Original Article
J. Korean Wood Sci. Technol. 2022, 50(6): 404-413
https://doi.org/10.5658/WOOD.2022.50.6.404

Journal of the Korean Wood Science and Technology
pISSN: 1017-0715 eISSN: 2233-7180
http://www.woodj.org

Investigation of Sound Absorption Ability of *Acanthopanax senticosus* Wastes

Eun-Suk JANG[1,2,†]

ABSTRACT

This study aims to investigate the sound absorption ability of *Acanthopanax senticosus* wastes as an eco-friendly sound-absorbing material. The sound absorption coefficient was examined with different heights of *A. senticosus* wastes filling (40, 60, 80, and 100 mm) in impedance tubes. The sound absorption peaks shifted to a lower frequency as the height of *A. senticosus* wastes inside the tubes increased. The sound absorption ability at filling heights of 80 and 100 mm was obtained as 0.3M and 0.5M grades, respectively, based on KS F 3503. The results suggest that *A. senticosus* wastes exhibit good sound absorption ability and can therefore be used as an efficient, eco-friendly sound-absorbing material.

Keywords: *Acanthopanax senticosus*, eco-friendly sound-absorbing material, sound absorption peak, sound absorption performance

1. INTRODUCTION

Forests are excellent carbon sinks. Trees store carbon as they grow, and harvesting trees for wood products can contribute to reduce greenhouse gas emissions (Ahn *et al.*, 2021; Galih *et al.*, 2020; Yang *et al.*, 2020). Because the most widely used building materials, such as steel and concrete, store very little carbon, whereas wood can store half its weight as carbon dioxide (Churkina *et al.*, 2020). Also, carbon dioxide emissions from wood can be postponed until after it has completely decomposed (Kim *et al.*, 2019).

Wood is the most widely used material for the preparation of structures, floors, and interiors of a building. In addition, wood is one of the most eco-friendly materials in various application areas such as furniture, sports equipment, musical instruments, art, and pulp (Ahn *et al.*, 2021; Fortin-Smith *et al.*, 2019; Ghani and Lee, 2021; Han *et al.*, 2021; Jamaludin *et al.*, 2020; Kim and Kim, 2020; Lee *et al.*, 2021a, 2021b; Sedliačiková *et al.*, 2021; Yoo *et al.*, 2021).

Not only that, extracts of some tree species are used as herbal medicine. Especially, the extracts of the species such as *Kalopanax pictus, Prunus sargentii, Cudrania tricuspidata, Aralia eleta* Seemann, and *Acanthopanax senticosus* are widely used as herbal medicines and food products in Korea (Hong and Hong, 2015; Jia *et al.*, 2021; Kang, 2018; Lee *et al.*, 2001).

The present study focuses on *A. senticosus*. *A. senticosus* which has been classified as an adaptogen (anti-

Date Received March 10, 2022, Date Revised July 18, 2022, Date Accepted October 26, 2022
[1] Research Institute of Human Ecology, College of Human Ecology, Jeonbuk National University, Jeonju 54896, Korea
[2] R&D Center, Sambo Scientific Co. Ltd., Seoul 07258, Korea
[†] Corresponding author: Eun-Suk JANG (e-mail: esjang@sambosc.com, https://orcid.org/0000-0001-5995-8617)

stress natural substance that improves adaptability to various stresses) herbal medicine candidate by the European Medicines Agency (Lee, 2020). In addition, Korean (red) ginseng, *Rhodiola sachalinensis*, and *Schiznadra chinensis* are few other adaptogen herbal medicine candidates; however, only *A. senticosus* is material from wood (Lee, 2020). Thus, *A. senticosus* is widely used in herbal medicine or a functional food in Korea. About 21.7 hectares of *A. senticosus* are cultivated in Gangwon-do. Recently, the cultivated area has been increasing in Jeollabuk-do, and Chungcheongnam-do (GNARES, 2020).

The extracts of *A. senticosus* have been widely used. However, their by-products have been rarely studied for any applications. The by-products of *A. senticosus* store carbon dioxide even after the extraction of their active ingredients. Therefore, in this study, the recycling method of *A. senticosus* wastes was reviewed in terms of using wood by-products that contribute to carbon neutrality.

