bioresources.com

Energy-related Characteristics of Poplars and Black Locust

Szabolcs Komán

Poplar and black locust plantations are widely used for production of raw materials for biofuel. In this study, the main characteristics affecting energy content were evaluated for 2-year-old plantations obtained from 3 different sites of various qualities were evaluated. The 'I-214' poplar and the black locust had smaller (16 to 21%) bark ratios, while the 'Kopecky' poplar had a higher (22 to 26%) bark gain yield. The black locust had a higher basic density than that of the poplars, which were wood (446 kg/m³) and bark (402 kg/m³). The higher heating value of the bark of the black locust (19.51 to 19.59 MJ/kg) and of the 'Kopecky' (19.58 to 19.86 MJ/kg) was greater than that of the wood; in the case of the 'I-214' (19.59 to 19.81 MJ/kg), the higher heating value of the wood was higher. The ash content of the bark (4.50 to 8.22%) was several times greater in the case of poplars and black locust than that of the wood (0.46 to 1.29%). In the case of the wood, the ash content increased by the degradation of the site's quality. There were remarkable differences between the black locust and the poplars, as well as the individual poplar clones among the main energetic characteristics.

Contact information: Institute of Wood Science, Simonyi Karoly Faculty of Engineering, Wood Sciences and Applied Arts, University of Sopron, 4. Bajcsy-Zsilinszky., H-9400 Sopron, Hungary;
* Corresponding author: koman.szabolcs@uni-sopron.hu

INTRODUCTION

As a result of continued development within the energy sector, biological renewable energy sources are gaining an increasing role. Tree plantations are included, and they have been recognized by the Kyoto Convention as a means of reducing greenhouse gas emissions (Updegraff *et al*. 2004). In the case of tree plantations intended to serve as sources for bioenergy, fast-growing tree species (poplar, willow, black locust) can be emphasized (Murach *et al*. 2007). There are several reasons for this, for example, high rates of dry matter production and good sprouting ability.

The most important parameters for the use of woody biomass raw material for energy generation are the bark ratio, moisture content, basic density, and the heating value (Thakaran *et al*. 2003). The energy yield, determined by the higher heating value and moisture content, is one of the most important quality characteristics of the plantations (Kenney *et al*. 1990). The higher heating value is influenced by the tree species, the parts of the living tree (stem, branch, and root), the parts of the wood (wood, bark, and foliage), and the size of the wood (Nurmi 2000). The heating value of the bark is lower than that of the wood (Knige and Schultz 1966; Požgaj *et al*. 1997; Klašnja *et al*. 2002; Jamnická *et al*. 2014).

From a quantitative point of view, one of the most important predictors of aboveground biomass is the basic density (Chave *et al*. 2005). The basic density also plays an important role in specifying the carbon stored (Fearnside 1997; Chave *et al*. 2005; Malhi

et al. 2006; Keeling and Phillips 2007; Navarro *et al*. 2013). Plants that purchase logs often use it as an ATRO tons/m^3 factor, which is derived from the abbreviation of the German expression "Absolut Trockenes Holz". This factor expresses what quantity of dry timber content of live wood or freshly logged wood, *i.e.*, above the net moisture content of approximately 30% (Komán and Fehér 2015). The basic density depends on many factors, including geography and moisture content, which in turn depends on the diameter, age, and stem position (Miles and Smith 2009).

For wooden biomass, the difference between the bark and wood has a direct impact on the quality and economic value regarding utilization as an energy source (Guidi *et al*. 2008). The thickness of the bark depends on tree species, age, and ecological factors. In addition to the diameter, the age also affects the thickness of the bark. Young trees of a specified diameter have thinner bark, while the older trees of the same diameter have thicker bark (Cellini *et al.* 2012). On more favorable sites however, the trunks will reach larger diameter earlier. To be aware of the wood-bark ratio is also important, because there are remarkable differences between the wood and the bark properties. These wood parts, compared to each other have e.g. different density and moisture content.

Compared with the wood, the bark shows a greater variability, especially the ash content. The wood generally has a relatively lower ash content (0.3 to 1.3%), while the bark has significantly higher ash (3.8 to 8.6%) (Passialis *et al*. 2008; Nosek *et al*. 2016; Pásztory *et al*. 2016). According to Lieskovsky *et al.* (2017), a 1% ash content increase results in a 0.11 MJ/kg higher heating value decrease.

