Improvement of Acoustic Properties of Alder and Soft Maple Modified with Wood Rot Fungi

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Wood has been used as the primary material for musical instruments for a long time. The density and elastic modulus of wood are known to be important factors in determining its acoustic properties of stringed instruments. The objective of this study was to show that fungal decay processes can be applied to improve the acoustic quality of the woods. The effects of biological modification of two woods, alder and soft maple, which were treated with wood rot fungi, were evaluated in terms of density (ρ), dynamic modulus of elasticity along the wood grain (E_L), acoustic constant (A), and acoustic conversion efficiency (ACE). Incubation of two woods in eight species of wood rot fungi was carried out for 4 weeks. Among the fungi, *Trametes versicolor* and *Ceriporia lacerata* significantly increases the A (33.0% and 21.0%, respectively) and ACE (50.4% and 37.6%, respectively) values of alder woods. These two strains also increased the A (51.4% and 29.1%, respectively) and ACE (42.4% and 35.3%, respectively) values of soft maple. This study showed that fungal treatment significantly altered the density and elastic modulus of wood, which ultimately influenced the factor A value and the ACE value, both of which determine sound quality.

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Keywords: Acoustic conversion efficiency; Modulus of elasticity; Sound quality; Polyporales

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INTRODUCTION

Wood is the most widely used material for musical instruments in human history. Even in the case of stringed instruments, although the strings are not wooden, the vibrations generated by rubbing or plucking strings are amplified by a wooden resonator, which serves to radiate the vibrations of strings to the outside (Dunlop and Shaw 1991).

Antonio Stradivari violins made in the 17th to 18th century have historically been evaluated as having good tonal quality (Schwarze and Schubert 2011). Consequently, numerous studies have been conducted to investigate the reason behind this phenomenon. The high elasticity and low density of wood improve the acoustic properties (Wegst 2006). According to a wood dendrochronology study, the low density and high elasticity of Sycamore maple trees grown during the Little Ice Age in the late 17th century were the cause of the exceptional tonal quality observed in Stradivari instruments (Topham and McCormick 2000).

The decay of wood by fungi may have been a contributing cause of the excellent acoustic properties of string instruments (Schwarze *et al*. 2008). For studies on the improvement of wood acoustic characteristics resulting from fungal damage, white rot fungi (*Physisporinus vitreus*) have been relatively well-studied (Spycher 2007). Previous studies show that isolates of *P. vitreus* have an extraordinary capacity to induce substantial permeability changes in the heart wood of *Picea abies* without causing significant loss of impacting bending strength (Spycher 2007; Schwarze and Schubert 2011). Nevertheless, given that only a limited number of additional fungal strains have been investigated (Čulík *et al*. 2016; Danihelová *et al*. 2019), further research is needed.

The acoustic properties of wood can be evaluated through various indicators. The ratio of sound speed and the density of wood are called the radiation ratio (*R*) or acoustic constant (*A*) and are used as acoustic parameters (Haines 1979; Spycher 2007; Meincken *et al*. 2021). Attenuation is the rate at which the amplitude of a wave decreases. Attenuation is also an important indicator of the acoustic properties of wood (Dunlop and Shaw 1991; Spycher 2007). Generally, the reciprocal of the logarithmic decrement is used as the *Q* factor (Quality factor) (Green 1955). Acoustic conversion efficiency (ACE) is an indicator for expressing amplitude and attenuation simultaneously and can be expressed as the product of the *A* and *Q* factors (Danihelová *et al*. 2019).

This study aimed to investigate the improvement of wood acoustic constant *A* and ACE by domestic white rot fungi. To quantify these acoustic properties, the density changes of the woods were measured, and the resonant frequency of wood was measured using the frequency response function method, from which *A* and ACE values were subsequently calculated.

EXPERIMENTAL

Wood Specimen Preparation

Two species of wood were included in this study, respectively: alder (*Alnus* sp.) and soft maple (*Acer* sp.). The experiment used five samples produced from each wood species. Wood specimens were manufactured by cutting into 150 × 20 × 10 mm size pieces with a length of 150 mm in the axial direction. These manufactured specimens were then weighed after 48 h in a drying oven at 60 °C. Subsequently, the wood specimens were sterilized at 121 °C for 30 min using a high-pressure sterilizer before the decay test.