Wood and forest-by products have been suggested as a natural sound-absorbing materials (Iswanto *et al.*, 2020; Jang, 2022a, 2022b, 2022d; Jung *et al.*, 2020; Jung *et al.*, 2021). Previous studies have reported that the pore structure of wood has a sound-absorbing effect (Jang and Kang, 2021a, 2021d, 2021e; Jiang *et al.*, 2004; Taghiyari *et al.*, 2014). When wood is subjected to heat treatment such as high-temperature oven-drying, microwave, or steam explosion, the pores are converted into an open-pore structure, and the sound absorption performance can be further improved (Jang and Kang, 2021b; Jang and Kang, 2022; Kang *et al.*, 2021). *A. senticosus* is boiled at a high temperature for a long time to obtain the extract for herbal medicine. The porosity of *A. senticosus* increases after the removal of the extract; accordingly, the sound-absorption performance improves (Jia *et al.*, 2021).

This study expected that the porous structure of *A. senticosus* and the gap between *A. senticosus* could produce a sound absorption effect. The primary purpose of this study was to investigate whether *A. senticosus* wastes from which valuable components have been removed can be utilized as a natural porous sound-absorbing material. Furthermore, this study intends to increase the application value of *A. senticosus* wastes.

2. MATERIALS and METHODS

2.1. Sample preparation

Fig. 1 shows a schematic of the preparation of the one-year-old *A. senticosus* samples used in this study. The samples were supplied by a Korean herbal medicine shop (Jecheon, Korea). Their diameter and length were approximately 5–10 mm and 50–60 mm, respectively. The samples were boiled at 100℃ for 2 h and then cut

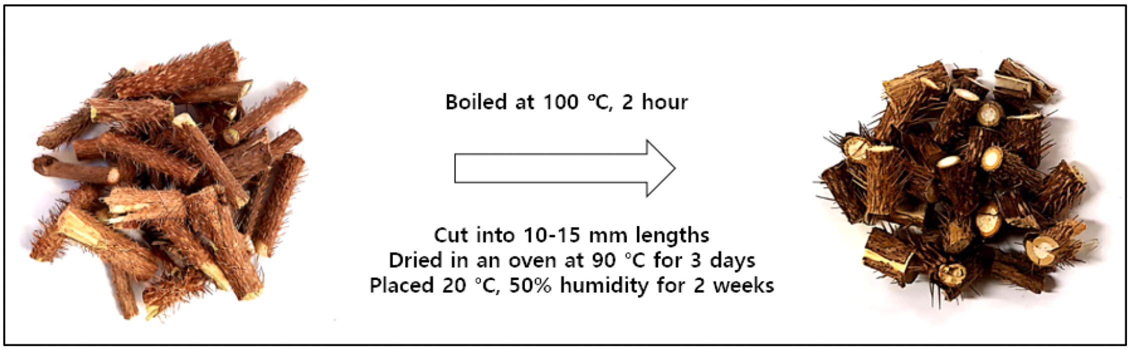

Fig. 1. Preparation of *Acanthopanax senticosus* wastes.

into 10–15 mm lengths followed by drying in an oven at 90℃ for three days.

The shorter lengths of the *A. senticosus* wastes enhance the exposed cross-sectional area and number of open pores to the incident sound wave. The samples were then stored in a laboratory at a temperature of 20℃ and a humidity of 50% for approximately two weeks. Then, 100 g of wastes was dried at 105℃ for approximately seven days to measure the moisture content (MC) in the samples (Korean Standards Association, 2016). The final weight of the dried wastes was measured as 91 g, which indicates that the MC was approximately 9%.

2.2. Scanning electron microscopy (SEM)

The pore structure of the *A. senticosus* wastes was observed by SEM (Genesis-1000, Emcraft, Gwangju, Korea). Prior to SEM imaging, the samples were dried in a laboratory oven at 50℃ for approximately 2 h to remove the surface moisture. Then, a thin layer of gold was deposited on the samples to prevent the surface charging during SEM imaging. Then, the cross-sections and thorn surfaces of the wastes samples were observed at magnifications of 200 × and 500 ×.

