - X_B}{100}\right).H_W^{daf} + \frac{X_B}{100}.H_B^{daf} \\ N_{CH}^{daf} &= \left(\frac{100 - X_B}{100}\right).N_W^{daf} + \frac{X_B}{100}.N_B^{daf} \\ O_{CH}^{daf} &= \left(\frac{100 - X_B}{100}\right).O_W^{daf} + \frac{X_B}{100}.O_B^{daf} \end{aligned} \qquad (5)$$

where: $C_{CH}^{daf}, H_{CH}^{daf}, N_{CH}^{daf}, O_{CH}^{daf}$ = carbon, hydrogen, nitrogen and oxygen content in the combustible of chips (%)

$C_W^{daf}, H_W^{daf}, N_W^{daf}, O_W^{daf}$ = carbon, hydrogen, nitrogen and oxygen content in the combustible of juvenile wood (%)
$C_B^{daf}, H_B^{daf}, N_B^{daf}, O_B^{daf}$ = carbon, hydrogen, nitrogen and oxygen content in the combustible of juvenile bark (%)

X_B = share of bark in chips (%)

Quantification of ash content from juvenile wood and juvenile bark was carried out in a laboratory according to ISO 1171:2010 Solid mineral fuels – Determination of ash. The ash content from the dry mass of green wood chips is determined by a calculation based on the shares of bark and wood in dendromass and the average share of ash in analyzed samples of juvenile wood and juvenile bark of green wood chips according to the formula:

$$A_{CH}^{d} = \left[\frac{100 - X_B}{100}\right].A_W^d + \frac{X_B}{100}.A_B^d \qquad [\%] \qquad (6)$$

where: $A^d{}_W$ = ash content from dry mass of juvenile wood samples (%)

$A^d{}_B$ = ash content from dry mass of juvenile bark samples (%)

X_B = share of bark in chips (%)

Lower heating value of juvenile wood, juvenile bark, and green wood chips from the dendromass of analyzed clones of *Robinia pseudoacacia* grown on plantations is determined on the basis of chemical composition of the combustibles and the ash content in dry mass of the biofuel according to the formula by M.I. Mendelejev *(Prereligyn 1965; Golovkov–Koperin–Najdenov 1987; Dzurenda – Jandačka 2010):*

$$Q_n^d = \left[339.C_{CH}^{daf} + 1029{,}8.H_{CH}^{daf} - 109.O_{CH}^{daf}\right].\left[\frac{100 - A_{CH}^d}{100}\right] \quad \left[\mathrm{kJ.kg^{-1}}\right] \tag{7}$$

where: C_{CH}^{daf} = carbon content in the combustible of biofuel (%)

H_{CH}^{daf} *f* = hydrogen content in the combustible of biofuel (%)

O_{CH}^{daf} = oxygen content in the combustible of biofuel (%)

A_{CH}^{d} = ash content in biofuel (%)

RESULTS AND DISCUSSION

The analyses results of relative samples humidity of analyzed acacia clones during the harvest time – during dormancy, is shown in the Table 1.

Table 1: Relative chips humidity of analyzed clones Robinia pseudoacacia.

Plant clones Robinia pseudoacacia	Number of analyzes	Relative humidity [%]
Ambigua	15	34.9 ± 1.8
Debrecenyi 2	15	37.3 ± 1.6
Göri	13	36.0 ± 1.7
Matyasi	16	38.3 ± 1.8
Nyirsegi	16	38.1 ± 1.7
Rozaszin	15	38.2 ± 1.6
Zalyi	14	36.7 ± 1.8

The values of relative humidity are presented in the form of mean and standard deviation.

The values of bulk density of clones acacia chips with humidity during harvest time are set according to EN 15103:2010 and are presented in Table 2.

Table 2: Bulk density of wood chips of analyzed clones Robinia pseudoacacia during harvest time (W^r = 34,9 ÷ 38,3 %).