This article discusses the properties of factors relevant to the energetic use of woody biomass, such as wood-bark ratio, ash content, higher heating value, and basic density. The aim of the research is to explore the differences between the utilization of poplars and black locust for energy purposes. Due to the fact that the examined plants has been grown on the very same sites we can get exact pictures about the real difference between the wood species/varieties. The main energetic feature can be compared both for the wood and also for the barks. The 3 different quality sites gives us opportunity to examine the effect of a site on these features.

EXPERIMENTAL

Materials

For this study, there were three energy plantations selected which were planted at three different sites and cultivated by sprouting technology. Regarding the site quality, good (later marked G as good), medium (later marked M as medium), and weak (later marked W as weak) sites were selected for notation purposes. The quality classification was differentiated according to the yields of maintained experimental plantation in the sites. At the second harvesting cycle from the two-year-old sprouts, the *Populus euramericana* x 'I-214', *Populus euramericana* x 'Koltay' and the *Robinia pseudoacacia* L. were selected for this study. The poplar samples came from all three sites, while the black locust samples came from two sites. The samples required for the tests were 6 pieces of average stems. For each test, the samples were mixed from the lower, middle, and upper parts of the tree stems.

Methods

To determine the wood to bark ratio, 3 cm long pieces were cut from the sprouts. Images were taken about the cross sections of the samples, which were analyzed, using an Image-Pro Plus. The total cross-sectional area and wood area were calculated in the images. With the cross-sectional area and wood area calculated, it was also possible to determine the area ratio of the bark. Based on the results obtained, it was possible to specify the average percentage ratio area of the wood, inside of the sprouts and the bark.

The basic density was determined by the oven-dry mass and the saturated volume ratio. The samples that were used for the determination of the bark ratio were soaked in water until they reached their constant volume. Excess water was removed from the surface prior to measurement and then, by the water displacement method, the measurement of the volume was carried out. First, the volumes were measured in the bark, and after the bark was removed, the wood measurement was also performed. The volume of the bark could be calculated in this way by using the volume of the sample with the bark and then the one of the wood. After that, the bark and the wood were separately put into the drying chamber, where drying was carried out at 103 °C until constant weight was achieved.

The ash content was tested on the oven-dry samples, which were used to determine the basic density separately, regarding the wood and the bark. After grinding, 2 g samples were analyzed. Three measurements were carried out regarding each sample. The testing was performed in accordance with the ISO 18122 (2015) standard.

For the determination of the higher heating value (HHV), pellets of 1 g mass were made from the ground wood and used for the examination of the ash content. The samples were in oven-dry condition and three repetitions were carried out. The measuring equipment used was of IKA 2000C type (IKA®-Werke GmbH & Co. KG, Staufen, Germany) in accordance with the ISO 1928 (2009) standard.

RESULTS AND DISCUSSION

Differences were apparent when comparing the wood-bark ratio of the examined species even at this age. These differences could be traced back to the unique characteristics of the varieties (Fig. 1). While the bark ratio of the 'I-214' and the black locust ranged from 16 to 21%, the corresponding value for 'Kopecky' was between 22 and 26%. This coincides with Tóth's (2006) description of 'Kopecky', in which it was reported that the bark of this species in the lower part of the stem is very early (already in year 2) suberized and then it is of rough nature. With regard to site quality, the black locust bark quantity showed no difference between sites, but it was not possible to draw a clear conclusion in the case of the poplars. In the case of 'I-214', the bark ratio of the trees, growing in the site of medium quality was lower, while in the case of 'Kopecky', the bark ratio of the trees, growing in the weakest quality sites, was higher. There were practically no differences between the two sites from the point of view of the bark ratio of the black locust. The decreasing bark ratio is naturally influenced by other features, such as the diameter and growth (Klasnja *et al.* 2002; Tharakan *et al.* 2003; Guidi *et al.* 2008).

Between the two species, the difference in the basic density was already visible at a young age (Figs. 2 and 3). The basic density results were highest in the case of the black locust, regarding both of the tree-parts.