2.3. Sound absorption coefficient

The sound absorption coefficients of *A. senticosus* wastes were evaluated using an impedance tube (type 4206, Brüel & Kjær, Nærum, Denmark) designed in accordance with the ISO 10534-2 (International Organization for Standardization, 2001) same as the author's previous studies (Jang, 2022b, 2022c, 2022d). *A. senticosus* wastes were filled to a height of 40, 60, 80, and 100 mm in two different impedance tubes with diame-

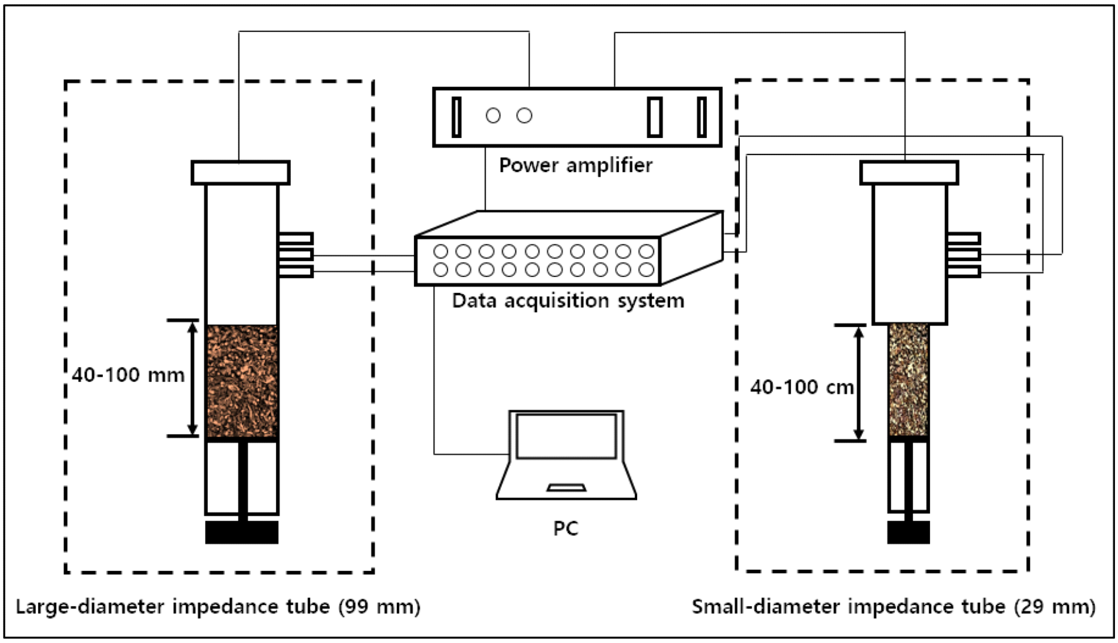

Fig. 2. Schematic of the experimental setup for sound absorption coefficient measurement using impedance tubes of 29 mm and 99 mm diameter.

ters of 29 and 99 mm (Fig. 2). The absorption coefficient was measured in the frequency ranges of 500–6,400 Hz and 100–1,600 Hz for the small diameter (29 mm) and large diameter (99 mm) impedance tubes, respectively.

The sound absorption coefficient of a material varies with different frequencies. In the industrial setting, the sound absorption ability of a material is evaluated as a single-number index using noise reduction coefficient (NRC). In this study, NRC was computed using the following Equation (1).

$$\mathrm{NRC} = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \tag{1}$$

where, α_{250}, α_{500}, α_{1000}, and α_{2000} are the sound absorption coefficients at 250 Hz, 500 Hz, 1,000 Hz, and 2,000 Hz, respectively.

Originally, NRC should be calculated using the reverberation chamber method (Korean Standards Association, 2012). However, many researchers also apply NRC to the sound absorption coefficient through the impedance tube (Gokulkumar *et al.*, 2019; Jang and Kang, 2021b; Voronina and Horoshenkov, 2004). Accordingly, this study calculated NRC as the sound absorption coefficient value from the impedance tube.

The values of the sound absorption coefficients at 250, 500, and 1,000 Hz were collected from the 99 mm diameter impedance tube, and those at 2,000 Hz were collected from the small-diameter impedance tube (Jang, 2022b, 2022c, 2022d).