Wood Rot Fungi Culture and Wood Decay Test

A total of eight wood-rotting fungal species were utilized in the experiment, as detailed in Table 1. Each strain was introduced into the solidified medium by adding 300 mL of Potato Dextrose Agar (PDA) into a 250 mm square dish. Following approximately one week, when the medium was fully colonized by the fungi, a sterilized wood sample was placed into the medium and incubated at 25 °C for 8 weeks. Samples were taken at 4 weeks during which the wood samples were harvested to eliminate surface hyphae and then dried at 60 °C for 48 h. The dry weight of the specimens was measured to determine their density, and the weight loss rate of the culture was calculated based on the initial weight before incubation.

Table 1. List of Wood Rot Fungi Used in the Experiment

Order	Family	Species	ID
Polyporales	Irpicaceae	*Ceriporia lacerata*	NIFOS*5039
		Irpex lacteus	NIFOS*5046
	Meruliaceae	*Phlebia acerina*	NIFOS*5023
	Phanerochaetaceae	*Phanerochaete chrysosporium*	NIFOS*5063
		Phanerochaete sordida	NIFOS*5031
	Podoscyphaceae	*Abortiporus biennis*	NIFOS*5013
	Polyporaceae	*Pycnoporus coccineus*	NIFOS*5019
		Trametes versicolor	NIFOS*5017

* NIFOS : National Institute of Forest Science

Resonant Frequency Measurement of Decay Treated Wood

The wood specimen was positioned on a pedestal with an 80 mm interval (Spycher 2007), and the resonance frequency (F_r) of the wood specimen and the frequencies (F_1, F_2) at the two points where the amplitude was halved at the F_r peak were determined using the Frequency Response Function (FRF) technique (Fig. 1). The FRF analysis was performed employing a dynamic signal analyzer (Data Physics, CA, USA), accelerometer, and impact hammer. Data analysis was carried out using the SignalCalc 240 software (Data Physics, CA, USA).

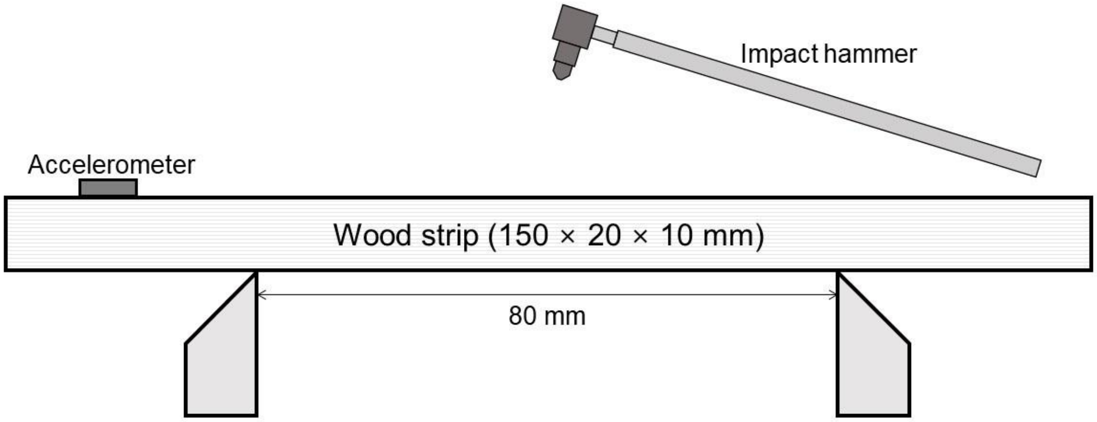

Fig. 1. Outline of wood resonant frequency measurement method

Calculation of Wood Acoustic Properties

The acoustic constant (A), dynamic modulus of elasticity (E_L), sound quality factor (Q), and acoustic conversion efficiency (ACE) were all determined based on the experimentally derived data. A is expressed as the speed of sound (c, m/s) divided by the density of wood (ρ, kg/m^3) (Haines 1979). According to Rajčan (1998), A can be utilized to compute the dynamic modulus of elasticity (E_L) of wood from its density (ρ) as shown in Eq. 1.

