ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 59(2): 127−135, 2017
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2017.59.2.12

ENERGETIC CHARACTERISTICS OF THE DENDROMASS OF BRANCHES IN THE SWEET CHESTNUT (*CASTANEA SATIVA* MILL.)

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ABSTRACT

This paper presents the results of assessing the energetic properties of the dendromass of branches in the sweet chestnut (*Castanea sativa* Mill.), in particular: density, rate of bark, content of the basic chemical elements in the combustible matter, content of ash in the dry mass and heating value in dry state.

The ascertained rate of bark in woodchips from the dendromass of sweet chestnut branches is X_K = 29.72 %. That fact is reflected their energetic characteristics, above all density, ash content and the heating value.

The combustible matter of the dendromass of sweet chestnut branches does not differ in its chemical composition from the fuel wood of other hardwoods with an exception of nitrogen – endothermic component of combustible matter. The nitrogen content in the fuel from the dendromass of sweet chestnut branches is, with the value of N = 0.42 %, 2.62-times higher than the usual nitrogen rate in the combustible matter of the fuel from other broadleaved trees.

The mean content of ash – the rest after combustion of the dendromass of branches, assessed according to ISO 1171: 2003, is A^d = 2.26 %. The mentioned value is 3.8-times higher than the usual content of ash from the wood combustion of other broadleaved woody plants.

The heating value of the dry branch wood with bark, Qn = 17 245 kJ·kg^{-1}, is by 7.3 % lower than the heating value of hardwoods in dry state according to the norm EN 14 961 „Solid biofuels – specifications and fuel classes“.

Key words: biofuel, biomass, dendromass of branches, energetic properties, sweet chestnut, combustible matter composition, ash, heating value.

INTRODUCTION

Sweet chestnut (*Castanea sativa* Mill.) is a deciduous tree from the family *Fagaceae.* From among the members of genus *Castanea* Mill., it is the sole species native to Europe (CONEDERA, KREBS 2008). This significant cultural woody plant is a multipurpose species that is cultivated for timber, nuts, tannin, and contributes positively to the forestry landscape (PEREIRA-LORENZO *et al*. 2009). It thrives well in warmer and subtropical regions and is native to mountainous regions of Western Asia, Northern Africa and Southern Europe. The Atlantic regions of France, Spain and Portugal are considered the most important from viewpoints of the occurrence and economic values of sweet chestnut (CONEDERA *et al*. 2004; KREBS *et al*. 2004).

In the last 200–400 years, the sweet chestnut has also been grown in forests of southern regions of Slovakia in the geomorphological units Malé Karpaty Mts., Považský Inovec Mts., Tribeč Mts., Krupinská planina plateau, as well as in South-Eastern Slovakia in the region of Ondavská vrchovina highland with the elevation of 200–500 m a. s. l. (BOLVANSKÝ *et al*. 2008).

Sweet chestnut has cylindrical, branched trunk with the height of 20 to 35 m. Its wood is considered moderately hard with the density in dry state of ρ_0 = 440–610 kg·m^{-3} (ENCHEV 1984). From the viewpoint of the natural durability, the sweet chestnut belongs, according to EN 350: 1994, to class 2 among the resistant woody plants. The mentioned fact is ascribed to the presence of tannins in the wood (PERELYGIN 1965, GIRONI, PIEMONTE 2011).

Besides that, the sweet chestnut is frequently characterised as „bread tree", because its fruits were used as the major compensation of cereals in the years insufficient harvests (BOUNOUS, MARINONI 2005). Also in the territory of Slovakia, sweet chestnut is grown in orchards due to the high nutritive value of its nuts. Besides the nuts, the sweet chestnut orchards produce dendromass in form of branches as a result of the regular pruning. One of the possibilities for utilization of this dendromass is the production of biofuel – energetic woodchips.

This paper presents the results of analyses, carried out for the purpose of assessing the following energetic properties of the dendromass of the sweet chestnut branches: density, rate of bark, content of the basic chemical elements in the combustible matter of wood and bark, content of ash in the dry mass and heating value of the dendromass of branches in dry state.

MATERIAL AND METHODS

Samples of dendromass from trunks and branches of sweet chestnut individuals were taken in 2016 during the dormant period from the private orchard at the locality Modrý Kameň in Southern Slovakia (Fig.1).