3. RESULTS and DISCUSSION

3.1. Scanning electron microscopy (SEM) analysis

Fig. 3 shows SEM images of the cross-section and

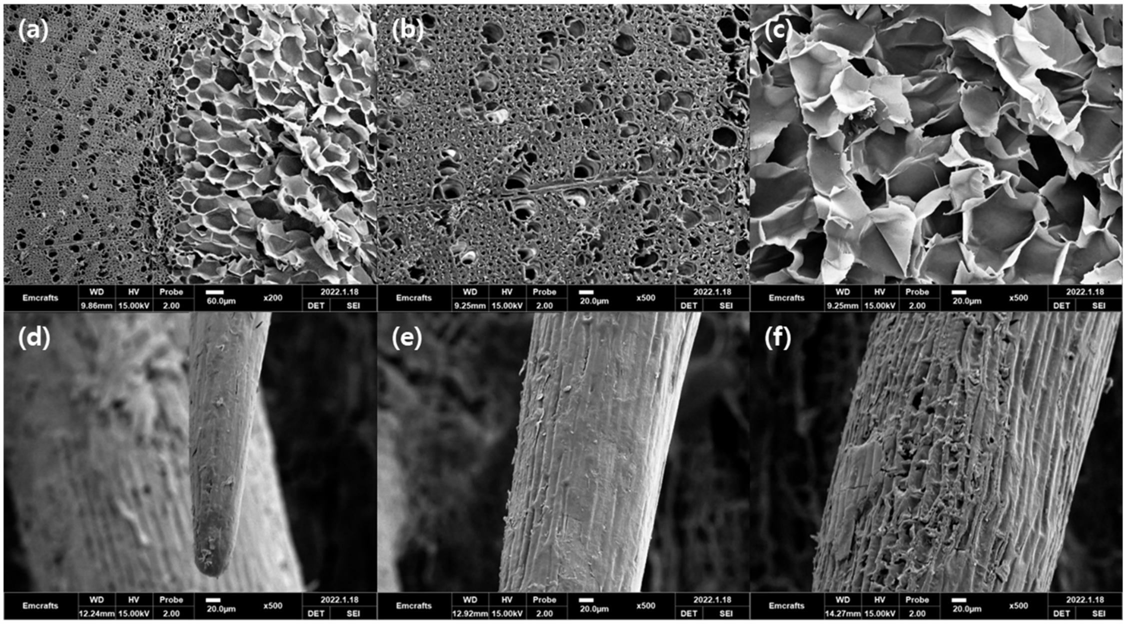

Fig. 3. SEM images of *Acanthopanax senticosus* cross-section and thorn. (a) Sapwood and pith (200 ×), (b) sapwood (500 ×), (c) pith (500 ×), (d) the tip of thorn (500 ×), (e) the middle of thorn (500 ×), (f) the thorn attached to the bark (500 ×). SEM: scanning electron microscopy.

thorn surface of the *A. senticosus* wastes. Fig. 3(a) shows the sapwood and pith together. The SEM images indicated that the cross-section of *A. senticosus* was significantly different from that of the sapwood and pith. The distribution of vessels in the sapwood [Fig. 3(b)] indicates the characteristics of ring-porous wood, and vessel clusters are abundant. This structure is advantageous for absorbing sound (Jang and Kang, 2021e). Fig. 3(c) shows a pith. The core has more large cells and less developed through-pores compared with the sapwood. The surfaces of the pith are found to be rough.

Fig. 3(d–f) shows the surface of the thorn of *A. senticosus*. Fig. 3(d) and (e) show the tip and the middle part, respectively. The thorn surfaces were found to be smooth. Fig. 3(e) shows a thorn connected to the bark of *A. senticosus*, showing a rougher texture than that of the middle and tip. The rough surfaces of the material can contribute to improved sound absorption at low frequencies (Chung *et al.*, 2017).

3.2. Sound absorption ability

The sound absorption coefficient curves are shown in Fig. 4. When the filling height of the *A. senticosus* wastes inside the impedance tube was 40 mm, the maximum sound absorption coefficient was 0.387 at 1,540 Hz; when the filling height was increased to 100 mm, the maximum sound absorption coefficient increased to 0.535 at 714 Hz [Fig. 4(a)]. As the filling height of *A. senticosus* wastes increased, the maximum sound absorption coefficient shifted towards a lower frequency.

The sound wave incident on the porous material is converted into thermal energy as it collides with the material's pores or void space between materials, and the sound energy is lost. As the thickness of the sound absorber increases, the sound absorption performance improves in the low-frequency region, as it provides more space for sound waves to convert thermal energy (Bhingare *et al.*, 2019). However, the thickness of the sound-absorber needs to regulate within the optimum range. The efficiency of transferring sound energy into thermal energy significantly may decline as the sound absorber's thickness exceeds the ideal values (Taban *et al.*, 2021).