$$A = \sqrt{E_L/\rho^3} \tag{1}$$

The speed of sound can be determined by multiplying the density of wood in the aforementioned formula. Additionally, the dynamic modulus of elasticity can be calculated using the F_r value, length (ℓ), and density of wood, as demonstrated in Eq. 2 (Wegst 2006; Čulík *et al*. 2016).

$$E_L = 4\ell^2 F_r^2 \rho \tag{2}$$

The Q factor and ACE are parameters that account for the attenuation of vibrations in wood. They are derived from the logarithmic decrement (δ) of wood. As stated by Rajčan (1998), the calculation of δ is expressed as follows (Eq. 3):

$$\delta = \frac{\pi}{\sqrt{3}} \cdot \frac{F_2 - F_1}{F_r} \tag{3}$$

The attenuation coefficient (η) can be calculated as the logarithmic decrement (δ) divided by the mathematical constant pi (π) (Eq. 4).

$$\eta = \delta / \pi \tag{4}$$

The Q factor is the inverse of the attenuation coefficient (Eq. 5). The Attenuation Coefficient Efficiency (ACE) is defined as the multiplication of A and the Q factor (Danihelová *et al*. 2019; Eq. 6).

$$Q = 1/\eta \tag{5}$$

$$\mathrm{ACE} = A \times Q \tag{6}$$

The significance of the experimental group and control group in relation to the data calculated for each acoustic characteristic was assessed using a t-test. Additionally, the correlations between each characteristic were examined through correlation analysis.

RESULTS AND DISCUSSION

Change of Wood Density and E_L

It has been stated that a lower density of wood used for musical instruments results in a better acoustic quality (Schwarze and Schubert 2011). The densities of untreated woods were determined as follows: alder 445.12 ± 1.11 kg/m^3) and soft maple (548.94 + 0.11 kg/m^3). These values did not show significant deviations from previous reports (Niklas and Spatz 2010). Alder and soft maple woods are widely used to produce stringed instruments such as guitars. In electric guitars, low density wood such as alder is suitable for the body; medium density wood such as soft maple is used in body and neck (Shirmohammadi *et al*. 2020).

After fungal modification for 4 weeks, the densities of alder woods were decreased. Reductions of densities of alder woods by more than 20% after fungal treatment were identified in *A. biennis* (354.07± 9.30 kg/m^3, 20.45%), *T. versicolor* (300.40±7.32 kg/m^{3,} 32.59%), *P. coccineus* (350.48±33.93 kg/m^3, 21.26%) and *C. lacerata* (346.55±4.42 kg/m^3, 22.14%). The fungi used in this study belong to the group of white rot fungus that mainly degrades hardwoods. However, no significant density changes were observed following treatments with three fungi, *P. acerina*, *L. lacteus*, and *P. chrysosporium* (Fig. 2).

Density changes by eight fungi were confirmed in the soft maple. Decreased density was demonstrated in *A. biennis* (429.29 ± 7.15 kg/m^3, 21.79%), *T. versicolor* (338.22 + 0.06 kg/m^3, 38.38%), *P. coccineus* (444.53 ± 18 kg/m^3, 19.01%), and *C. lacerata* (409.36 ± 2.05 kg/m^3, 25.42%). In both experiment groups of alder and soft maple, the rates of density caused by fungi, *T. versicolor*, belonging to Polyporaceae family, is relatively changed. The Polyporaceae group is the most representative order of saprotrophic homobasidiomycetes causing wood decay, and high lignocellulolytic potential is recognized (Lomascolo *et al*. 2011).

The dynamic modulus of elasticity (E_L) of wood is shown to have a direct positive correlation with the A, and therefore the higher the value, the better the acoustical quality (Rajčan 1998). The dynamic modulus of elasticity shown in Fig. 3 was estimated by measuring the resonant frequency (F_r) of a wood specimen long in the shrinkage direction by referring to the method outlined by Spycher (2007) and Čulík *et al*. (2016).

