

# Solid Bioenergy Properties of Paulownia tomentosa Grown in Korea

*By* Yue Qi; Chunmei Yang; Wahyu Hidayat; Jae-Hyuk Jang; Nam-Hun Kim

16

## Journal of The Korean Wood Science and Technology

### Aims and Scope

The *Journal of The Korean Wood Science and Technology* (JKWST) launched in 1973 as an official publication of The Korean Society of Wood Science and Technology has been served as a core of knowledges on wood science and technology. The Journal acts as a medium for the exchange of research in the area of science and technology related to wood, and publishes results on the biology, chemistry, physics and technology of wood and wood-based products. Research results about applied sciences of wood-based materials are also welcome. The Journal is published bimonthly, and printing six issues per year. Supplemental or special issues are published occasionally.

The abbreviated and official title of the journal is '*J. Korean Wood Sci. Technol.*'. All submitted manuscripts written in Korean or English are peer-reviewed by more than two reviewers. The title, abstract, acknowledgement, references, and captions of figures and tables should be provided in English for all submitted manuscripts. Some of the articles are indexed in Korea Citation Index (KCI) and SCOPUS.

All manuscripts should be submitted to the editorial office via the e-mail. The URL address of the Society is <http://www.kswst.or.kr/>. The URL address of Journal is [http://www.kswst.or.kr/html/sub03\\_06.asp](http://www.kswst.or.kr/html/sub03_06.asp) where full text is available. This journal was supported by the Korean Federation of Science and Technology Societies (KOFST) Grant funded by the Korean Government.

## Journal of The Korean Wood Science and Technology

Volume 44, Number 6, Printed on November 25, 2016

© All rights are reserved for The Korean Society of Wood Science and Technology.

Published by and Subscription Order to:  
The Korean Society of Wood Science and Technology  
c/o Department of Forest Products  
Korea Forest Research Institute (KFRI)  
2nd Floor, Namu Byungwon-dong  
57 Hoegi-ro, Dongdaemun-Gu  
Seoul 02455, Republic of Korea  
E-mail : wood@kswst.or.kr  
There is a charge for the subscription.

Printed by:  
Green Pine Media Inc.  
Tel: (02)2274-1128, Fax: (02)2266-4427

## Solid Bioenergy Properties of *Paulownia tomentosa* Grown in Korea<sup>1</sup>

Yue Qi<sup>2,4</sup> · Chunmei Yang<sup>3</sup> · Wahyu Hidayat<sup>2,5</sup> · Jae-Hyuk Jang<sup>2</sup> · Nam-Hun Kim<sup>2,†</sup>

### 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 con-

sumption (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.

<sup>1</sup> Date Received August 19, 2016, Date Accepted October 12, 2016

<sup>2</sup> College of Forest and Environmental Sciences, Kangwon National University, Chuncheon 24341, Republic of Korea

<sup>3</sup> Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing 100091, China

<sup>4</sup> Forestry and Wood Working Machinery Engineering Technology Center, Northeast Forestry University, Harbin 150040, China

<sup>5</sup> Department of Forestry, Faculty of Agriculture, Lampung University, Bandar Lampung, Indonesia

<sup>†</sup> Corresponding author: Nam-Hun Kim (e-mail: kimnh@kangwon.ac.kr)

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

Characteristics	Stem	Branch	Root
Green Density (g/cm <sup>3</sup> )	0.75 ± 0.05	0.61 ± 0.04	0.75 ± 0.05
Air-dry Density (g/cm <sup>3</sup> )	0.34 ± 0.01	0.37 ± 0.01	0.32 ± 0.01
Oven-dry Density (g/cm <sup>3</sup> )	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 policies, 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<sub>2</sub> emission, it needs trying to find out valuable tree species which have fast growth rate and high CO<sub>2</sub> 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 serious 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°C 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°C 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:

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

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 high-

er 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.

#### ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. NRF-2016R1D1A1B01008339). Yue Qi also sincerely thanks the ACES-KNU scholarship of Kangwon National University for financial

support from 2012.