As shown in Fig. 4(b), the sound absorption coefficient's curves fluctuated. As the hollow space between the granules acts as a resonator, the sound absorption curve has oscillated in the high-frequency region above

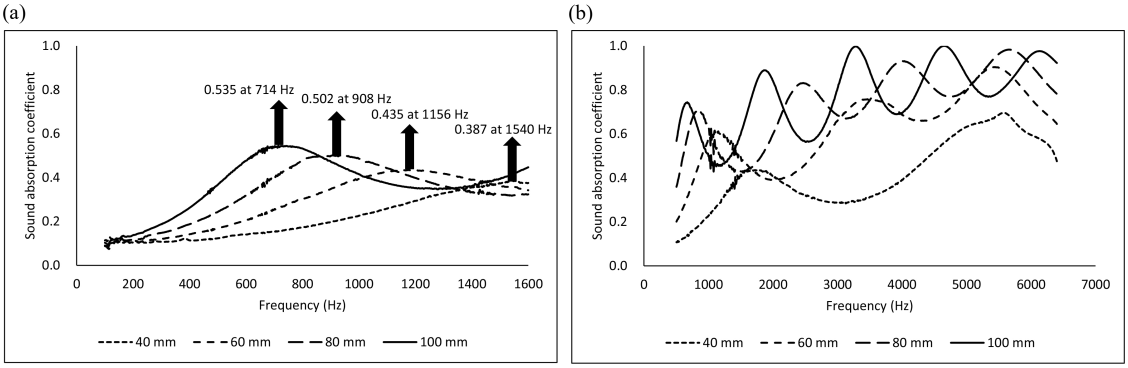

Fig. 4. Sound absorption curves of *Acanthopanax senticosus*. (a) Measured sound absorption coefficients for different filling heights of *A. senticosus* wastes using an impedance tube of dimeter 99 mm. (b) Measured sound absorption coefficients for different filling heights of *A. senticosus* wastes using an impedance tube of dimeter 29 mm.

1,000 Hz (Voronina and Horoshenkov, 2004). This phenomenon is observed in most of granular type sound-absorbing materials (Jang, 2022b, 2022c, 2022d; Maderuelo-Sanz *et al.*, 2014; Vašina *et al.*, 2006).

In addition, the number of sound absorption peaks increased as the filling height was increased in the high-frequency region. There were only two sound absorption peaks at a filling height of 40 mm. The number of sound absorption peaks increased by one, three, four and five as the filling height was increased by 40, 60, 80, and 100 mm, respectively.

Table 1 depicts the sound absorption coefficient at 250, 500, 1,000, and 2,000 Hz and the NRC of *A. senticosus* wastes. As the filling height of *A. senticosus* wastes inside the impedance tube was increased from 40 to 100 mm, the sound absorption coefficient at 250 Hz increased by 1.56 times, at 250 Hz by 2.97 times, at 500 Hz by 1.83 times, and at 2,000 Hz by 2.09 times. The NRC also increased by approximately 2.1 times, from 0.214 to 0.446, as the filling height was increased from 40 to 100 mm. The improvement of NRC is due to improving the sound absorption effect depending on the increase in thickness. This trend is typical of porous or granular sound-absorbing materials (Jang, 2022b, 2022c, 2022d; Jang and Kang, 2021c).

The KS F 3503 (Korean Standards Association, 2012) classifies the sound absorption performance into four grades (0.3M grade: 0.21–0.40, 0.5M grade: 0.41–0.60, 0.7M grade: 0.61–0.80, and 0.9M grade: Above 0.81) depending on the NRC of the sound absorption material. The sound absorption rating of *A. senticosus* wastes investigated in this study is 0.3M and 0.5M grade for filling heights of 80 and 100 mm, respectively. Therefore, our results confirm that *A. senticosus* wastes can be considered as an eco-friendly sound-absorbing material. The rough surfaces of the pith and thorn of *A. senticosus* and the vessel structure of the cross-section have a favorable effect on sound absorption. Furthermore, a large number of thorns complicated the paths of empty spaces between *A. senticosus* wastes, which would have created a practical path for sound absorption.