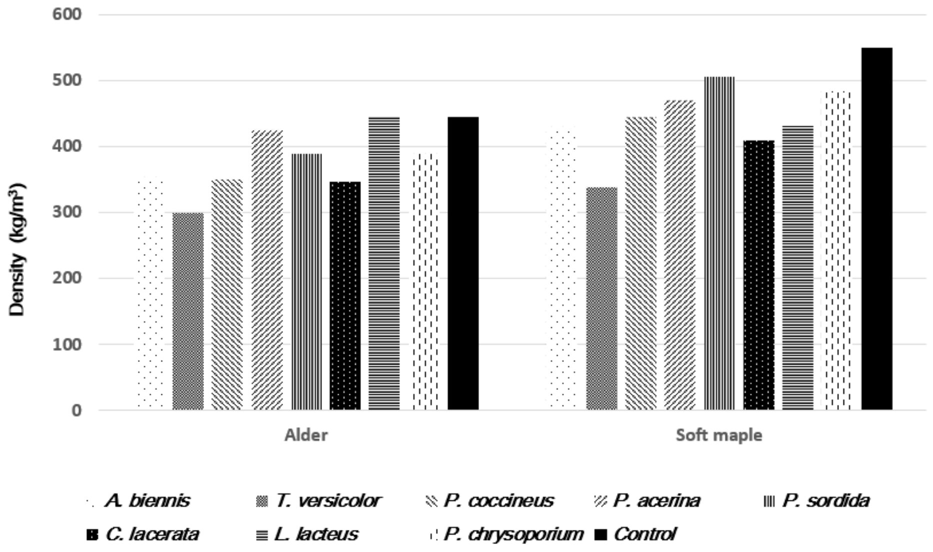

Fig. 2. Density of wood species (alder and soft maple) by eight wood rot fungi for 4 weeks

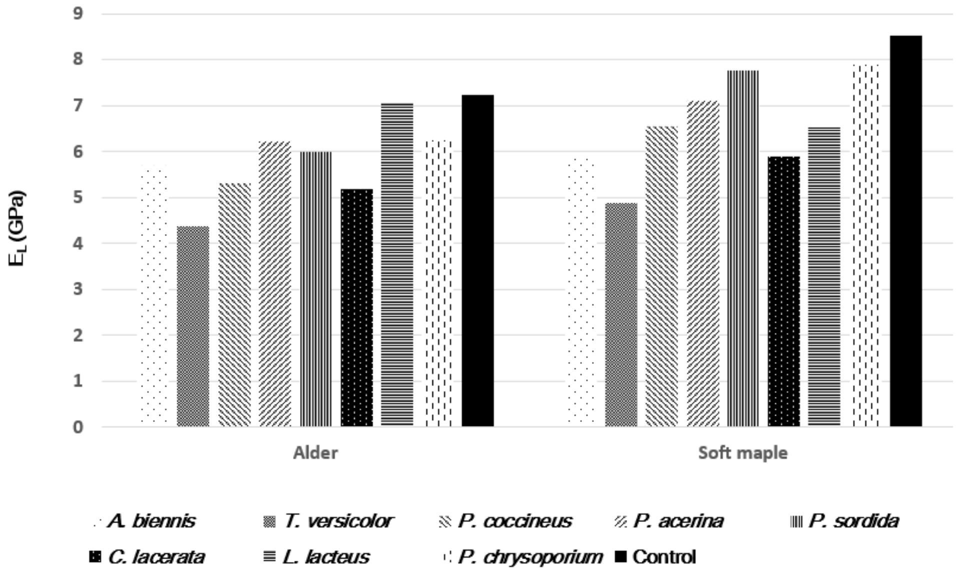

Fig. 3. Dynamic modulus of elasticity (E_L) of wood species (alder and soft maple) by eight wood rot fungi for 4 weeks

In the untreated woods with fungi, the E_L of soft maple (8.51 GPa) was higher than alder (7.24 GPa). The E_L of alder (9.5 GPa) and soft maple (12.6 GPa) are also specified in the wood handbook (wood handbook 2021). After 4 weeks, the overall E_L had decreased in all wood species, when all treated samples and control group were compared (Fig. 3; $p < 0.05$).

Generally, the density and E_L of wood show a positive correlation with each other (Niklas and Spatz 2010; Meincken *et al*. 2021). Therefore, due to the decrease in density caused by the wood rot fungi, the values of E_L are also decreased. The value E_L of alder woods were changed in *T. versicolor* (4.37 ± 0.16 GPa, 39.72%), *A. biennis* (5.69 ± 0.05 GPa, 21.44%), *P. coccineus* (5.32 ± 0.02 GPa, 26.53%), and *C. lacerata* (5.18 ± 0.02 GPa, 28.44%). The values E_L of soft maple woods were changed in *T. versicolor* (4.89 ± 0.37 GPa, 42.55%), *A. biennis* (5.88 ± 0.48 GPa, 30.86%), *C. lacerata* (5.88 ± 50.16 GPa, 30.83%), *P. coccineus* (6.54 ± 0.30 GPa, 23.13%), and *L. lacteus* (6.53 ± 0.24 GPa, 23.28%).

