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Original Article

Solid Bioenergy Properties of *Paulownia tomentosa* Grown in Korea[1]

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ABSTRACT

Paulownia tomentosa is one of fast-growing wood species in Korea. In order to evaluate the solid bioenergy properties of *Paulownia* tree, this study examined the heating value, moisture content (MC), pH and proximate analysis of stem, branch, root, bark and leaf. The heating values of wood parts were slightly higher than those of bark and leaf, and that of branch was the highest among all the samples. The higher moisture content of bark and leaf referred to their lower heating value. Also, the pH of stem, branch and root was similar and lower than those of bark and leaf. The ash content of bark and leaf was much higher than that of wood parts, which is the one of the reasons for effect on the lower heating value and higher pH. While, the volatile matter content (VMC) of bark and leaf was lower than those of wood parts. The bark showed the highest fixed carbon content (FCC), while the FCC of stem was the lowest among all the samples. The obtained results are encouraging that the *Paulownia* tree could be totally utilized as alternative fuels for bioenergy production.

Keywords: solid bioenergy properties, fast-growing species, *Paulownia tomentosa*, whole tree utilization

1. INTRODUCTION

Presently, there is great need of alternative energy resources which are potentially sustainable and environmentally friendly. Therefore, attention is being given to alternate and renewable source such as biomass. Biomass is the fourth largest source of energy in the world after coal, petroleum and natural gas, providing about 14% of the world's primary energy consumption (Saxena *et al*., 2009). It can be used for energy production cover a wide range of materials, and is being considered as an important energy resource all over the world. Biomass is used to meet a variety of energy needs, including generating electricity, fueling vehicles and providing process heat for industries. Among all the renewable sources of energy, biomass is unique as it effectively stores solar energy.

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Table 1. The basic information of samples in *Paulownia tomentosa*

Characteristics	Stem	Branch	Root
Green Density (g/cm^3)	0.75 ± 0.05	0.61 ± 0.04	0.75 ± 0.05
Air-dry Density (g/cm^3)	0.34 ± 0.01	0.37 ± 0.01	0.32 ± 0.01
Oven-dry Density (g/cm^3)	0.28 ± 0.01	0.32 ± 0.01	0.25 ± 0.01
Green Moisture Content (%)	233.1 ± 3.1	94.4 ± 6.6	204.6 ± 7.1

Furthermore, among different biomasses, wood has received the much more attention because of its long and continuing precedent as a fuel and biomass feed stock (Kumar *et al*., 2009). However, due to forest protection polices, there is hardly any large amount of supply from wood as feedstock. Thus, the waste wood such as small branch, root, leaf or bark should be utilized for available biomass materials. Equally, the choice of biomass source is influenced by the form in which the energy is required and it is the interplay between these two aspects that enables flexibility to be introduced into the use of biomass as an energy source. As indicated above, dependent on the energy conversion process selected, particular material properties become important during subsequent processing.

In order to solve the policy of wood demand and supply and the problem of CO_2 emission, it needs trying to find out valuable tree species which have fast growth rate and high CO_2 absorption capability. Moreover, it is necessary to explore and evaluate the utilization of fast growing tree species.

In this situation, *Paulownia* tree must be optimum wood species to meet above problems. That is, *Paulownia* tree is widely growing all over the world as potential biomass resources. It is known as a fast-growing tree, and could produce a cubic meter of wood at age of 5-7 years and reach about 15-25 m high in 5 years (Caparrós *et al*., 2008). It can be easily processed because of its soft and low density. Moreover, *Paulownia* timber can be easily air-dried without serous drying defects (Akyildiz and Kol, 2010). It has a low shrinkage coefficient and does not easily warp or crack (Flynn & Holder, 2001; Akhtari *et al*., 2011).

On the study of solid bioenergy properties, we could not find the references on bioenergy properties of *Paulownia* tree, except our precious report (Qi *et al*., 2016). The objective of this study, therefore, is to evaluate the solid bioenergy properties as heating value, pH, proximate analysis for whole tree utilization of *P. tomentosa*, and compare them in stem, branch, root, bark and leaf.

2. MATERIALS and METHODS

2.1. Materials

Paulownia tomentosa trees of the eleven and thirteen years old were obtained from research forest (N 37°51'/ E 127°48') of Kangwon national university in South Korea. The sample trees were separated into stem, branch, root, bark and leaf. The DBH of sample trees was 30.9 and 31.2 cm (Qi *et al*., 2016). The basic information of samples is shown in Table 1.

2.2. Heating value and pH

The heating value was measured with oven-dried powder of 0.5 g using an oxygen bomb calorimeter (Parr 6300 calorimeter) in accordance with the Korean standard (KS E 3707 2011).