Modrý Kameň is a small town situated in the southern part of Krupinská Planina plateau and its vicinity represents the largest area with the occurrence of sweet chestnut in Slovakia. The studied locality belongs to the climatic subregion T4 (warm, moderately dry with mild winters). The average annual rainfall is 600–700 mm and the average annual air temperature is 8–9° C. The warmest month is July, with an average temperature of 18–20 °C and the coldest month is January, with an average temperature of 2–3 °C (LAPIN *et al*. 2002).

Sweet chestnut trees are grown here in orchards and also in forests. They are predominantly spread in a hilly country, on the slopes with eastern and western exposure and the elevation of 250–500 m a. s. l. The estimated number of trees growing at this locality is 1500–2000 (BENČAŤ 1960).

Fig. 1 Location of studied area Modrý Kameň.

The density of the dendromass of trunks and branches in dry state was measured according to the Slovak technical norm STN 49 0108: 1993 „Wood – determination of density“. The density of analysed samples was calculated from the measured weight and volume, according to the following formula (1):

$$\rho_0 = \frac{m_0}{V_0} \qquad \left[kg \cdot m^{-3}\right] \qquad (1)$$

In formula (1): m_0 – weight of the dry sample [kg],
V_0 – volume of the dry sample [m^3].

The rate of bark in the dendromass of branches was stated in laboratory, according to the Slovak technical norm STN 48 0058: 2004 „Timber assortments – broadleaved woodchips and sawdust“. The rate of bark was calculated from the formula (2):

$$X_B = \frac{m_B}{m_{Ch}} \cdot 100 \qquad [\%] \qquad (2)$$

In formula (2): m_g – weight of the bark on branch wood [g],
M_{Ch} – weight of the sample of the dendromass of branches [g].

The relative moisture of the dendromass of branches at the time of sampling was stated according to EN 14774-2 „Solid biofuels – determination of moisture content“. The values of the relative moisture of individual samples were calculated according to the formula (3):

$$W^r = \frac{m_w - m_0}{m_w} \cdot 100 \qquad [\%] \qquad (3)$$

In formula (3): m_w – weight of the sample before drying [g],
m_0 – weight of the sample after drying to the constant weight [g].

The quantitative analysis of chemical elements in the combustible matters of wood and bark of sweet chestnut was carried out in Central Forestry Laboratory of National Forest Centre in Zvolen. Contents of carbon C^{daf} [%], hydrogen H^{daf} [%] and nitrogen N^{daf} [%] in the combustible matters of juvenile wood and juvenile bark were stated by NCS-FLASH EA 1112 analyser. The oxygen contents in combustible matters was calculated on the assumption of the inappreciable presence of sulphur in the dendromass and its combustible matters (presence of sulphur only in trace amount or $S^{daf} = 0$). Calculation was carried out according to the equation (4):

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

In equation (4): C^{daf} – content of carbon in combustible matter [%],
H^{daf} – content of hydrogen in combustible matter [%],
N^{daf} – content of nitrogen in combustible matter [%].

The chemical composition of the combustible matter of the dendromass of branches, composed of the combustible matter of wood and the combustible matter of bark, was assessed by calculation, based on the wood/bark ratio in the analysed dendromass and the measured contents of individual chemical elements in the combustible matters of wood and bark. The following equations were used in calculations (5):

$$C^{daf} = \left[\frac{100 - X_K}{100}\right] \cdot C_D^{daf} + \frac{X_K}{100} \cdot C_K^{daf}$$

$$H^{daf} = \left[\frac{100 - X_K}{100}\right] \cdot H_D^{daf} + \frac{X_K}{100} \cdot H_K^{daf} \tag{5}$$

$$N^{daf} = \left[\frac{100 - X_K}{100}\right] \cdot N_D^{daf} + \frac{X_K}{100} \cdot N_K^{daf}$$

$$O^{daf} = \left[\frac{100 - X_K}{100}\right] \cdot O_D^{daf} + \frac{X_K}{100} \cdot O_K^{daf}$$

In equations (5):

C^{daf}, H^{daf}, N^{daf}, O^{daf} – C, H, N and O contents in the combustible matter of the dendromass of branches [%],

$C_W^{daf}, H_W^{daf}, N_W^{daf}, O_W^{daf}$ – C, H, N and O contents in the combustible matter of wood [%],

$C_B^{daf}, H_B^{daf}, N_B^{daf}, O_B^{daf}$ – C, H, N and O contents in the combustible matter of bark [%],

X_B – rate of bark in the woodchips dendromass of branches [%].

