EUROPEAN MOUNTAIN ASH AS A POSSIBLE SUBSTITUTE FOR HONDURAN ROSEWOOD IN THE PRODUCTION OF XYLOPHONES

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Abstract: The sound quality of a xylophone depends on the material it is made of. The xylophone produces sound through the vibration of the wooden bars. The bars are usually made of rosewood or padauk due to their properties, resonance, and durability. However, the Honduran rosewood is a protected wood species, so it is necessary to look for other suitable wood species. Based on the investigation of the physical and acoustical characteristics of the various wood species, it appears that the European mountain ash (also known as rowan) may be a suitable substitute for the Honduran rosewood. Unlike the Honduran rosewood, the European ash is not listed in the CITES appendices or on the IUCN Red List of Threatened Species. The effect of modification of the European mountain ash on the physical and acoustical characteristics (PACHs) and sound quality was investigated. The wood samples were modified in two ways: mechanical densification and a combination of mechanical densification and thermal modification. The PACHs (density of wood ρ_w, modulus of elasticity along the wood grain E_L, acoustical constant A, loss coefficient η, specific modulus of elasticity E_{sp}, acoustic conversion efficiency ACE, speed of sound along the wood grain c_L) were measured before and after modification. These PACHs were compared with the characteristics of the Honduran rosewood. The sound quality of the xylophone bars produced before and after modification was also determined. Following the experiment results it can be stated that the wood of the European mountain ash, after combination mechanical densification and thermal modification, can be used as an alternative to the Honduran rosewood for the xylophones of lower quality.

Keywords: Xylophone, European mountain ash, wood modification, physical and acoustical characteristics.

1. INTRODUCTION

Musical instruments in which a vibrating solid material (stone, wood, or metal) is used to produce the sound are called idiophones. They are ones of the oldest musical instruments. Xylophone is made only of wood. It is a percussion instrument consisting of a row of chromatically tuned wooden bars, arranged in the manner of a piano keyboard. The bars are supported at nodal points, which vibrate when struck with a mallet, creating sound waves (Fig. 1). Nowadays a standard xylophone has a range of three-and-a-half octave (*f* to c^4). Commercial sizes can have as few as three octaves and as many as five octaves.

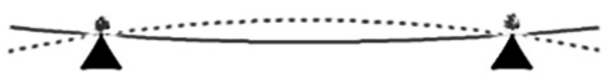

Fig. 1: Principle of xylophone bar vibration

Since the xylophone produces the tone through the vibration of wooden bars, the wood significantly affects the natural frequencies at which xylophone bar vibrates, so proper wood selection is very important [1, 6]. Hardwoods are used in the manufacture of xylophones and marimbas, especially the Honduran rosewood, whose wood has optimal characteristics (i.e., high density and durability, high modulus of elasticity E_L, speed of sound, hardness, and low internal friction) to achieve the desired acoustic quality of the xylophone [18]. However, the Honduran rosewood is on the list of plants protected by CITES Appendix II. An alternative to rosewood is the African Padauk, whose characteristics meet the requirements for idiophonic instruments [7, 8]. The central European wood species that could be used in the production of idiophones do not have as high a density as tropical species. Therefore, a highly specialized modification of the characteristics of the selected European wood species aimed at an increase in the density and hardness is required [9].

Based on the macroscopic structure, physical properties, and vibrational behaviour, the European mountain ash was selected for the modification. Particularly two methods of modification – mechanical densification and mechanical densification plus thermal modification – showed to be the suitable ones.

The resonant dynamic method was used to determine the physical and acoustical characteristics before and after modifications. The PACHs of modified wood influence the quality and timbre of the musical instrument sound significantly [4, 5]. Therefore, the sound quality of the xylophone bars produced before and after modification was also investigated.

2. MATERIAL AND METHODS

Wood samples have been prepared from the European mountain ash (*Sorbus aucuparia,* L.) and the Honduran rosewood (*Dalbergia stevensonii,* Standl.). The mechanical densification consisted of preheating of the samples to 100 °C for 15 minutes and then pressing for 5 minutes was performed to achieve 20 % compression. The samples were subsequently stabilized for 14 days in laboratory conditions (air conditioning aquarium: relative humidity of air φ = 40 % and temperature t = 20 ± 2 °C) to achieve (8±1) % moisture content. After stabilization the samples were modified thermally.