For pH measurement, oven-dried powder samples (1 g) were mixed with distilled water of 100 mℓ and boiled for 10 min. After cooling to room temperature, the pH of the supernatant solution was determined with a pH meter (InoLab, pH Level 2).

2.3. Proximate analysis

For measurement of ash content, oven-dried samples powder (1 g) was burned in an electric furnace at 815℃ for 3 h. After cooling to room temperature in a desiccator, the samples were reweighed (KS E ISO562 2012).

For measurement of volatile matter content (VMC), oven-dried samples powder (1 g) was burned in an electric furnace at 900℃ for 7 min. After cooling to room temperature in a desiccator, the samples were reweighed (KS E ISO117 2012).

The fixed carbon content (FCC) was estimated using the following equation:

$$FCC\ (\%) = 100 - \text{ash content}\ (\%) - VMC\ (\%)$$

All the measurements were repeated five times.

3. RESULTS and DISCUSSIONS

3.1. Heating value

Heating value is an important thermochemical property which evaluates the quality of fuel in combustion process. It can be attributed to the quantitative conversion of fuel carbon and hydrogen into water and carbon dioxide, and is a function of fuel chemical components (Senelawa and Sims, 1999).

The heating values of *P. tomentosa* are shown in Table 2. The heating values of stem, branch, root, bark and leaf were found to be 4521, 4593.3, 4425.8, 4258.4, and 4114.8 kJ/g, respectively. The branch showed highest heating value, while leaf was the lowest among all the samples. The difference in heating value among different parts may be depending on the ash content of biomass fuel. In our previous study, the higher heating value was observed in the compression wood (CW) with lower ash content, while that of tension wood (TW) with higher ash content showed lower heating value than CW (Qi *et al*., 2016). Kataki and Konwer (2001) examined that the heating value of raw wood and the ash-free modified wood. They reported that ash content has negative effect on the heating value, and revealed that high ash content in some wood species makes them less

Table 2. The heating value and pH of *Paulownia tomentosa*

Experimental samples	Heating value (cal/g)	pH	*Heating value NIFS (2013)
Stem	4521.5 ± 23.9	4.94 ± 0.03	> 4300 kcal/kg
Branch	4593.3 ± 22.1	4.88 ± 0.05	> 4300 kcal/kg
Root	4425.8 ± 47.8	4.96 ± 0.01	> 4300 kcal/kg
Bark	4258.4 ± 23.1	5.48 ± 0.11	> 3500, < 4300 kcal/kg
Leaf	4114.8 ± 19.2	6.17 ± 0.20	> 3500, < 4300 kcal/kg

Note: *According to the standards and quality compliant of wood chips for fuel (NIFS, 2013)

available for fuelwood. Gravalos *et al*. (2010) also investigated the calorific energy distribution in the main stem, branches, root and leaves of cotton, and reported that the caloric value of leaves (16.06 kJ/g) was lower than that of stem (17.7 kJ/g), branches (17.4 kJ/g) and root (17.7 kJ/g). They suggested that the ash content might be one of the reasons which influence the heating values. According to Ebeling and Jenkins (1985), the ash content in wheat and barley straws influenced to their lower heating values.

In comparison with the standards and quality compliant of wood chips for fuel (NIFS, 2013) in Table 2, the heating values of stem, branch and root obtained from *P. tomentosa* were more than 4300 kcal/kg, while those of bark and leaf were ranged from 3500 to 4300 kcal/kg. As a result, the results in this study satisfied with the standard of NIFS.

Consequently, these results suggest that the utilization of *P. tomentosa* for bioenergy resources must be possible. Even though there was a little difference in heating value among wood, bark and leaf, the obtained data also showed that the bark and leaf could be used as a bioresource.

3.2. pH

The pH of all samples from *P. tomentosa* is summarized in Table 2. The pH of stem, branch, root, bark and leaf was found to be 4.94, 4.88, 4.96, 5.48 and 6.17, respectively. Specifically, pH of branch was the lowest, and that of leaf was the highest among all the samples. These results might be attributable to the ash content. Todaro *et al*. (2015) compared the effect of ash content on pH of three wood species, and stated that higher pH value could be depend on the higher ash content. The ash content of branch was the lowest among all the samples, and hence the branch showed lower pH value as for weak acidity. On the other hand, the pH might be due to the moisture content of samples. Read *et al*. (1969) determined that the pH of western red cedar increased from 4.3 to 5.3 as the moisture content of the wood increased from 20 to 70%, and the pH of western hemlock increased from 4.0 to 4.8 when the moisture content increased from 10 to 55%. Sitholé (2005) also stated that the pH of the black spruce chips increased with increasing moisture content. The reason of lower pH at lower