Changes in Wood Acoustic Property (*A*) Indicators by Decay

The *A* values of the untreated woods are as follows: alder 9.06 ± 0.03 $m^4/kg \cdot s$ and soft maple 7.18± 0.06 $m^4/kg \cdot s$. The acoustic constant (*A*) of wood has been reported to differ significantly between species. The *A* value of alder has been reported at 6.7 to 9.8 $m^4/kg \cdot s$ (Saadat-Nia *et al*. 2011; Čulík *et al*. 2016), whilst the values recorded in this study were in a similar range. Also, the *A* value of maple has been reported to be in the range of approximately 5 to 8.5 $m^4/kg \cdot s$, and the values of specimens used in the study were at an average level in accordance with this (Spycher 2007; Čulík *et al*. 2016).

The *A* value showed a tendency to increase due to decay from wood rot fungi ($P < 0.05$). After treatment with *T. versicolor* (12.05 ± 0.31 $m^4/kg \cdot s$, 32.96%), *A. biennis* (10.29 ± 0.38 $m^4/kg \cdot s$, 13.53%), *P. coccineus* (10.98 ± 1.30 $m^4/kg \cdot s$, 21.20%), *C. lacerata* (10.97 ± 0.2 $m^4/kg \cdot s$, 21.02%), alder woods showed a higher A values average than the control group (Fig. 4).

The increase in *A* value was particularly high in soft maple. Increases of *A* values were identified following treatments with *T. versicolor* (10.86 ± 0.08 $m^4/kg \cdot s$, 51.37%), *C. lacerata* (9.26 ± 0.07 $m^4/kg \cdot s$, 29.14%), *P. coccineus* (8.64 ± 0.36 $m^4/kg \cdot s$, 20.47%), *A. biennis* (8.92 ± 1.82 $m^4/kg \cdot s$, 24.16%), and *L. lacteus* (9.03 ± 0.45 $m^4/kg \cdot s$, 25.93%); all showed increases in *A* value greater than 20%. A comparison in term of strains, *T. versicolor* showed the highest percentage changes compared to other strains, in alder (35.7%), and soft maple (51.4%). This fungus has become known as the most efficient species in the decay of the maple samples (Brglez *et al*. 2020). The *A* value exhibits a direct proportionality to the sound speed in wood or the elastic modulus of wood, while it demonstrates an inverse proportionality to the density. Consequently, species with lower densities typically exhibit high *A* values, which is a key characteristic of wood utilized in the production of musical instruments (Obataya *et al.* 2000; Sedik *et al.* 2010; Baar *et al.* 2016; Čulík *et al.* 2016).

However, the density of wood varies significantly depending on the species. For example, the density of *Picea abies* widely used in instruments is relatively low at 370 to 468 kg/m^3 (Čulík *et al*. 2016; Danihelová *et al*. 2019). In addition, tropical species with low densities (less than 350 kg/m^3) show *A* values of 12 or higher (Sedik *et al*. 2010). In this study, alder and soft maple showed the greatest decay progress. The correlation between density and *A* value increase rate due to decay was quite high. For alder, $r = 0.893$, whereas for soft maple $r = 0.775$.