According to the previous study, the NRC of boards made of natural materials such as coir, corn, banana, bamboo, and bagasse was 0.21–0.40 (Sim *et al.*, 2014). In addition, the NRC of peanut shells investigated in the author's previous study was 0.23–0.53 (Jang, 2022c), and that of pine pollen corns was 0.30–0.52 (Jang, 2022d). The sound absorption ability investigated in this study was approximately similar to these. In the future, if the *A. senticosus* wastes is compressed more to increase the density and the path of the void space between materials is made more complicated, it is estimated that the sound absorption performance can be further improved.

This study is meaningful because it is the first approach to investigate the sound absorption ability of *A. senticosus* wastes. However, there is a limit to the conti-

Table 1. Sound absorption coefficients at 250, 500, 1,000, and 2,000 Hz frequency, and NRC for different filling heights of *Acanthopanax senticosus* wastes inside the impedance tubes

Filling height (mm)	Sound absorption coefficient (Hz)				NRC
	250	500	1,000	2,000	
40	0.103	0.124	0.226	0.402	0.214
60	0.114	0.169	0.393	0.391	0.267
80	0.134	0.244	0.486	0.599	0.366
100	0.161	0.367	0.416	0.841	0.446

NRC: noise reduction coefficient.

nuous supply of materials to produce commercial sound-absorbing materials. Therefore, it is necessary to investigate whether all medicinal plants (e.g., herbal medicines), including *A. senticosus* wastes, can be used as sound-absorbing materials. In the future, if their excellent sound absorption performance is revealed, it will be a more meaningful study from a practical point of view.

4. CONCLUSIONS

This study investigated the sound absorption ability of *A. senticosus* wastes. The main conclusions are as follows:

1. As the filling heights of *A. senticosus* wastes inside the impedance tube were increased, the sound absorption peaks shifted to a lower frequency.
2. The sound absorption performance at 80 and 100 mm filling heights corresponded to 0.3M and 0.5M grades based on KS F 3503 (Korean Standards Association, 2012), respectively.
3. *A. senticosus* wastes is an efficient eco-friendly sound-absorbing material.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

This research was supported by a grant from the Basic Science Research Program of the National Research Foundation of Korea (NRF), funded by the Ministry of Education (NRF-2019R1I1A3A02059471). It was also supported by a grant from the international cooperation program framework managed by the NRF (NRF-2020K2A9A2A08000181). I am also thankful for the ‘‘Business Startup Incubator Support Program’’ supported by the Ministry of Education and the National Research Foundation of Korea.

REFERENCES

Ahn, K.S., Pang, S.J., Oh, J.K. 2021. Prediction of withdrawal resistance of single screw on Korean wood products. Journal of the Korean Wood Science and Technology 49(1): 93-102.

Bhingare, N.H., Prakash, S., Jatti, V.S. 2019. A review on natural and waste material composite as acoustic material. Polymer Testing 80: 80106142.

Chung, H., Park, Y., Yang, S.Y., Kim, H., Han, Y., Chang, Y.S., Yeo, H. 2017. Effect of heat treatment temperature and time on sound absorption coefficient of *Larix kaempferi* wood. Journal of Wood Science 63(6): 575-579.

Churkina, G., Organschi, A., Reyer, C.P.O., Ruff, A., Vinke, K., Liu, Z., Reck, B.K., Graedel, T.E., Schellnhuber, H.J. 2020. Buildings as a global carbon sink. Nature Sustainability 3(4): 269-276.

Fortin-Smith, J., Sherwood, J., Drane, P., Ruggiero, E., Campshure, B., Kretschmann, D. 2019. A finite element investigation into the effect of slope of grain on wood baseball bat durability. Applied Sciences 9(18): 3733.

Galih, N.M., Yang, S.M., Yu, S.M., Kang, S.G. 2020. Study on the mechanical properties of tropical hybrid cross laminated timber using bamboo laminated board as core layer. Journal of the Korean Wood Science and Technology 48(2): 245-252.

Ghani, R.S.M., Lee, M.D. 2021. Challenges of wood modification process for plantation *Eucalyptus*: A review of Australian setting. Journal of the Korean Wood Science and Technology 49(2): 191-209.

Gokulkumar, S., Thyla, P.R., Prabhu, L., Sathish, S. 2019. Measuring methods of acoustic properties and influence of physical parameters on natural fibers: A review. Journal of Natural Fibers 17(12): 1719-

1738.