Table 3. The bioenergy properties in stem, branch, root, bark and leaf of *Paulownia tomentosa*

samples	Ash content (%)	VMC (%)	FCC (%)	*Ash content NIFS (2013)
Stem	0.23 ± 0.02	87.87 ± 1.21	11.94 ± 0.05	< 0.7%
Branch	0.19 ± 0.01	86.66 ± 0.20	13.10 ± 0.03	< 0.7%
Root	0.48 ± 0.01	86.55 ± 0.39	12.97 ± 0.13	< 0.7%
Bark	2.89 ± 0.13	79.77 ± 1.1	17.36 ± 1.20	> 1.5, < 3.0
Leaf	6.0 ± 0.07	81.41 ± 0.55	12.61 ± 1.50	≒ 6.0

Note: *According to the standards and quality compliant of wood chips for fuel (NIFS, 2013).

moisture content might be depended on the hydrolysis of the acetyl groups to form acetic acid (Allen, 2000). Thus, in this study, it can be considered that the highest pH of leaf was attributable to its highest moisture content, and the lowest pH of branch was referred to its lowest moisture content. Furthermore, the pH values of bark and leaf were much higher than those of stem, branch and root, which resulted in the drastically higher moisture content of bark and leaf.

3.3. Proximate analysis

The proximate analysis data of all samples from *P. tomentosa* are summarized in Table 3. The higher ash content existed in the bark and leaf compared to the wood materials, 2.8 and 6.0%, respectively. Whereas, ash contents of stem, branch, and root were 0.23, 0.19, and 0.48%, respectively, which showed the lowest value in the branch among all samples. This variation of ash at different parts of one tree was due to the concentration of potassium in the actively metabolizing positions of the tree crown and leaf where the nutrients from the soil and fixed prior to relocation to other parts of the plant (Senelawa and Sims, 1999). Rhen *et al*. (2007) compared the different type woody materials from same tree, such as stem, branch and bark, and reported that the ash content of bark was highest among these three types. Kataki and Konwer (2001) revealed that leaf and bark had much higher ash content than stem and twig of four indigenous perennial tree species. Moreover, the ash contents of woody parts, as stem, branch and root obtained from *P. tomentosa*, were lower than 0.7% in the standards and quality compliant of wood chips for fuel (NIFS, 2013). Ash contents of bark and leaf were 2.89% and 6%, which were satisfied with the standard of NIFS.

The volatile matter content (VMC) obtained in this experiment is shown in Table 3. The wood parts in stem, branch and root showed higher VMC than bark and leaf. These results might be indicated that wood is more reactive than bark and leaf.

The bark had the highest FCC among all samples. Some previous studies (Demirbas, 2003; Qi *et al*., 2016) suggested that lignin content of biomass materials had a highly significant correlation with FCC, which the higher FCC was referred to the higher lignin content and lower contents of cellulose and hemicelluloses.

4. CONCLUSION

The bioenergy characteristics varied among different parts of whole tree, such as wood, bark and leaves. The heating values of wood parts were slightly higher than those of bark and leaf, and that of branch was highest among all the samples. The higher moisture content of bark and leaf referred to the lower heating value. Also, the pH of stem, branch and root was similar, and lower than those of bark and leaf. The ash content of bark and leaf was much higher than those of wood parts. The stem, branch and root showed higher VMC than bark and leaf. The bark showed the highest FCC among all the samples. Overall, the bioenergy properties as heating value and ash content of *P. tomentosa* satisfied with the standard of NIFS. Even if there are somewhat differences in bioenergy properties among samples, but the waste forest materials such as bark and leaf could be also used as the bioenergy materials.

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Tanem, B.S., Kvien, I., van Helvoort, A.T.J. 2006. Morphology of Cellulose and Its Nanocomposites. In: Cellulose Nanocomposites: Processing, Characterization, and Properties, ACS Symposium Series 938, Ed. by Oksman, K. and Sain, M., American Chemical Society, Washington DC, USA.

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Walford, G.B. 2003. Research and wood industry in Australia and New Zealand. In: Lee, H.-H. and Jang, S.-S., (eds), Daejeon, Republic of Korea, Proc. of 11th the International Association of Wood Products Societies (IAWPS 2003), pp. 3~13.

<Thesis>

Lyons, C.K. 2001. Mechanical stresses in trees resulting from strain compatibility in an anisotropic material. Ph.D. Thesis, Oregon State University, USA.

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