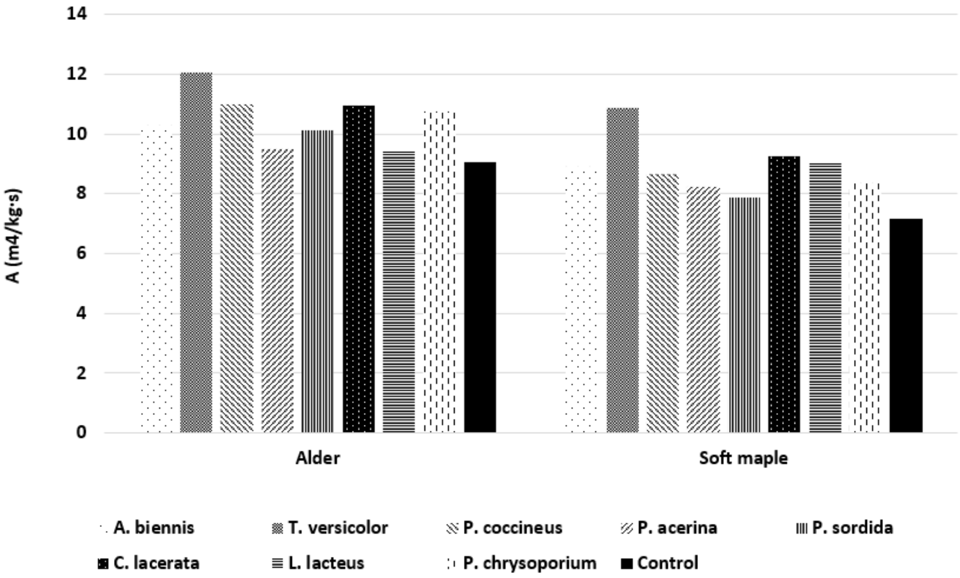

Fig. 4. Change of A values of wood species (alder and soft maple) by eight wood rot fungi for 4 weeks

Changes in Wood Acoustic Property (ACE) Indicators by Decay

The ACE values of untreated woods were as follows: alder (280 ± 41 m^4/kg·s) and soft maple (273 ± 42 m^4/kg*s) showed similar values. After fungal treatment, the average ACE value was shown to have increased in woods. ACE values of alder within the range of 294 to 421 m^4/kg·s were shown after 4 weeks. Also, ACE values of soft maple within the range of 317 to 387 m^4/kg·s were shown, respectively.

After treatment with *T. versicolor* (421.16 ± 18.09 m^4/kg·s, 50.45%), *A. biennis* (342.63 ± 36.48 m^4/kg·s, 22.39%), *P. coccineus* (321.97 ± 21.70 m^4/kg·s, 15.01%), *C. lacerata* (385.19 ± 13.34 m^4/kg·s, 37.6%), alder woods showed a higher *A* values average than the control group (Fig. 5). An increased *A* value was also identified in soft maple. ACE values identified in *T. versicolor* (388.82 ± 27.3 m^4/kg·s, 42.39%), *C. lacerata* (369.54 ± 39.53 m^4/kg·s, 35.33%), *P. coccineus* (339.62 ± 11.75 m^4/kg·s, 24.37%), *A. biennis* (321.39 ± 6.40 m^4/kg·s, 17.70%), and *I. lacteus* (317.27 ± 21.93 m^4/kg·s, 16.19%).

T. versicolor, which showed high average values of A and ACE that increased rates relative to the fungi used, was used as a test train for white rot fungi in the Korean National Standard Wood Weather Resistance Test Method (KS F 2213:2018), and is reported to generally exhibit wood decay activity (Chen *et al*. 2017). It seemed that sufficient density change must occur in order for A and ACE value to be increased to a meaningful level after fungal treatment.

Damage by living organisms can cause a decrease in the structural strength of wood (Spycher 2007; Suprapti *et al.* 2020; Oh 2021). When brown rot fungi are used instead of white rot fungi, the reduction in structural strength is too strong compared to the wood weight reduction, therefore resulting in negative results for wood acoustical properties (Schwarze *et al*. 1995). After fungal modification, the woods should remain highly workable; their density should decrease moderately with minimum change in the dynamic modulus of elasticity along the wood grain and acoustic constant, and coloration of the modified wood should be acceptable in terms of aesthetics. Therefore, in future studies, it is necessary to select strains and optimal degrees of decay by considering the changes in the physical strength of the wood.