Gyeongsangnam-do Agricultural Research & Extension Services [GNARES]. 2020. The cultivation technology of *Acanthopanax senticosus*. https://www.gnares.go.kr/startup/00001/00021.web?amode=view&idx=7162&cpage=80

Han, Y., Lee, S.M., Choi, J., Park, C.Y. 2021. A study on classification of wood cultural resources in South Korea. Journal of the Korean Wood Science and Technology 49(5): 430-452.

Hong, H.H., Hong, C.H. 2015. Research of functional components and antioxidant capacity by extract solvents from *Aralia eleta* Seemann and *Cudrania tricuspidata*. Journal of Foodservice Management 11(1): 77-90.

International Organization for Standardization. 2001. Acoustics-Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes-Part 2: Transfer-Function Method. ISO 10534-2. International Organization for Standardization, Geneva, Switzerland.

Iswanto, A.H., Hakim, A.R., Azhar, I., Wirjosentono, B., Prabuningrum, D.S. 2020. The physical, mechanical, and sound absorption properties of sandwich particleboard (SPb). Journal of the Korean Wood Science and Technology 48(1): 32-40.

Jamaludin, M.A., Bahari, S.A., Zakaria, M.N., Saipolbahri, N.S. 2020. Influence of rice straw, bagasse, and their combination on the properties of binderless particleboard. Journal of the Korean Wood Science and Technology 48(1): 22-31.

Jang, E.S. 2022a. Experimental investigation of the sound absorption capability of wood pellets as an eco-friendly material. Journal of the Korean Wood Science and Technology 50(2): 126-133.

Jang, E.S. 2022b. Investigation of sound absorption ability of Hinoki cypress (*Chamaecyparis obtusa*) cubes. Journal of the Korean Wood Science and Technology 50(5): 365-374.

Jang, E.S. 2022c. Peanut shells as an environmentally beneficial sound-absorbing material. Journal of the Korean Wood Science and Technology 50(3): 179-185.

Jang, E.S. 2022d. Use of pine (*Pinus densiflora*) pollen cones as an environmentally friendly sound-absorbing material. Journal of the Korean Wood Science and Technology 50(3): 186-192.

Jang, E.S., Kang, C.W. 2021a. How do the pore traits of hardwoods affect sound absorption performance of their cross sections? -Focus on 6 species of Korean hardwoods. Wood and Fiber Science 53(4): 260-272.

Jang, E.S., Kang, C.W. 2021b. Investigation of sound absorption properties of heat-treated Indonesian Momala (*Homalium foetidum* (Roxb.) Benth.) and Korean red toon (*Toona sinensis* (A. Juss.) M. Roem.) cross sections. Forests 12(11): 1447.

Jang, E.S., Kang, C.W. 2021c. The pore structure and sound absorption capabilities of Homalium (*Homalium foetidum*) and Jelutong (*Dyera costulata*). Wood Science and Technology 56(1): 323-344.

Jang, E.S., Kang, C.W. 2021d. Sound absorption characteristics of three species (Binuang, Balsa and Paulownia) of low density hardwood. Holzforschung 75(12): 1115-1124.

Jang, E.S., Kang, C.W. 2021e. The use of ring-porous East Asian ash (*Fraxinus japonica* (Thunb.) Steud.) and oak (*Quercus* spp.) cross-sections as eco-friendly resonance-absorbing materials for building. Wood Material Science & Engineering. https://doi.org/10.1080/17480272.2021.1987518

Jang, E.S., Kang, C.W. 2022. An experimental study on changes in sound absorption capability of spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), and larch (*Larix kaempferi*) after microwave treatment. Journal of Wood Science 68: 2.

Jia, A., Zhang, Y., Gao, H., Zhang, Z., Zhang, Y., Wang, Z., Zhang, J., Deng, B., Qiu, Z., Fu, C. 2021. A review of *Acanthopanax senticosus* (Rupr and Maxim.) harms: From ethnopharmacological use to modern application. Journal of Ethnopharmacology 268: 113586.

Jiang, Z.H., Zhao, R.J., Fei, B.H. 2004. Sound absorption property of wood for five eucalypt species. Journal of Forestry Research 15(3): 207-210.

Jung, S.Y., Kong, R.K., Lee, K.S., Byeon, H.S. 2021. Effects of air-dried leaves of evergreen broad-leaved trees on sound absorption property. Journal of the Korean Wood Science and Technology 49(5): 482-490.