The thermal modification was carried out in a hot air sterilization chamber HS 122A with forced air circulation as follows: pre-drying at t = 100 °C for 4 hours; thermal modification at t = 160 °C for 4 hours and cooling to reach 20 °C and to obtain $w \approx$ (8±1) % moisture content like before modification. Density of wood ρ_w of each sample was calculated from the measured dimensions and mass.

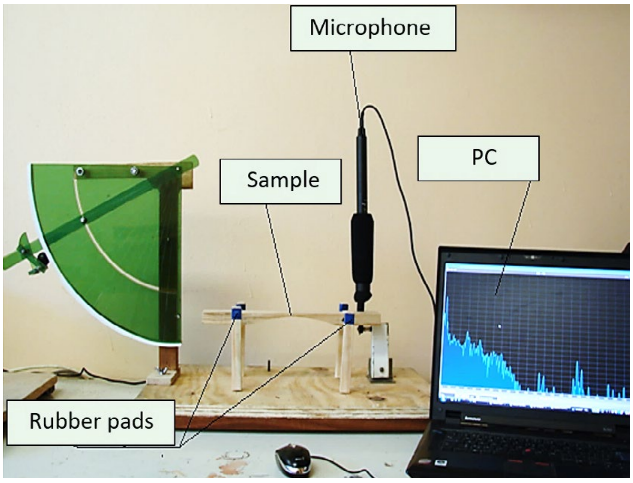

Fig. 2: Device designed for measurement of sound radiation

The resonant dynamic method was used to measure the resonant frequency f_r of bar and the Young's modulus along the wood grain E_L can be determined [9]. Other PACHs (acoustical constant *A,* speed of sound along the wood grain c_L loss coefficient η, specific modulus of elasticity E_{sp} acoustic conversion efficiency *ACE*) were calculated according to the equations given and described in more detail in [2, 9, 17].

Vibrations of xylophone bars tuned to the tone C4 = 264 Hz were excited by the impulse method (a device designed by [10]) before and after the combined modification (the arc dimensions were all the same). The device for measuring the sound radiation of a xylophone bar is shown on Fig. 2. The measurement was carried out in an anechoic chamber. The Fast Fourier Transformation (FFT) analysis was performed using Adobe Audition programme. The sound quality (before and after modification) was evaluated based on frequency analysis. The results were compared with the results obtained from measurements of xylophone bars made of the Honduran rosewood.

3. RESULTS AND DISCUSSION

3.1. Physical and acoustical characteristics (PACHs)

Tab. 1 presents measured average PACHs values of the European mountain ash (MA) before, after mechanical densification, combined modification (mechanical densification and thermal modification) and PACHs of the Honduran rosewood (HR).

Wood	ρ_w (kg.m^{-3})	E_L (GPa)	A (m^4.kg^{-1}.s^{-1})	η (-)	E_{sp} (10^6.m^2.s^{-2})	ACE (m^4.kg^{-1}.s^{-1})	c_L (m.s^{-1})
MA	699	12.46	6.05	0.0217	17.83	278.97	4 223
MA – mechanical densification	809	13.09	4.97	0.0184	16.18	270.11	4 010
MA – combined modification	724	13.63	5.99	0.0172	18.83	348.26	4 338
HR	996	23.24	4.85	0.0101	23.33	482.27	4 820

Tab. 1: PACHs (ρ_w – density, E_L – modulus of elasticity, A – acoustical constant, η – loss coefficient, Esp – specific modulus of elasticity, ACE – acoustic conversion efficiency, c_L – speed of sound) of European mountain ash (MA) and Honduran rosewood (HR)

As can be seen from Tab. 1, the density of European mountain ash increased much more after densification than after the combined modification. The decrease in density after thermal modification is caused by the decomposition of hemicellulose and some accompanying substances at higher temperatures [12]. This causes a decrease in mass (at temperature around 160 °C) and a reduction in the dimensions of the samples. However, the sample volume decreases less than the corresponding mass losses [3, 11]. Densification of the European mountain ash caused an increase in the modulus of elasticity E_L (Tab. 1) by 5.1 % but after the combined modification it increase by 9.4 %. When compared acoustical constant A of MA with the reference HR (A = 4.85 m^4·kg^{-1}·s^{-1}), it can be stated that densification (A = 4.97 m^4·kg^{-1}·s^{-1}) is more suitable modification like combined modification. The acoustical constant of wood for xylophone bars must be relatively low, because then the amplitude of the bar vibration is small, and the sound is radiated into the environment for a longer time. Duncan's test showed a statistically significant difference between relevant PACHs (except acoustical constant after mechanical densification) of European mountain ash (after both modification) and Honduran rosewood.