#### REFERENCES

- Akyildiz, M.H., Kol, H.S. 2010. Some technological properties and uses of paulownia (*Paulownia tomentosa* Steud.) wood. *Journal of Environmental Biology* 31: 351~355.
- Akhtari, M., Ghorbani-Kokandeh, M., Taghiyari, H.R. 2012. Mechanical properties of *Paulownia fortunei* wood impregnated with silver, copper and zinc oxide nanoparticles. *Journal of Tropical Forest Science* 24: 507~511.
- Allen, L.H. 2000. Pitch control in pulp mills, in *Pitch Control, Wood Resin and Deresination*, E.L. Back and L.H. Allen (editors), TAPPI Press, Atlanta, Ch 11.
- Caparrós, S., Díaz, M.J., Ariza, J., López, F., Jiménez, L. 2008. New perspectives for *Paulownia fortunei* L. valorisation of the autohydrolysis and pulping processes. *Bioresource Technology* 99: 741~749.
- Demirbas, A. 2003. Relationships between lignin contents and fixed carbon contents of biomass samples. *Energy Conversion and Management* 44: 1481~1486.
- Ebeling, J.M., Jenkins, B.M. 1985. *Physical and Chemical Properties of Biomass Fuels*. American Society of Agricultural Engineers 28: 898~902.
- Flynn, H., Holder, C. 2001. *Useful wood of the world*. Forest Products Society 2nd Ed, Madison, WI, p.618.
- Gravalos, I., Kateris, D., Xyradakis, P., Gialamas, T., Loutridis, S., Augousti, A., Georgiades, A., Tsiropoulos, Z. 2010. A study on calorific energy values of biomass residue pellets for heating purposes. In: *forest engineering: meeting the needs of the society and the environment*; FORMEC symposium, Padua, Italy.



- Kataki, R., Konwer, D. 2001. Fuelwood characteristics of some indigenous woody species of north-east India. *Biomass and Bioenergy* 20: 17 ~23.
- Kaltschmitt, M., Hartmann, H., Hofbauer, H. 2009. Energy from biomass. Fundamentals, techniques and procedures. 2nd ed. Springer, Berlin.
- Kumar, R., Chandrashekar, N., Pandey, K.K. 2009. Fuel properties and combustion characteristics of Lantana camara wood charcoal. *Journal of Indian Academic Wood Science* 10: 134~139.
- KS E 3707. 2011. Determination of calorific of coal and coke. Korean standards association.
- KS E ISO1171. 2012. Solid mineral fuels-Determination of ash content. Korean standards association.
- KS E ISO562. 2012. Hard coal and coke-Determination of volatile matter. Korean standards association.
- Poddar, S., Kamruzzaman, M., Sujan, S.M.A., Hossain, M., Jamal, M.S., Gafur, M.A., Khanam, M. 2014. Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. *Fuel* 131: 43~48.
- Qi, Y., Jang, J.H., Hidayat, W., Lee, A.H., Lee, S.H., Chae, H.M., Kim, N.H. 2016. Carbonization of reaction wood from *Paulownia tomentosa* and *Pinus densiflora* branch woods. *Wood Science and Technology* pp. 1-15.
- Qi, Y., Jang, J.H., Hidayat, W., Lee, A.H., Kim, N.H. 2016. Anatomical characteristics of *Paulownia tomentosa* root wood. *Journal of Korean wood science and technology* 44(2): 157 ~165.
- Reardon, D.W., Wong, P.Y., Eade, B.D. 1969. Determination of wood pH with indicators. *Pulp Paper Can.* 70(18): 80~85.
- Rhena, C., Ohmanb, M., Grefa, R., Wasterlunda, I. 2007. Effect of raw material composition in woody biomass pellets on combustion characteristics. *Biomass and Bioenergy* 31: 66~72.
- Saxena, R.C., Adhikari, D.K., Goyal, H.B. 2009. Biomass-based energy fuel through biochemical routes: A review. *Renewable and Sustainable Energy Reviews* (13): 167~178.
- Senelick, K., Sims, R.E.H. 1999. Fuel characteristics of short rotation forest biomass. *Biomass and Bioenergy* 17: 127~144.
- Siththaratne, B. 2005. New method of measuring the pH of wood chips. *Pulp and Paper Canada* 106: 42 ~45.
- Standards and quality compliant of wood chips for fuel. 2013. National Institute of Forest Science 4: 1~16.
- Todaro, L., Rita, A., Cetera, P., D'Auria, M. 2015. Thermal treatment modifies the calorific value and ash content in some wood species. *Fuel* 140: 1~3.