Regardless of the site, in the case of the black locust and the 'Kopecky', the wood had higher basic density than the bark. Regarding the 'I-214', the same relationship was

observed only for the weakest site. Between the two poplar varieties, the 'Kopecky' wood had higher basic density, which was an average of 25%. The average density values in the poplars did not change significantly. Due to the degradation of the site quality, perhaps the wood may grow only slightly. In the black locust and the 'I-214', the measured values were less than those mentioned by Klašnja *et al.* (2013). The standard deviations for all three varieties were the highest in the weakest quality site.
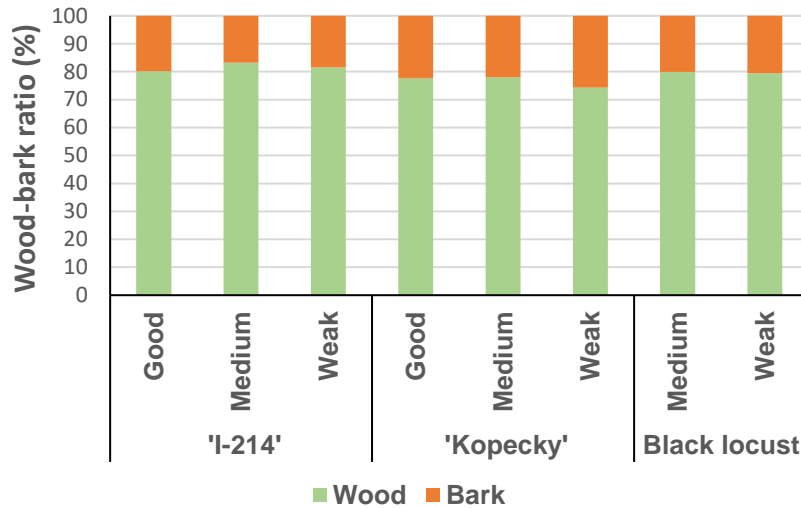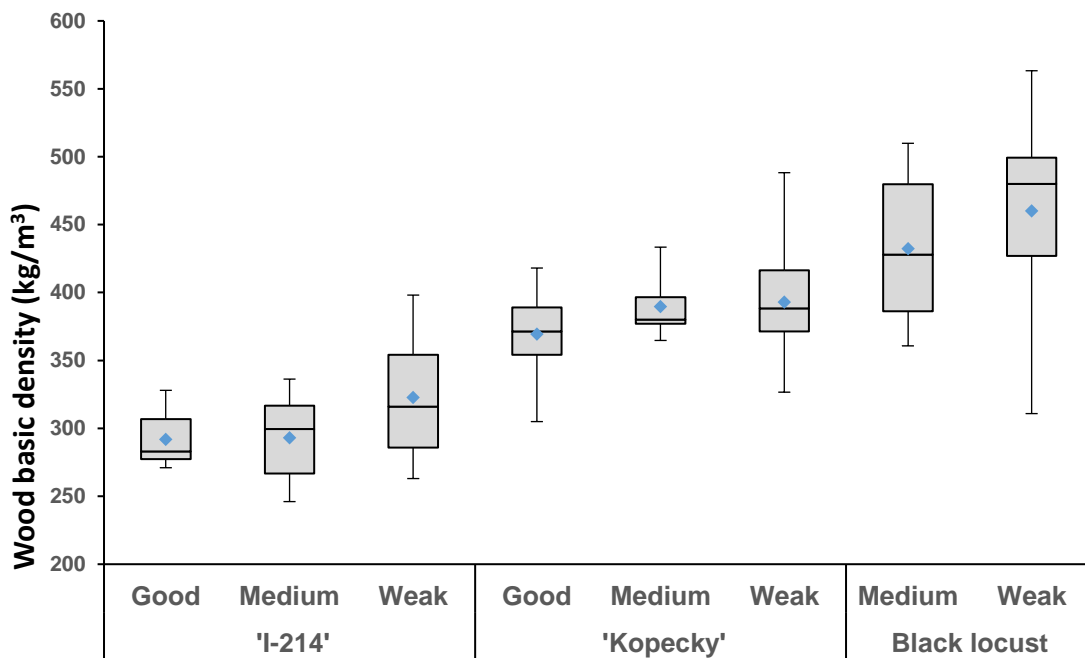