Plant clones Robinia pseudoacacia	Number of analyzes	Chips bulk density [kg.m^{-3}]
Ambigua	5	490 ± 37
Debrecenyi 2	5	468 ± 34
Göri	5	505 ± 43
Matyasi	5	496 ± 39
Nyirsegi	5	500 ± 41
Rozaszin	5	485 ± 36
Zalyi	5	492 ± 39

The share of bark in analyzed samples of green wood chips of the individual species is shown in Fig. 2. The average value of the share of bark in green wood chips of analyzed clones of *Robinia pseudoacacia* grown on plantations is X_B = 22.97 ± 1.95%.

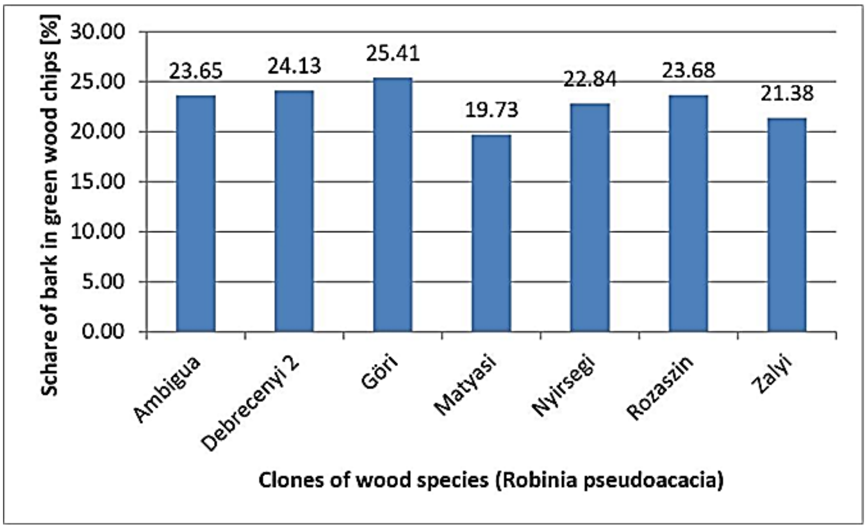

Figure 2: Share of bark in green wood chips of analyzed clones of *Robinia pseudoacacia.*

The shares of juvenile wood and juvenile bark, chemical composition of the combustible, and the ash content of individual components of green wood chips of *Robinia pseudoacacia* analyzed clones are shown in Table 3.

Table 3: Chemical composition of the combustible and the ash content of juvenile wood and juvenile bark of analyzed clones of *Robinia pseudoacacia.*