학회소식

**2016 대한민국 산림문화박람회 홍보 부스 운영**

- 주 제 : 숨과 쉼이 함께하는 웰니스의 향연
- 일 시 : 2016년 10월 21일(금) ~ 10월 30일(일)
- 장 소 : 충남 예산군 덕산온천 관광지구 일원
- 주요내용 : 공식행사, 전시, 산림 및 온천 체험, 임산물시장, 산림경영 컨설팅, 공연, 국화 전시

회원소식

- 김광철 이사, 목조주택 설계 가이드 출판. 전북대학교출판문화원. ISBN 978-89-98534-93-6 (2016. 8. 31)
- 박상범 상임이사, 제19회 농림축산식품과학기술대상 대통령상 수상(2016. 10. 19.)
- 조남석 고문, 제4회 현신규학술상 대상 수상(2016. 10. 21)
- 한규성 상임부회장, 제15회 산의날 근정포장 수상(2016. 10. 18)

## Instruction to Authors

Authors are requested to carefully abide by the 'Instruction to Authors' to ensure that reviewing and publication process of the manuscript be properly handled in a due course. Manuscript will be returned to the author if it is not properly presented according to the following instructions.

### Types of Publications

The Journal publishes original article, short note, communication, and review article. The original article should be a comprehensive report containing significant new research data and/or new interpretations of existing data with special emphasis on industrial applications.

### Research Ethics Policy

Manuscripts submitted to the Journal are not copyrighted, published, or submitted elsewhere, except in abstract form. Review articles should provide critical surveys of progresses in a specific field of science, engineering, or technology related to wood. For the policies on the research and publication ethics not stated in this instructions, International standards for editors and authors (<http://publicationethics.org/international-standards-editors-and-authors>) can be applied. And the corresponding author should submit the Declaration of Ethical Conduct in Research and Publication.

### Process of a Disciplinary Action

When a disciplinary action is recommended by the ethics committee, the chairman should convene a board meeting to determine whether or not to take any disciplinary action. A warning, suspension or dismissal of a membership can be applied to the member who has violated ethical policy. The result of the final decision may be made public if necessary.

When the manuscript submitted is proved to have committed misconduct in its research, the editorial board should reject or withdraw it. The author should be banned of submitting a manuscript to this journal for three years from the time of decision.

### Submission and Inquiry

Manuscript that contains all texts (title page, abstract, body of the article, captions, and references) and tables should be one file in a format of Microsoft Word for Windows or Hangul (Korean Word Processor). Name the file with the corresponding author's name. Do not include any page-layout instructions such as graphics placement. Carriage returns should be used only to end headings and paragraphs, and the auto-hyphenation should be turned off. Tables may be created using text mode or table format; the latter is preferred.

Submission of electronic illustrations is encouraged, but not required. Each illustration (figure, scheme, etc.) should be in a separate file. The file should be named descriptively; e.g. Figure 1 or Figure 2.

Authors are requested to submit the manuscript via e-mail, and to send any inquiry to the Editorial Office shown below:

Editorial Office of The Korean Society of Wood Science and Technology  
c/o Department of Forest Products  
Korea Forest Research Institute (KFRI)  
2nd Floor, Namu Byungwon-dong  
57 Hoegi-ro, Dongdaemun-Gu  
Seoul, 130-712, Republic of Korea  
Tel: +82-2-877-4781  
Fax: +82-2-877-4780  
E-mail: [kswstwood@gmail.com](mailto:kswstwood@gmail.com)

### Review and Revisions

All contributions are reviewed by two or more peer referees to ensure both accuracy and relevance, and revisions may thus be required. Reviewers make decision on the review of a manuscript upon four categories: 1) Accept without revision, 2) Accept with minor revision, 3) Accept with major revision and re-review, and 4) Reject.

When a manuscript is sent back to an author for the revision, the revised version should be returned with 'Response to Reviewer's Comments', specifying changes made in the revision as soon as possible after the corresponding author receives the reviewers' reports. Revised manuscript that is not returned in two (2) months is considered withdrawn. A formal notification will be sent to the corresponding author after the manuscript has been accepted for publication.

### Preparation of Manuscripts

All manuscripts must be written in clear and concise either in Korean or English, typewritten, double-spaced, on one side of A4 paper with adequate margins and proper page number at every sheet of paper.

### Arrangement

Manuscript is arranged in the following order. Each starts on a new sheet.