The contents of ash in analysed samples were stated using the muffle furnace according to the norms EN 14775: 2010 „Solid biofuels – determination of ash content" at the annealing point of t = 550 °C and ISO 1171: 2003 „Solid mineral fuels – determination of ash" at the annealing point of t = 815 °C. The calculations of the ash rates in wood (A_D^d) and bark (A_K^d) are explained by the following formulae (6):

$$A_D^d = \frac{m_{A\text{--}D}^d}{m_D^d} \cdot 100 \quad [\%]$$

$$A_K^d = \frac{m_{A\text{--}K}^d}{m_K^d} \cdot 100 \quad [\%] \tag{6}$$

In formulae (6): m_{A-W}^d – weight of ash in dry sample of wood [g],

m_W^d – weight of dry sample of wood [g],

m_{A-B}^d – weight of ash in dry sample of bark [g],

m_B^d – weight of dry sample of bark [g].

The content of ash from the combustion of the dendromass of sweet chestnut branches was stated by technical calculation, based on the rate of bark in the dendromass of branches and the rates of ash from wood and bark. Calculation is derived from the equation (7):

$$A^d = \left[\frac{100 - X_K}{100}\right] \cdot A_D^d + \frac{X_K}{100} \cdot A_K^d \qquad [\%] \tag{7}$$

In equation (7): A_W^d – content of ash from the dry sample of wood [%],

A_B^d – content of ash from the dry sample of bark [%],

X_B – rate of bark in the sample of the dendromass of branches [%].

The heating value of the dendromass of sweet chestnut branches was stated by the technical calculation for energetic woodchips, i.e. the two-component biofuel, composed of wood and bark. Calculation is based on the chemical composition of the combustible matter of energetic woodchips and the ash rate in the dry mass of fuel wood (DZURENDA, BANSKI 2016), and was carried out according to the equation of M. I. Mendeleev (8):

$$Q_n^d = \left[339 \cdot C^{daf} + 1029.8 \cdot H^{daf} - 108.8 \cdot O^{daf}\right] \cdot \left[\frac{100 - A^d}{100}\right] \qquad \left[kJ \cdot kg^{-1}\right] \tag{8}$$

In equation (8):

C^{daf} – content of carbon in the combustible matter of the dendromass of branches [%],
H^{daf} – content of hydrogen in the combustible matter of the dendromass of branches [%],
O^{daf} – content of oxygen in the combustible matter of the dendromass of branches [%],
A^{d} – content of ash from the dry mass of branches [%].

RESULTS AND DISCUSSION

The results of the density determination for the dendromass of trunks and branches of sweet chestnut in dry state are summarized in Tab. 1.

Tab. 1. Basic statistical characteristics for the density of the dendromass of trunks and branches of sweet chestnut in dry state.

Fuel wood assortment	Basic statistical characteristics (ρ_0: mean density in dry state, s: standard deviation, v_x: variation coefficient, n: number of samples)			
	ρ_0 [kg·m^{-3}]	s [kg·m^{-3}]	v_x [%]	n [−]
Trunk wood with bark	550.0	17.3	3.1	15
Branch wood with bark	703.1	61.6	8.7	24

The ascertained mean density of sweet chestnut trunk wood with bark in dry state ρ_0 = 550.0 kg·m^{-3} corresponds to the previously published data, related to the dry wood density of this woody plant (ENCHEV 1984, KYUCHUKOV *et. al*. 2011). The cited authors mention the values of sweet chestnut wood density in range from 444 kg·m^{-3} to 610 kg·m^{-3}.

The density of the dendromass of branches in dry state (ρ_0 = 703.1 kg·m^{-3}) is in sweet chestnut, compared to the density of the dry trunk wood with bark, by 21.8 % higher. This difference is caused by ca 30 % rate of bark in the dendromass of branches (bark has generally higher density than wood) and partially, also by the higher density of branch wood, when compared to the density of the wood from trunks. The mentioned statements about the higher density of bark (compared to the wood density) correspond to the knowledge of the bark morphology, as well as to the knowledge of the chemical composition of bark, described in the literature (PELERYGIN 1965, BLAŽEJ *et al.* 1975, POŽGAJ *et al.* 1997, BANSKI, DZURENDA 2014).