juvenile wood - a component of green wood chips made of Robinia pseudoacacia grown on plantations													
clone	samples	$X_W \pm U_W$		$C^{daf} \pm U_C$ [%]		$H^{daf} \pm U_H$ [%]		$O^{daf} \pm U_O$ [%]		$N^{daf} \pm U_N$ [%]		$A^d \pm U_A$ [%]	
Ambigua	15	76.35	± 1.78	50.27	± 0.96	5.86	± 0.25	43.32	± 0.89	0.55	± 0.02	0.46	± 0.02
Debrecenyi 2	15	75.87	± 2.23	50.45	± 0.83	6.21	± 0.24	42.82	± 0.87	0.52	± 0.02	0.55	± 0.03
Göri	13	74.59	± 1.98	49.75	± 0.93	6.06	± 0.25	43.71	± 0.88	0.48	± 0.02	0.53	± 0.03
Matyasi	16	80.27	± 1.64	50.48	± 0.99	5.92	± 0.25	42.96	± 0.91	0.64	± 0.02	0.69	± 0.03
Nyirsegi	16	77.16	± 2.39	50.13	± 0.91	5.88	± 0.24	43.35	± 0.89	0.64	± 0.02	0.51	± 0.03
Rozaszin	15	76.32	± 2.41	49.65	± 0.96	5.82	± 0.23	43.92	± 0.92	0.61	± 0.03	0.52	± 0.03
Zalyi	14	78.62	± 2.18	50.51	± 0.97	5.87	± 0.23	43.01	± 0.93	0.61	± 0.02	0.54	± 0.03
average	**104**	**77.03**	**± 1.23**	**50.18**	**± 0.96**	**5.95**	**± 0.25**	**43.30**	**± 0.88**	**0.58**	**± 0.02**	**0.54**	**± 0.03**
juvenile bark - a component of green wood chips made of Robinia pseudoacacia grown on plantations													
clone	samples	$X_B \pm U_B$		$C^{daf} \pm U_C$ [%]		$H^{daf} \pm U_H$ [%]		$O^{daf} \pm U_O$ [%]		$N^{daf} \pm U_N$ [%]		$A^d \pm U_A$ [%]	
Ambigua	15	23.65	± 1.73	50.08	± 0.96	6.08	± 0.23	40.44	± 0.85	3.40	± 0.08	5.49	± 0.23
Debreceny2	15	24.13	± 1.19	49.16	± 0.97	5.86	± 0.22	41.47	± 0.83	3.51	± 0.08	4.94	± 0.17
Göri	13	25.41	± 1.82	49.39	± 0.96	5.84	± *0.24*	42.71	± 0.85	2.06	± 0.08	5.08	± 0.18
Matyasi	16	19.73	± 1.77	48.83	± 0.96	5.87	± 0.24	41.29	± 0.84	4.01	± 0.07	6.21	± 0.21
Nyirsegi	16	22.84	± 2.42	48.15	± 0.96	5.71	± 0.24	42.47	± 0.83	3.67	± 0.08	6.05	± 0.19
Rozaszin	15	23.68	± 2,38	49.5	± 0.97	5.92	± 0.24	41.86	± 0.84	3.72	± 0.09	5.36	± 0.16
Zalyi	14	21.38	± 2,18	49.29	± 0.96	5.98	± 0.22	40.45	± 0.84	4.28	± 0.07	5.73	± 0.19
average	**104**	**22.97**	± 1.95	**49.20**	± 0.96	**5.89**	± 0.23	**41.53**	± 0.84	**3.52**	± 0.08	**5.55**	± 0.19

The applied Multivariate Analysis of Variance (MANOVA) shows a significant difference in the nitrogen contents and ash content between the juvenile wood and juvenile bark in green wood chips ($P < 0.05$ for all the variables).

Average chemical composition of the combustible, ash content, and lower heating value of green wood chips and their components from dendromass of analyzed clones of *Robinia pseudoacacia* grown on plantations are shown in Table 4.

Table 4: Energetic properties of green wood chips and their components from dendromass of *Robinia pseudoacacia* grown on plantations

Green wood chips made of Robinia pseudoacacia grown on plantations														
component (i)	**samples**	**Xi**		**C^{daf} [%]**		**H^{daf} [%]**		**O^{daf} [%]**		**N^{daf} [%]**		**A^d [%]**		**Q_n [kJ/kg]**
wood	104	77.03		50.18		5.95		43.30		0.58		0.54		18319.1
bark	104	22.97		49.20		5.89		41.53		3.52		5.55		17170.7
chips	**208**	**100.00**		**49.95**		**5.94**		**42.16**		**1.26**		**1.73**		**18055.3**

Laboratory measurements of relative humidity of energy chips from 12 year old plantation-grown woods *Robinia pseudoacacia* show that relative humidity of a certain bio fuel during collection is in a range: W^r = 34.9 ÷ 38.3 %. Presented values are adequate to dendromass coppice and existing season. From energy point of view, it is important to allege that water necessary for a tree life in a dendromass is ballast in a bio fuel as it reduces its heat values and increases the transport costs of energy chips from plantations to a consumer.

Bulk density of energy chips of *Robinia pseudoacacia* analyzed clones with humidity during collection W^r = 34.9 ÷ 38.3 % produced by mower JUNKKARI HJ 10 was laboratory set for clones as follows ρ_{prms-w} = 468 ÷ 505 $kg.m^{-3}$. Presented weight data l of cubical m^3 of energy chips are important for planners in the design of warehouse for bio fuel storage, as well as for carriers of biofuels from plantations to stock. *(Oswald et al. 1992, Jandačka et al. 2007, Malaťák–Vaculík 2008, Dzurenda– Jandačka 2010, Marinov-Stoilov-Gochev 2013).*