Fig. 1. Wood to bark volume rates

Fig. 2. Basic density of wood

In the case of bark, the opposite tendency was observed based on the site quality. With the deterioration of the site in the case of the black locust and the 'I-214', the density

also dropped, while in the case of 'Kopecky', it practically did not change. Among the varieties, the order was the same as in the case of the wood, but there was less difference between them. The black locust's bark was about 400 kg/m^3, which was the same as mentioned by Kraszkiewicz (2016), while the poplars exhibited values between 300 and 370 kg/m^3. The values in poplars had a higher standard deviation compared with wood, while in the case of black locust it was the opposite.
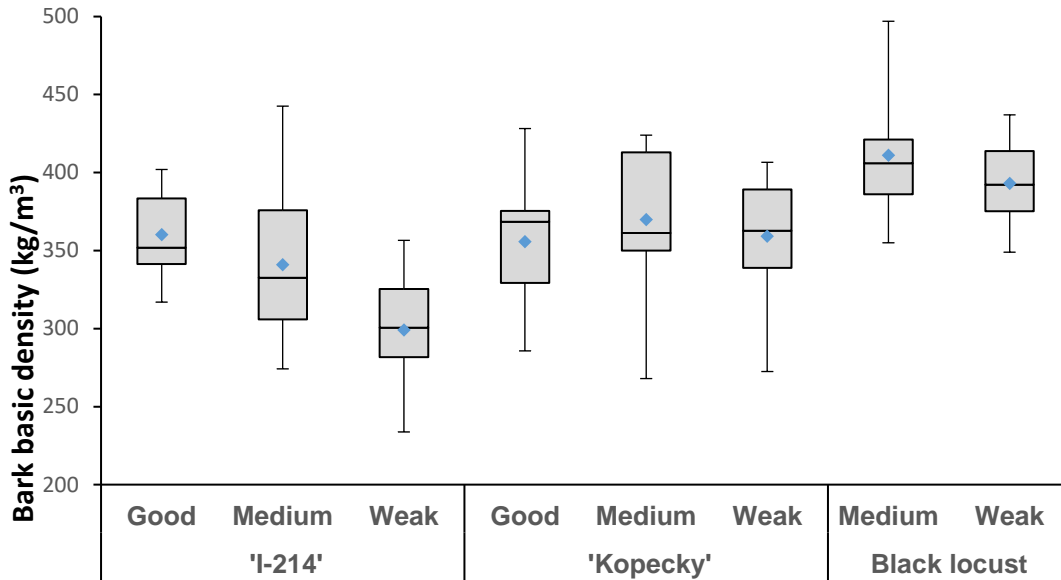

Fig. 3. Basic density of bark

The higher heating values (Fig. 4) showed different ratios for the examined varieties and for the different wood parts (wood and bark). The wood of the 'I-214' had much higher values at the three sites, while in the case of 'Kopecky' and the black locust, the value of the bark was larger.
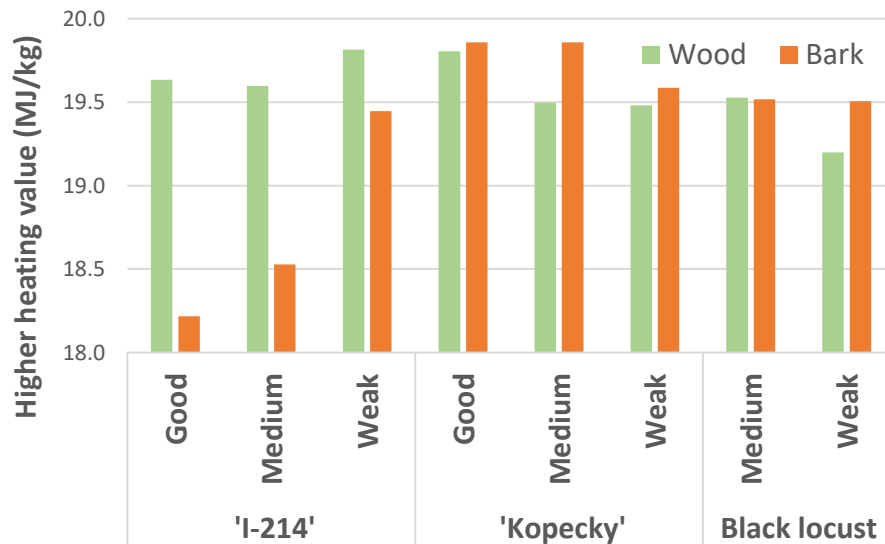