#### 1. Title Page.

Manuscript title, author's name, and affiliation. The corresponding author(s) should be clearly indicated with cross (†). The affiliation should comprise the department, institution, city, postal code, and nation. Please also suggest an abbreviated title limited to 80 characters (including spaces) for running head.

#### 2. Abstract.

An abstract that contains less than 250 words must be provided with all types of manuscripts. The abstract outlines in a single paragraph the

aims, scope, methods, significant findings, and conclusions of the contribution. Provide less than seven keywords that best represent the content of the paper.

#### 3. The Text.

Suitably divided under such headings as Introduction, Experimental, Results and Discussion, and Conclusions.

#### 4. Acknowledgment(s) (if any).

#### 5. References (and Notes, if any).

#### 6. Tables. Each on a separate sheet.

#### 7. Captions for Illustrations.

#### 8. Illustrations.

Each on a separate sheet containing no text. Labeled with the author's name and illustration number.

#### 9. Appendix (if any).

### Nomenclature and Units

Each paper should be consistent within itself as to abbreviations, symbols, and units. Authors should use SI units wherever possible. Nomenclature should conform to that recommended by the International Union of Pure and Applied Chemistry and Chemical Abstracts Service.

### Equations and Formulae

Complicated chemical equations, formulae, and schemes should be presented as furnished artwork. Mathematical expressions and chemical formulae should be typed with available symbols and letters. Capital, lower case, and Greek letters should be easily discernible, and identified in the margin so that ambiguities could be protected. Equations should be numbered consecutively throughout the paper with Arabic numerals in parentheses placed flush right, and should be thusly referred to in the text [such as Equation (2)].

### Tables

Tables should be numbered in Arabic numerals in

the order of mention in the text. A table should have a descriptive title (above the table) and appropriate column headings. Avoid tables and graphs that involve duplication. If you use a graph, do not include a table of the same data: If the readers need a table, omit the graph. Present a few representative results for lengthy table when practical.

### Illustrations

Figures and graphs should be carefully prepared in either black and white, or color. Figures and graphs in color could be printed in a PDF format at the web site. However, printing those in a hardcopy will result in an extra page charge. It should be of sufficient size so that after photo-reproduction to a single-column width (8 cm) the smallest letter could be 2 mm. Legend should be placed in a proper space of the drawings, not in the caption, whenever possible. Original copies of the graphs, drawings, and photographs should be numbered in Arabic numerals in the order of mention in the text, and included at the end of the manuscript.

### Photographs

Photographs are accepted with additional charge. The current charge for the processing of photographs is 2,500 Won or equivalent per each black-and-white photograph and 20,000 Won or equivalent per each color photograph.

### References (and Notes)

All references and explanatory notes, if any, should be cited within the text by authors last name and year of publication in parentheses. In the case of more than two authors, only the first author is listed, e.g. (Hill *et al.*, 2009).

An alphabetical order of all the cited references and notes should be listed according to the first authors' name, together with the title of the paper, the full journal title, and the full quotation of the bibliographical reference at the end of the text. Examples of bibliographic references are given below:

### <Articles in journals>

- Konnerth, J., Gindl, W. 2006. Mechanical characterisation of wood-adhesive interphase cell walls by nanoindentation. *Holzforschung* 60(4): 429~433.
- Kisser, J.G., Ylinen, A., Freudenberg, K., Kollmann, F.F.P., Liese, W., Thunell, B., Winkelmann, H.G., Côté Jr., W.A., Koch, P., Marian, J.E., Stamm, A.J. 1967. History of wood science. *Wood Science and Technology* 1(3): 161~190.

Examples of reference citation in the text:

- Two authors only: (Konnerth and Gindl, 2006)
- More than three authors: (Kisser *et al.*, 1967)

### <Books and Book Chapter>

- Fengel, D., Wegener, G. 1984. *Wood: Chemistry, Ultrastructure, Reactions*. De Gruyter, Berlin, Germany.
- 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.

### <Conference Papers>

- 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.

Any queries regarding accepted papers, proofs or reprints should be directed to the same address.

### Proofs and Reprints

Galley proofs, original manuscript, cut copy, and Reprint Order Form are sent by the Society directly to the corresponding author. The attention of the au-

thor is directed to the instruction which accompanies the proof, especially the requirement that all corrections, revisions, and additions should be entered on the proof and not on the manuscript. Proofs should be checked against the manuscript (in particular all tables, equations, and formulae, since this is not done by the editorial board), and returned as soon as possible.