Tab. 2 summarizes the ascertained rates of bark in the measured samples of the dendromass of branches.

Tab. 2 Rate of bark in samples of branches of the sweet chestnut.

Sample	Sample 1	Sample 2	Sample 3	Mean
Rate of bark [%]	29.13	28.91	30.38	29.72 ± 1.04

The results of our studies on the rates of bark in the dendromass of branches show that the mean bark rate in sweet chestnut is X_E = 29.72 ± 1.04. This value is on the upper limit of feasibility of the bark rate in fuel wood according to Slovak technical norm STN 48 0058: 2004 with the maximum feasible value of X_B = 30 %. This fact is reflected in the energetic properties of the dendromass of branches, above all density, ash content and heating value. The relative moisture of wood and bark, as well as the relative moisture of two-component dendromass of branches, collected at the period of the vegetative rest, is presented in Fig. 2.

The results of the quantitative analysis of basic chemical elements in the combustible matters of sweet chestnut wood, bark and two-component dendromass of branches are presented in Tab. 3 and 4.

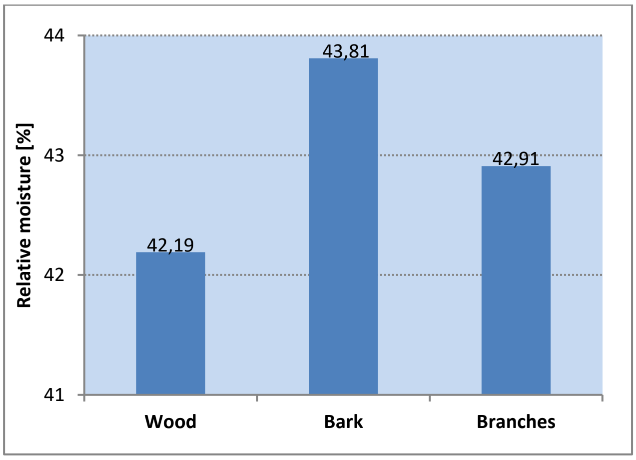

Fig. 2 Relative moisture of the dendromass of sweet chestnut branches and its components.

Tab. 3 Rates of the basic chemical elements in the combustible matters of sweet chestnut wood and bark.

Components of the dendromass of branches		C^{daf} [%]	H^{daf} [%]	O^{daf} [%]	N^{daf} [%]
Wood	Sample 1	48.19	5.99	45.41	0.41
	Sample 2	48.05	6.38	45.24	0.33
	Sample 3	49.29	5.48	44.84	0.38
	Mean	*48.51+0.68*	*5.95+0.45*	*45.17+0.29*	*0.37+0.04*
Bark	Sample 1	48.79	5.64	45.05	0.52
	Sample 2	49.21	5.86	44.31	0.59
	Sample 3	48.64	5.78	45.10	0.48
	Mean	*48.88+0.29*	*5.76+0.11*	*44.83+0.44*	*0.53+0.05*

Tab. 4 Rates of the basic chemical elements in the combustible matters of sweet chestnut wood, bark, and the two-component dendromass of branches.

Rate of wood and bark in the dendromass of branches [%]		Chemical composition of combustible matter [%]			
		C^{daf}	H^{daf}	O^{daf}	N^{daf}
Wood	70.28	48.51	5.95	45.17	0.37
Bark	29.72	48.88	5.76	44.83	0.53
Dendromass of branches	100.0	48.62	5.89	45.07	0.42

As it follows from above mentioned tables, there are no differences of chemical composition between the combustible matters of wood and bark from the branches of sweet chestnut. Only exception is nitrogen – the endothermic component of the combustible matter. The share of nitrogen in combustible matter of the dendromass of branches, N^{daf} = 0.42 % compared to the usual nitrogen rate N^{daf} = 0.16 % in the combustible matter of the wood of the other broadleaved trees reported in works (DZURENDA 2004, DZURENDA, BANSKI 2016) is 2.62 times hifher. The increased rate of nitrogen in the combustible matter of bark is due to the presence of amino acids and proteins in cambium cells, as well as to the presence of chlorophyll in the surface tissues of the juvenile bark of the branches (DZURENDA, ZOLIAK 2011). The mentioned fact has the negative impact in the production of emissions in form of NO_x (DZURENDA 2004, DZURENDA *et al.* 2017).