Fig. 4. Higher heating value of wood and bark

bioresources.com

The higher heating value of the bark of the 'I-214' gradually increased with the deterioration of the site, whereas, this tendency was not visible in the case of the wood. These values were well below those mentioned in other literature (Klašnja *et al.* 2013; Krajnc 2015). In the 'Kopecky', the weakest site provided the lowest values, regarding both main tree parts. In the black locust, the higher heating value of the bark did not change based on the site quality, however, in the case regarding the wood, the medium quality site provided a higher value than the lower quality one. Of the two species of the wood, on average, the poplars had the larger value of higher heating value. In the case of the bark, only the higher heating value of the 'Kopecky' exceeded that of the black locust.

For the ash content, there were remarkable differences between the two parts of the tree (Fig. 5). The ash content of the bark was much higher than that of the wood, as reported previously (Klašnja *et al.* 2002; Dzurenda *et al.* 2014). In the wood, this value had a narrower range (0.46 to 1.29%) than in the bark (4.50 to 8.22%).

In the wood, with the deterioration of the site quality, the ash content increased. Therefore, the values of the sample trees, growing in weak sites, are the highest in all cases. Regardless of the site, on average the black locust had the highest ash content (1.12%), followed by 'I-214' (0.80%) and 'Kopecky' (0.65%). In the black locust, this value exceeded those found in the literature (Adamopoulos *et al.* 2005; Panayotov *et al.* 2015).

In the case of the bark, the effect of the site quality on the ash content was not clear. Regardless of the site, the average value of the black locust (6.99%) was between the two poplar varieties, which was more than mentioned by Kraszkiewicz (2016). 'Kopecky' had the highest ash content (7.98%), while 'I-214' had the lowest (5.37%).
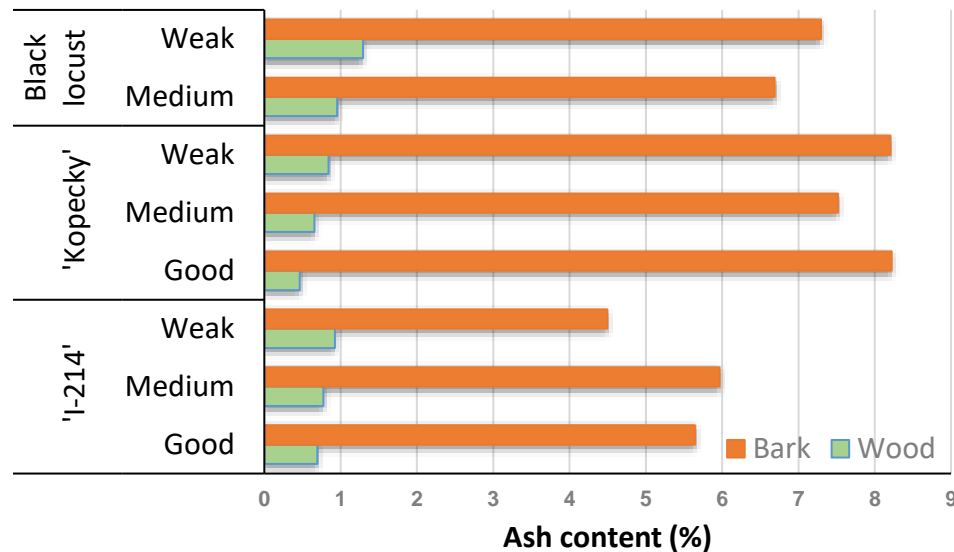

Fig. 5. Ash content of wood and bark

CONCLUSIONS

1. The two-year-old sprouts of black locust and the studied poplars had an average 18.4 to 23.4% bark ratio, regardless of their site. The influence of the quality of the site could not be demonstrated. The characteristics of the species had greater effect on the bark ratio than the quality of the site.