Authors are entitled 30 free reprints of the article. Should the author needs additional reprints, the fil-

led-out Reprint Order Form must be returned with the payment.

**Page Charges**

Page charges defray a part of the cost of publication. The bill is issued with the shipment of the reprints. The current charge is 80,000 Won for 6 printed pages, and 40,000 Won/printed page for more than 6 printed pages.

## Checklist for Authors

Title of the manuscript submitted:

Please check below items as ✓ mark before the submission of the manuscript.

### **1. General guidelines**

- The manuscript submission contains one original main text manuscript (Figure, Table or Images included) and author's checklist should be dispatched to the Editorial Office via email (Statement of copyright transfer should be dispatched in a PDF format file after the end of reviewing process).
- Manuscript should be typed in Korean or English using word processor with a space of 30 mm from upper, lower, left and right margin, 10.0 pt in font size, and line space of 180%.
- The main text consists of title page, abstract, main text, references, tables and figures, which are properly placed throughout the main text.
- The main text consists of INTRODUCTION, MATERIALS AND METHODS, and RESULTS AND DISCUSSION, CONCLUSION, and REFERENCES.

### **2. Title page**

- Title, name of author and affiliation is written both in English and Korean, while all these should be written in English for the article that is expected to be published in English issue.
- The title page should provide the name, address, e-mail, telephone, and fax of the corresponding author.

### **3. Abstract and Keywords**

- The abstract is supposed to be less than 250 words.
- Less than seven keywords should be provided with the manuscript.

### **4. Main text**

- The order of the subtitle is described according to the Instruction to Authors.
- References in the main text are described according to the Instruction to Authors.

### **5. References**

- Every article in REFERENCES should be cited in the main text.
- References are cited the author's name and publication year as described in the Instruction to Authors.
- All references should be written in English, and listed by the same format as the Instruction to Authors.

### **6. Tables, figures, or Images**

- The titles and legends of the tables and figures should be written in English.
- Photos and images should have high quality enough to publication.

## Statement of Copyright Transfer

To: Editor-in-Chief of the Journal of The Korean Wood Science and Technology

Title of the manuscript submitted:

I hereby certify that I agree to submit the manuscript entitled as the above to Journal of The Korean Wood Science and Technology by abiding the following statements;

- This manuscript is original and there is no copyright problem, defamation and privacy intrusion. Any legal or ethical damage should not be directed to The Korean Society of Wood Science and Technology due to this manuscript.
- All authors made actual contribution to the manuscript in terms of scientific aspects, and were equally responsible for the manuscript.
- This manuscript was not published or considered for publication to any other scientific journals in the world. It will not be submitted again to other journals without permission from Editor-in-Chief of the Journal of The Korean Wood Science and Technology if it is accepted for publication.
- Copyright of this manuscript shall be transferred to The Korean Society of Wood Science and Technology if it is published in the Journal of The Korean Wood Science and Technology. It means that if any persons including authors want to use the contents of this manuscript, they should obtain the permission from the Society and the source of contents cited should be properly clarified.

Date:

Author Name	Signature

### **Disclosure Statement of Conflicts of Interests**

List any potential conflicts of interests of this manuscript (any financial support or benefits have been received by the author(s) that could affect the work reported in the article) or indicate "None".

---



## Declaration of Ethical Conduct in Research and Publication

Title:

	Name	Affiliation	Contact Information
<b>Corresponding Author</b>			Address: Tel: E-mail:

On the behalf of all authors, and as a corresponding author of the above manuscript submitted to the Journal of The Korean Wood Science and Technology, hereby, I swear that I follow the research ethics policy of The Korean Society of Wood Science and Technology, and I do not commit research misconduct as falsification, distortion of research findings, or plagiarism which damages any academic and ethical integrity, by declaring this ethical conduct in research and publication.

I am also declaring to accept the decision by the Editorial Board Members of The Korean Society of Wood Science and Technology if any misconduct occurs at any stage of the above mentioned research work.