The results of the laboratory analyses, quantifying the rates of ash in components of the dendromass of branches (i.e. in wood and bark), are summarised in Tab. 5.

Tab. 5 Results of analyses of the ash rate from wood, bark, and dendromass of branches in the sweet chestnut.

Ash content [%]	Analysis method	
	EN 14775: 2010	ISO 1171: 2003
Wood	$A^d = 0.65 \pm 0.09$	$A^d = 0.57 \pm 0.07$
Bark	$A^d = 9.59 \pm 0.13$	$A^d = 6.27 \pm 0.11$
Dendromass of branches	$A^d = 3.31 \pm 0.11$	$A^d = 2.26 \pm 0.08$

The ascertained differences of the ash contents in individual components of the dendromass of branches (Tab. 5), confirms the well-known data about the higher contents of the ash substances in bark than in wood (BLAŽEJ *et al.* 1975, PITMAN 2002, ZULE, DOLENC 2012, DZURENDA *et al.* 2013, HYTÖNEN, NURMI 2015, PÉREZ *et al.* 2015, PŇAKOVIČ, DZURENDA 2016a, 2016b, NOSEK *et al*. 2016). The ash production is also influenced by the combustion temperature of fuel, determining the conditions of thermic decomposition of carbonates, sulphates or chlorides, i.e. parts of the ash substances of wood and bark. With the increasing combustion temperature of fuel the content of ash decreases (SIPPULA *et al.* 2007, TISSARI 2008, DZURENDA 2016b).

The new finding is the determination of the ash content in the dry mass of sweet chestnut branches, $A^d = 2.28$ %. This fact is usable in balancing the ash production from the biofuel combustion in the fire chambers of boilers, at the temperature interval of 750–900 °C. The above mentioned value of the ash rate in the dendromass of sweet chestnut branches is 3.8-times higher than the rate of the ash from the wood of broadleaved woody plants from the publications of SIMANOV (1995), DZURENDA, JANDAČKA (2010) and NOSEK *et al*. (2016). Despite this statement, dendromass of sweet chestnut branches can be still included among the biofuels with the low content of ash.

The heating value of the dry mass of green woodchips from sweet chestnut branches, calculated from the equation of M. I. Mendeleev, is $Q_n = 17\,245$ kJ·kg^{-1}. This value is, when compared to the heating value of the wood of broadleaved trees in the norm EN 14 961 „Solid biofuels – fuel specifications and classes“, by 7.3 % lower. That fact is caused by the increased rate of inorganic matters (ash substances) in the dendromass of sweet chestnut branches, as well as the increased rate of nitrogen (the endothermic component of the combustible matter) in the biofuel.

CONCLUSIONS

Based on the presented assessment of the energetic properties of sweet chestnut (*Castanea sativa* Mill.) branches dendromass, we can state that:

- the dendromass of its branches in dry state has the mean density of $\rho_0 = 703.1$ kg·m^{-3},
- the rate of bark in the dry dendromass of sweet chestnut branches, $X_K = 29.72$ %, is on the upper limit of feasibility for the production of the energetic woodchips,
- the combustible matter of the dendromass of sweet chestnut branches does not differ in its chemical composition from the fuel wood of other broadleaved trees with an exception of the content of nitrogen – endothermic component of the combustible matter; the nitrogen rate in the analysed dendromass of sweet chestnut is 2.62-times higher than in most of the other broadleaved trees,
- the mean rate of ash, stated according to the norm ISO 1171: 2003 after combustion of the dendromass of sweet chestnut branches in the fire chamber of boiler, is $A^d = 2.26$ %.
- the ascertained heating value of the dry dendromass of sweet chestnut branches is Q_n = 17 245 kJ·kg^{-1}.

According to these energetic characteristics we can draw the following final conclusion: the dendromass of sweet chestnut branches is, after drying out the air-dry state, the suitable material for the production of the energetic woodchips.

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