Jung, S.Y., Yeom, D.H., Kong, R.K., Shin, G.G., Lee, K.S., Byeon, H.S. 2020. Sound absorption property of the leaves of two evergreen broad-leaved tree species, *Dendropanax morbiferus* and *Fatsia japonica*. Journal of the Korean Wood Science and Technology 48(5): 631-640.

Kang, C.W., Kolya, H., Jang, E.S., Zhu, S., Choi, B.S. 2021. Steam exploded wood cell walls reveals improved gas permeability and sound absorption capability. Applied Acoustics 179: 108049.

Kang, J.H. 2018. Effects of fermented *Kalopanax pictus* on oxidative damage of neurofilament protein. Journal of the Korean Applied Science and Technology 35(1): 194-204.

Kim, G.C., Kim, J.H. 2020. Changes in mechanical properties of wood due to 1 year outdoor exposure. Journal of the Korean Wood Science Technology 48(1): 12-21.

Kim, M.J., Chang, Y.S., Kim, M.J., Shim, K.B., Eom, C.D. 2019. Assessment of carbon storage capacity by substitution of wood in public facility: Comparative analysis of Seoullo 7017. Journal of the Korea Furniture Society 30(4): 312-318.

Korean Standards Association. 2012. Sound Absrobing Materials. KS F 3503. Korean Standards Association, Seoul, Korea.

Korean Standards Association. 2016. Determination of Moisture Content of Wood. KS F 2199. Korean Standards Association, Seoul, Korea.

Lee, C., Jung, H., Chung, Y. 2021a. Functional characteristics of Nakdong Technique Treated on Paulownia Wood Surface. Journal of the Korean Wood Science and Technology 49(1): 82-92.

Lee, H.J., Lee, S.S., Choi, D.H., Kato, A. 2001. Studies on biological activity of wood extractives (VI): Flavonoids in heartwood of *Prunus sargentii*. Journal of the Korean Wood Science and Technology 29(2): 133-139.

Lee, H.M., Jeon, W.S., Lee, J.W. 2021b. Analysis of anatomical characteristics for wood species identification of commercial plywood in Korea. Journal of the Korean Wood Science and Technology 49(6): 574-590.

Lee, Y.D. 2020. Immune functional properties of Korean (red) ginseng as a traditional food. Food Industry and Nutrition 25(1): 1-10.

Maderuelo-Sanz, R., Barrigón Morillas, J.M., Gómez Escobar, V. 2014. Acoustical performance of loose cork granulates. European Journal of Wood and Wood Products 72(3): 321-330.

Sedliačiková, M., Moresová, M., Aláč, P., Malá, D. 2021. What is the supply and demand for coloured wood products? An empirical study in Slovakian practice. Forests 12(5): 530.

Sim, J.S.T., Zulkifli, R., Tahir, M.F.M., Elwaleed, A.K. 2014. Recycled paper fibres as sound absorbing material. Applied Mechanics and Materials 663: 459-463.

Taban, E., Valipour, F., Abdi, D.D., Amininasab, S. 2021. Mathematical and experimental investigation of sound absorption behavior of sustainable kenaf fiber at low frequency. International Journal of Environmental Science and Technology 18(9): 2765-2780.

Taghiyari, H.R., Zolfaghari, H., Sadeghi, M.E., Esmailpour, A., Jaffari, A. 2014. Correlation between specific gas permeability and sound absorption coefficient in solid wood. Journal of Tropical Forest Science 26(1): 92-100.

Vašina, M., Hughes, D.C., Horoshenkov, K.V., Lapčík, L. Jr. 2006. The acoustical properties of consolidated expanded clay granulates. Applied Acoustics 67(8): 787-796.

Voronina, V.V., Horoshenkov, K.V. 2004. Acoustic properties of unconsolidated granular mixes. Applied Acoustics 65(7): 673-691.

Yang, S.M., Lee, H.J., Kang, S.G. 2020. Analysis of heat transfer characteristics by materials in closed conditions using acrylic hemisphere (I): Comparison of interior finishing materials. Journal of the Korean Wood Science and Technology 48(2): 217-230.

Yoo, H.J., Ju, J.D., Park, J.H., Shin, C.S., Eom, C.D., Seo, J.W. 2021. Estimation of the optimal periods for planting and felling *Larix kaempferi* based on the period of its cambial activity. Journal of the Korean Wood Science Technology 49(5): 399-415.