Date:

Corresponding author:

(signature)

# Journal of The Korean Wood Science and Technology

## (Vol. 44, No. 6)

---

<b>Editor-in-Chief</b>	PARK, Byung-Dae (Kyungpook National University)
<b>Associate Editor</b>	ROH, Jung-Kwan (Gyeongnam National University of Science and Technology)
<b>Editorial Board Members</b>	JEONG, Gi Young (Chonnam National University) KANG, Seog Goo (Chungnam National University) KIM, Birm-June (Kookmin University) LEE, Seung-Hwan (Kangwon National University) LEE, Sun-Young (Forest Research Institute, Korea) LEE, Yang Soo (Chonbuk National University) PARK, Han-Min (Gyeongsang National University) PARK, Joo-Saeng (Forest Research Institute, Korea) SHIN, Soo-Jeong (Chungbuk National University) YEO, Hwanmyeong (Seoul National University)
<b>Editorial Assistant</b>	SUR, Sang-Hee (The Korean Society of Wood Science and Technology)
<b>Editing Manager</b>	PARK, Pyeong (Keuk Dong Design & Communication Co., Ltd)
<b>International Editorial Board Member</b>	DUFRESNE, Alain (Grenoble Institute of Technology, France) DUNKY, Manfred (Kronospan GmbH Lampertwalde, Germany) ENDO, Takashi (National Institute of Advanced Industrial Science and Technology, Japan) EVANS, Philip (University of British Columbia, Canada) FRIHART, Chuck R. (Forest Products Laboratory, USA) HADI, Yusuf Sudo (Bogor Agricultural University, Indonesia) LABBE, Nicole (University of Tennessee, USA) NIEMZ, Peter (Swiss Federal Institute of Technology (ETH), Switzerland) RAGAUSKAS, Arthur (Georgia Institute of Technology, USA) SAKA, Shiro (Kyoto University, Japan) SCHMITT, Uwe (Johann Heinrich von Thunen Institute (vTI), Germany) SINGH, Adya P. (SCION, New Zealand) SMITH, Greg (University of British Columbia, Canada) SUGIYAMA, Junji (Kyoto University, Japan) TOHMURA, Shin-ichiro (Forestry and Forest Products Research Institute, Japan) WONG, Andrew (University Malaysia Sarawak, Malaysia) YIN, Yafang (Chinese Academy of Forestry, China)

---

This Journal was supported by the Korean Federation of Science and Technology Societies  
Grant funded by the Korean Government (KFSTS).

**Published by THE KOREAN SOCIETY of WOOD SCIENCE & TECHNOLOGY**  
Volume 44, Number 6

Printed on November 22, 2016  
Issued on November 25, 2016

**Publisher:** Kim, Nam-Hun

**Editor:** Park, Byung-Dae

**Contact**

Tel: (+82)-2-877-4781

Fax: (+82)-2-877-4780

**Printed by** Keuk Dong Design & Communication Co., Ltd

Tel: (+82)-2-2274-7800

Fax: (+82)-2-2266-4427

**Submission to:**

Editor-in-Chief, Byung-Dae Park  
2<sup>nd</sup> Fl., Namoo Byungwondong,  
Korea Forest Research Institute,  
Seoul, 02455

Tel: (+82)-2-877-4781

Fax: (+82)-2-877-4780

E-mail: kswstwood@gmail.com

**Publisher:** Nam-Hun Kim

Department of Forest Biomaterials Engineering  
College of Forest and Environmental Sciences,  
Kangwon National University,  
Chuncheon, 24341

Tel: (+82)-33-250-8327

Fax: (+82)-33-256-8320

E-mail: wood@kswst.or.kr

# Solid Bioenergy Properties of Paulownia tomentosa Grown in Korea

ORIGINALITY REPORT

# 10%

SIMILARITY INDEX

## PRIMARY SOURCES

1	<a href="http://tappsa.co.za">tappsa.co.za</a> Internet	70 words — 1%
2	<a href="http://www.scribd.com">www.scribd.com</a> Internet	59 words — 1%
3	Kingiri Senelwa, Ralph E.H. Sims. "Fuel characteristics of short rotation forest biomass", <i>Biomass and Bioenergy</i> , 1999 Crossref	58 words — 1%
4	<a href="http://www.politesi.polimi.it">www.politesi.polimi.it</a> Internet	55 words — 1%
5	<a href="http://bioenergy.wvu.edu">bioenergy.wvu.edu</a> Internet	29 words — 1%
6	<a href="http://www.e-eml.org">www.e-eml.org</a> Internet	26 words — < 1%
7	"Handbook on Characterization of Biomass, Biowaste and Related By-products", Springer Science and Business Media LLC, 2020 Crossref	18 words — < 1%
8	Huanhuan Li, Xiuping Jiang, Hosahalli S. Ramaswamy, Songming Zhu, Yong Yu. "High-Pressure Treatment Effects on Density Profile, Surface Roughness, Hardness, and Abrasion Resistance of Paulownia Wood Boards", <i>Transactions of the ASABE</i> , 2018 Crossref	18 words — < 1%
9	J. L. Bowyer. "Wood science in a changing world - Where are we headed?", <i>Wood Science and</i>	18 words — < 1%