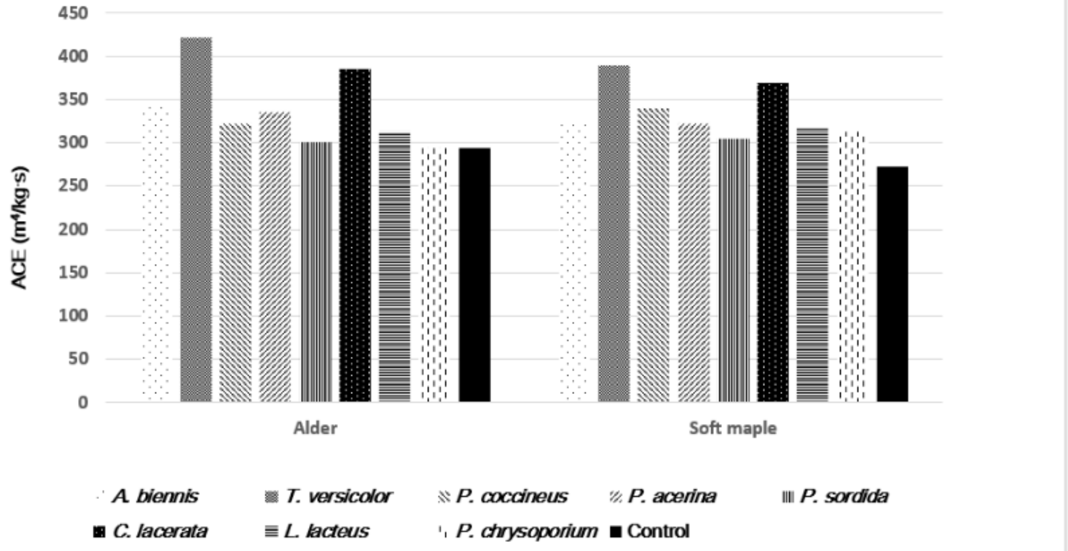

Fig. 5. Change of ACE values of wood species (alder and soft maple) by eight wood rot fungi for 4 weeks

This research focused solely on the enhancement of the acoustic properties of wood due to fungal decay, without addressing the reduction in wood strength. It is anticipated that further investigation into additional physical changes in the wood, including improvement mechanisms and strength loss, will be necessary.

CONCLUSIONS

1. This study showed that fungal treatment significantly altered the density and elastic modulus of wood, which ultimately influenced the factor A value and the ACE value, both of which determine sound quality.

2. Among the strains examined, the alterations in values caused by *T. versicolor* were the most highly observed over the 4 weeks. However, rapid decay within a short period could negatively impact the processing of the wood due to decrease in its structural strength. Therefore, additional anatomical and strength approaches are necessary.

3. This study focused on only two factors, *A* and ACE, among various parameters. For fundamental improvement in acoustical properties, research on a variety of parameters in necessary.

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REFERENCES CITED

Baar, J., Tippner, J., and Gryc, V. (2016). "Wood anatomy and acoustic properties of selected tropical hardwoods," *IAWA Journal* 37(1), 69-83. DOI: 10.1163/22941932-20160121

Brglez, A., Piškur, B., Humar, M., Gričar, J., and Ogris, N. (2020). "The effect of *Eutypella parasitica* on the wood decay of three maple species," *Forests* 11(6), article 671. DOI: 10.3390/f11060671

Chen, M., Wang, C., Fei, B., Ma, X., Zhang, B., Zhang, S., and Huang, A. (2017). "Biological degradation of Chinese fir with *Trametes versicolor* (L.) Lloyd," *Materials* 10(7), article 834. DOI: 10.3390/ma10070834

Čulík, M., Danihelová, A., Danihelová, Z. (2016). "Wood for musical instruments," *Akustika* 25, 66-72.

Danihelová, A., Spišiak, D., Reinprecht, L., Gergeľ, T., Vidholdová, Z., and Ondrejka, V. (2019). "Acoustic properties of Norway spruce wood modified with staining fungus (*Sydowia polyspora*)," *BioResources* 14(2), 3432-3444. DOI: 10.15376/biores.14.2.3432-3444

Dunlop, J. I., and Shaw, M. (1991). "Acoustical properties of some Australian woods," *J. Catgut Acoustical Society* 2nd ser, 1(7), 17-20.

Green, E. I. (1955). "The story of Q," *American Scientist* 43(4), 584-594.

Haines, D. W. (1979). "On musical instrument wood," *Caught Acoust. Soc. Newsletter* 31, 19-23.

Korean Standards & Certification. (2018). Test Methods for Weather Resistance of Wood. KS F 2213, Seoul, Republic of Korea.