The experiments dealing with the share of bark in green wood chips show that the average share of bark in chips of the individual analyzed clones of willows grown on plantations is X_B = 22,97 ± 1,95 %. The shares of bark in green wood chips of all clones were below the limit value $X_K \leq 30\%$ given by the Slovak technical standard STN 48 0058 : 2004. The values of share of bark in biofuel is higher, than the share of bark in dendromass of hardwoods. This statement is in agreement with the knowledge of dependence of share of bark on the diameter of trees *(Požgaj et al., 1997)* , as well as with the knowledge of share of bark in dendromass according to the age of trees *(Golovkov et al. 1987, Varga–Bartko 2010, Picchio, et al. 2012).*

Share of bark which is presented on the chip wood, influences not only the weight of chips in dry or humid condition, but as well as the bulk density and energy characteristics such as combustion heat, calorific value, and ash content.

From the comparison of chemical composition of green wood chips of *Robinia pseudoacacia* consisting of juvenile wood and juvenile bark with the chemical composition of fuel wood broad-leaved wood species, it follows that the combustibles of chips of willows grown on plantations differ due to noticeably higher nitrogen content – endothermic component of the biofuel combustibles. The nitrogen content in combustibles of chips of willow clones is 8 times higher than the nitrogen content in combustibles of fuel wood broad-leaved wood species. This higher nitrogen content is caused by the presence of proteins and amino acids in cambial cells and chlorophyll in surface tissues of juvenile bark *(Dzurenda–Zoliak 2011).*

A higher ash content in bark of the analyzed clones of *Robinia pseudoacacia* than in the wood of this species supports the known facts (Table 3 and Table 4). As a new fact can be considered the determination of the ash content in dry mass of green wood chips, the value for the analyzed clones of *Robinia pseudoacacia* being Ad = 1.73 %. This value is 6 times higher than the value of the ash content from wood of broad-leaved trees *(Perelygin, 1965, Blažej, 1975; Golovkov et al, 1987; Simanov 1995, Dzurenda–Jandačka, 2010)*. Despite this fact, green wood chips from willows grown on plantations belong to the group of low-ash fuels.

The lower heating value of green wood chips of analyzed clones of *Robinia pseudoacacia* in dry state, determined by formula (7), is Qn = 18 055.3 $kJ.kg^{-1}$. This value, if compared with the lower heating value of broad-leaved trees stated in EN 14961-1:2010, is by 4.3% lower. This difference is caused by an increased content of inorganic compounds (ash) in chips made of dendromass of fast growing trees grown on plantations, as well as by the increased nitrogen content – endothermic component of the combustibles of biofuel.

CONCLUSIONS

Based on the experimental research, we may conclude that the green wood chips made of dendromass from Robinia pseudoacacia coppices grown on plantations in maxi rotations is a two-component biofuel consisting of juvenile wood and juvenile bark. The share of bark in biofuel is X_B = 22.97 ± 1.95 %.

The average relative humidity of acacia chips in the harvest time is W^r = 34.9 ÷ 38.3 % and the bulk density of humid acacia is $\rho_{prms\text{-}w}$ = 468 ÷ 505 $kg.m^{-3}$.

The combustibles of the green wood chips differ in chemical composition from the combustibles of the fuel wood broad-leaved wood species by a higher nitrogen content. The content of nitrogen – the endothermic component of the combustibles in the green wood chips made of trees grown on plantations – is 8 times higher than the nitrogen content in the combustibles of the fuel wood broad-leaved wood species. From the environmental aspect, this fact points to an increase of emission production – concentration of nitrogen oxides NOx in combustion products.

The content of inorganic compounds in green wood chips of the analyzed clones of *Robinia pseudoacacia* (Ad = 1.73 %) places this biofuel into the group of low-ash fuels. The average value of the ash content in the green wood chips of the analyzed clones of *Robinia pseudoacacia* is 6 times higher than the ash content in wood of broad-leaved trees.

The lower heating value of green wood chips of the analyzed clones of *Robinia pseudoacacia* in dry state is Qn = 18 055.3 $kJ.kg^{-1}$.

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