- 
- 10 [www.frim.gov.my](http://www.frim.gov.my) 16 words — < 1%  
Internet
- 
- 11 [www.pubmedcentral.nih.gov](http://www.pubmedcentral.nih.gov) 16 words — < 1%  
Internet
- 
- 12 Timothy Thamae, Ryan Marien, Lisa Chong, Christina Wu, Caroline Baillie. "Developing and characterizing new materials based on waste plastic and agro-fibre", *Journal of Materials Science*, 2008  
Crossref
- 
- 13 [www.ajol.info](http://www.ajol.info) 13 words — < 1%  
Internet
- 
- 14 Bhagwan Goyal, Hari, Diptendu Seal, and Rakesh Chandra Saxena. "Thermochemical Conversion of Biomass to Liquids and Gaseous Fuels", *Handbook of Plant-Based Biofuels*, 2008.  
Crossref
- 
- 15 [media.neliti.com](http://media.neliti.com) 12 words — < 1%  
Internet
- 
- 16 Unsal, O.. "Decay and termite resistance, water absorption and swelling of thermally compressed wood panels", *International Biodeterioration & Biodegradation*, 200907  
Crossref
- 
- 17 Sevgi Şensöz, Mukaddes Can. "Pyrolysis of Pine ( Pinus Brutia Ten.) Chips: 2. Structural Analysis of Bio-oil", *Energy Sources*, 2002  
Crossref
- 
- 18 Ritesh Kumar, K. K. Pandey, N. Chandrashekar, Sanjai Mohan. "Effect of tree-age on calorific value and other fuel properties of Eucalyptus hybrid", *Journal of Forestry Research*, 2010  
Crossref
- 
- 19 [costfp1407.iam.upr.si](http://costfp1407.iam.upr.si) 11 words — < 1%  
Internet

- 20 [ascelibrary.org](http://ascelibrary.org) Internet 10 words — < 1%
- 21 Ediger, V.S.. "Forecasting production of fossil fuel sources in Turkey using a comparative regression and ARIMA model", Energy Policy, 200612 Crossref 10 words — < 1%
- 22 Bruna Goncalves, Dustin Till, Oladiran Fasina, Bijay Tamang, Tom Gallagher. "Influence of Bark on the Physical and Thermal Decomposition Properties of Short-Rotation Eucalyptus", BioEnergy Research, 2015 Crossref 9 words — < 1%
- 23 [www.ejustice.lk](http://www.ejustice.lk) Internet 9 words — < 1%
- 24 Wei Sheng Zeng, Shou Zheng Tang, Qian Hui Xiao. "Calorific values and ash contents of different organs of Masson pine (Pinus massoniana) in southern China", Nature Precedings, 2012 Crossref 8 words — < 1%
- 25 [www.scirp.org](http://www.scirp.org) Internet 8 words — < 1%
- 26 [link.springer.com](http://link.springer.com) Internet 8 words — < 1%
- 27 Saumen Poddar, Mohammed Kamruzzaman, S.M.A. Sujan, M. Hossain, M.S. Jamal, M.A. Gafur, Mahfuza Khanam. "Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value", Fuel, 2014 Crossref 8 words — < 1%
- 28 "Wood is Good", Springer Science and Business Media LLC, 2017 Crossref 8 words — < 1%
- 29 Xu, H.. "Study on coalbed methane accumulation characteristics and favorable areas in the Binchang area, southwestern Ordos Basin, China", International Journal of Coal Geology, 20120601 Crossref 7 words — < 1%

---

EXCLUDE QUOTES    ON  
EXCLUDE  
BIBLIOGRAPHY    ON

EXCLUDE MATCHES    OFF