2. Regardless of the site quality, the black locust had an average higher basic density higher than poplars in the wood (446 kg/m³) and the bark (402 kg/m³). From the basic density point of view the energy utilization of black locust and 'Kopecky' is more favorable than 'I-214', because the stems of these have greater density than their bark. There is a remarkable difference among the density of the examined poplar species what is to be taken into consideration in the final use.

3. The higher heating value of the bark of black locust (19.5 MJ/kg) and of 'Kopecky' (19.6 to 19.9 MJ/kg) exceeded that of the wood, while in the case of the 'I-214', the values of the wood (19.6 to 19.8 MJ/kg) were higher. The influence of the site was observed only in the case of the bark of 'I-214', whereas the quality decreased, the heating value increased.

4. Irrespective of the site and variety, the ash content of the bark (4.5 to 8.2%) in a remarkable way exceeded that of the wood (0.46 to 1.29%). The better quality site also had a beneficial effect on ash content of black locust and poplar, which is beneficial for energy use.

5. For the energy characteristics examined, there were remarkable differences in such at a young age, not only between the black locust and the poplars, but also among some clones of poplars. Improving the quality of the site did not produce better values in all features; therefore it is unlikely that the lower quality sites will produce lower quality raw material.

ACKNOWLEDGMENTS

REFERENCES CITED

Adamopoulos, S., Voulgaridis, E., and Passialis, C. (2005). "Variation of certain chemical properties within the stemwood of black locust (*Robinia pseudoacacia* L.)," *Holz als Roh- und Werkstoff* 63, 327-333. DOI: 10.1007/s00107-005-0018-3

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., and Fölster, H. (2005). "Tree allometry and improved estimation of carbon stocks and balance in tropical forests," *Oecologia* 145, 87-99. DOI: 10.1007/s00442-005-0100-x

Cellini, J. M., Galarza, M., Burns S. L., Martinez-Pastur, G. J., and Lencinas, M. V. (2012). "Equations of bark thickness and volume profiles at different heights with easy-measurement variables," *Forest Systems* 21(1). 23-30 DOI: 10.5424/fs/2112211-01963

Dzurenda, L., Banski, A., and Dzurenda, M. (2014). "Energetic properties of green wood chips from *Salix viminalis* grown on plantations," *Scientia Agriculturae Bohemica* 45(1), 44-49. DOI: 10.7160/sab.2014.450106

Fearnside, P. M. (1997). "Wood density for estimating forest biomass in Brazilian Amazoni," *Forest Ecology and Management* 90, 59-87. DOI: 10.1016/S0378-1127(96)03840-6

bioresources.com

Guidi, W., Piccioni, E., Ginanni, M., and Bonari, E. (2008). "Bark content estimation in poplar (*Populus deltoides* L.) short-rotation coppice in Central Italy," *Biomass and Bioenergy* 32(6), 518-524. DOI: 10.1016/j.biombioe.2007.11.012

ISO 18122 (2015). "Solid biofuels. Determination of ash content," International Organization for Standardization, Geneva, Switzerland.

ISO 1928 (2009). "Solid mineral fuels -- Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value," International Organization for Standardization, Geneva, Switzerland.

Jamnická, G., Petrášová, V., Petráš, R., Mecko, J., and Oszlányi, J. (2014). "Energy production of poplar clones and their energy use efficiency," *iForest* 7, 150-155.

Keeling, H. C., and Phillips, O. L. (2007). "The global relationship between forest productivity and biomass," *Global Ecology and Biogeography* 16, 618-631. DOI: 10.1111/j.1466-8238.2007.00314.x

Kenney, W. A., Sennerby-Forsse, L., and Layton, P. (1990). "A review of biomass quality research relevant to the use of poplar and willow for energy conversion," *Biomass* 21(3), 163-188. DOI: 10.1016/0144-4565(90)90063-P

Klašnja, B., Kopitovic, S., and Orlovic, S. (2002). "Wood and bark of some poplar and willow clones as fuelwood," *Biomass Bioenergy* 23, 427-432. DOI: 10.1016/S0961-9534(02)00069-7

Klašnja, B., Orlović, S., and Galić, Z. (2013). "Comparison of different wood species as raw materials for bioenergy," *South-East Eur For*. 4(2), 81-88. DOI: 10.15177/seefor.13-08

Komán, Sz., and Fehér, S. (2015). "Basic density of hardwoods depending on age and site," *Wood Research* 60 (6), 907-912.