Lomascolo, A., Uzan-Boukhris, E., Herpoël-Gimbert, I., Sigoillot, J. C., and Lesage-Meessen, L. (2011). "Peculiarities of *Pycnoporus* species for applications in biotechnology," *Applied Microbiology and Biotechnology* 92, 1129-1149. DOI: 10.1007/s00253-011-3596-5

Meincken, M., Roux, G., and Niesler, T. (2021). "An African violin – The feasibility of using indigenous wood from southern Africa as tonewood," *South African Journal of Science* 117(11-12), 1-8. DOI: 10.17159/sajs.2021/11175

Niklas, K. J., and Spatz, H. C. (2010). "Worldwide correlations of mechanical properties and green wood density," *American Journal of Botany* 97(10), 1587-1594. DOI: 10.3732/ajb.1000150

Obataya, E., Ono, T., and Norimoto, M. (2000). "Vibrational properties of wood along the grain," *Journal of Materials Science* 35(12), 2993-3001. DOI: 10.1023/A:1004782827844

Oh, S. C. (2021). "Residual strength estimation of decayed wood by insect damage through in situ screw withdrawal strength and compression parallel to the grain related to density," *Journal of the Korean Wood Science and Technology* 49(6), 541-549. DOI: 10.5658/WOOD.2021.49.6.541

Rajčan, E. (1998). "Application of acoustics to some problems of material science related to the making of musical instruments," *Acta Acustica United with Acustica* 84(1), 122-128.

Rajcan, E., and Urgela, S. (2002). "Maple wood for bowed musical instruments, its quality and heterogeneity," *Acta Acustica United with Acustica* 88(6), 1005-1011.

Saadat-Nia, M. A., Brancheriau, L., Gallet, P., Enayati, A. A., Pourtahmasi, K., and Honarvar, F. (2011). "Ultrasonic wave parameter changes during propagation through poplar and spruce reaction wood," *BioResources* 6(2), 1172-1185.

Schwarze, F. W., Spycher, M., and Fink. S. (2008). "Superior wood for violins – Wood decay fungi as a substitute for cold climate," *New Phytologist Foundation* 179(4), 1095-1104. DOI: 10.1111/j.1469-8137.2008.02524.x

Schwarze, F. W., and Schubert, M. (2011). "*Physisporinus vitreus*: A versatile white rot fungus for engineering value-added wood products," *Applied Microbiology and Biotechnology* 92(3), 431-440.

Schwarze, F. W. M. R., Lonsdale, D., and Mattheck, C. (1995). "Detectability of wood decay caused by *Ustulina deusta* in comparison with other tree-decay fungi," *European Journal of Forest Pathology* 25(6-7), 327-341.

Sedik, Y., Hamdan, S., Jusoh, I., and Hasan, M. (2010). "Acoustic properties of selected tropical wood species," *Journal of Nondestructive Evaluation* 29(1), 38-42.

Shirmohammadi, M., Faircloth, A., and Redman, A. (2020). "Determining acoustic and mechanical properties of Australian native hardwood species for guitar fretboard production," *European Journal of Wood and Wood Products* 78, 1161-1171. DOI: 10.1111/j.1439-0329.1995.tb01348.x

Suprapti, S., Djarwanto, D., and Dewi, L. M. (2020). "Determining the wood (*Parashorea* spp.) decaying and metal corroding abilities of eight fungi," *Journal of the Korean Wood Science and Technology* 48(1), 50-60. DOI: 10.5658/WOOD.2020.48.1.50

Spycher, M. (2007). *The Application of Wood Decay Fungi to Improve the Acoustic Properties of Resonance Wood for Violins*, Ph.D. Dissertation, Freiburg University, Germany.

Topham, J., and McCormick, D. (2000). "A dendrochronological investigation of stringed instruments of the Cremonese School (1666–1757) including 'The Messiah' violin attributed to Antonio Stradivari," *Journal of Archaeological Science* 27(3), 183-192. DOI: 10.1006/jasc.1999.0516

Wegst, U., G. (2006). "Wood for sound," *American Journal of Botany* 93(10), 1439-1448. DOI: 10.3732/ajb.93.10.1439

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Erratum: April 10, 2025; Figure 5 has been updated to reflect the value for *T. versicolor*. These changes do not alter the results of the research.