Krajnc, N. (2015). *Wood Fuels Handbook*, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. ISBN 978-92-5-108728-2.

Kraszkiewicz, A. (2016). "Chemical composition and selected energy properties of black locust bark (*Robinia pseudoacacia* L.)," *Agricultural Engineering* 20(2), 117-124. DOI: 10.1515/agriceng-2016-0033

Lieskovský, M., Jankovský, M., Trenčiansky, M., Merganič, J., and Dvořák, J. (2017). "Ash content *vs*. the economics of using wood chips for energy: Model based on data from Central Europe," *BioResources* 12(1), 1579-1592. DOI: 10.15376/biores.12.1.1579-1592

Malhi, Y., Wood, D., Baker, T. R., Wright, J., Phillips, O. L., Cochrane, T., and Meir, P. (2006). "The regional variation of aboveground live biomass in old-growth Amazonian forests," *Global Change Biology* 12, 1107-1138. DOI: 10.1111/j.1365-2486.2006.01120.x

Miles, P. D., and Smith, W. B. (2009). *Specific Gravity and Other Properties of Wood and Bark for the 156 Tree Species found in North America* (Res. Note NRS-38), U.S. Department of Agriculture Forest Service, Northern Research Station, Newtown Square, PA, USA. DOI: 10.2737/NRS-RN-38

Murach, D., Knur, L., Murn, Y., Walotek, P., Bilke, G., Muchin, A., Grundmann, P., Eberts, J., and Schneider, U. (2007). "Wood - Raw material of the future," in: *Sustainable Neighbourhood from Lisbon to Leipzig through Research (L2L)*, Leipzig, Germany.

Navarro, M., Moya, R., Chazdon, R.L., Ortiz, E., and Vilchez, B. (2013). "Successional variation in carbon content and wood specific gravity of four tropical tree species," *Bosque* 34, 33-43. DOI: 10.4067/S0717-92002013000100005

Nosek, R., Holubcik, M., and Jandacka, J. (2016). "The impact of bark content of wood biomass on biofuel properties," *BioResources* 11(1), 44-53. DOI: 10.15376/biores.11.1.44-53

Nurmi, J. (2000). *Characteristics and Storage of Whole-tree Biomass (Metsäntutkimuslaitoksen tiedonantoja)*, The Finnish Forest Research Institute, Kannus, Finland.

Panayotov, P., Valchev, I., Kalmukov, K., Panayotov, M., Petrin, S., and Yavorov, N. (2015). "Black locust wood – Perspective raw material for production of chemical pulp and glucose," *Forestry Ideas* 21 (50), 307-316.

Passialis, C., Voulgaridis, E., Adamopoulus, S., and Matsouka, M. (2008). "Extractives, acidity, buffering capacity, ash and inorganic elements of black locust wood and bark of different clones and origin," *European Journal of Wood and Wood Products* 66, 395-400. DOI: 10.1007/s00107-008-0254-4

Pásztory, Z., Mohácsiné, I.R., Gorbacheva, G., and Börcsök, Z. (2016). "The utilization of tree bark," *BioResources* 11 (3), 7859-7888. DOI: 10.15376/biores.11.3.Pasztory

Požgaj, A., Chovanec, D., Kurjatko, S., and Babiak, M. (1997). *Structure and Properties of Wood*, Príroda, Bratislava, Slovak Republic. (In Slovak)

Tharakan, P. J., Volk, T. A., Abrahamson, L. P., and White, E. H. (2003). "Energy feedstock characteristics of willow and hybrid poplar clones at harvest age," *Biomass and Bioenergy* 25, 571-580. DOI: 10.1016/S0961-9534(03)00054-0

Tóth, B. (2006). *Description of Hybrid Poplar Species*, Agroinform Kiadó, Budapest. (In Hungarian)

Updegraff, K., Baughman, M. J., and Taff, S. J. (2004). "Environmental benefits of cropland conversion to hybrid poplar: Economic and policy consideration," *Biomass Bioenergy* 27, 411-428. DOI: 10.1016/j.biombioe.2004.05.002