Since the sound of the xylophone bars should decay sufficiently slowly, a low loss coefficient η is required [15]. It is a reliable indicator quantifying the damping of vibrations due to internal friction. As is evident from Tab. 1, HR has a very low loss coefficient, which is due to the high content of extractives [13, 14]. The results for the loss coefficient η showed that neither densification (η = 0.0184) nor combined modification (η = 0.0172) achieved a reduction to the level of rosewood (η = 0.0101).

The specific modulus of elasticity E_{sp} describes the ability of a material to withstand a load without significant deformation or damage. Thermal modification causes the degradation of cellulose and hemicelluloses, while increasing the lignin content. Lignin acts as a binding material in the cell wall, giving it stiffness, which is reflected in a specific modulus [16]. Due to the higher specific modulus after combined modification, the vibrations of xylophone bar are less damped by the sound radiation and the decay time of the bar vibration is longer. The sound of a xylophone is produced by striking with mallets and wood with a high specific modulus of elasticity is more suitable for xylophone bars. For these reasons, the combined modification of MA appears to be more appropriate.

Acoustic conversion efficiency (ACE) describes how much of the input power to a xylophone bar is converted into sound [9]. Wegst [13] suggested that woods for xylophone bars have rather high values of ACE (peak response) but not of *R* (average loudness). Ono [10] proved that a higher *ACE* correlates with a greater overall power level of sound from wooden bar. Our results show that higher values of *ACE* (348.26 $m^4 \cdot kg^{-1} \cdot s^{-1}$) were achieved after the combined modification of MA.

3. 2. FFT analysis – harmonic frequencies of the sound

The 1st bending natural frequency (fundamental frequency) and resonant frequency were obtained from the sound generated using Fast Fourier Transform (FFT). Results of FFT analysis (time course of signal, a sound spectrum of tone C4 = 264 Hz) of tuned bars of the European mountain ash before and after combined modification are presented in Fig. 3 and Fig. 4 and of the Honduran rosewood in Fig. 5.

For xylophone bars, the optimal frequency ratio of the 1st and 2nd harmonic frequencies to the fundamental frequency is 3:1 and 6:1. For the higher notes the 3:1 tuning is applied to xylophone bars, while 4:1 tuning characterizes the sound of the instruments of the lower register [19].

As can be seen from the sound spectrum of the C4 tone (Fig. 4 and Fig. 5), the European mountain ash after combined modification approached the spectrum of Honduran rosewood through the ratio of harmonic frequencies. The ratio of harmonic frequencies of the Honduran rosewood is (1:3.7:7.8) and the European mountain ash after combined modification is (1:3.4:7.1). Only the 1st harmonic frequency was excited in the European mountain ash before modifications and the ratio of frequencies is (1:3.8).

The combined modification reduced the ratio of harmonic frequencies to the fundamental frequency. The wood of European mountain ash after combined modification can probably be used in manufacture of xylophones of the lower register.

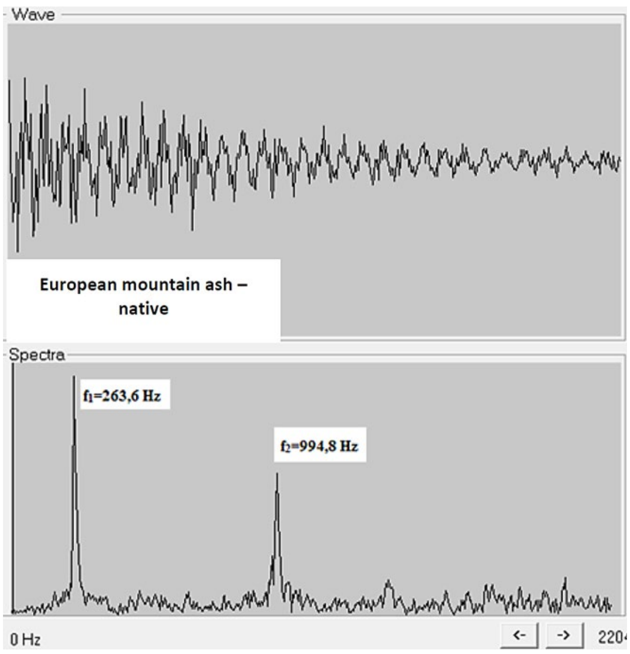

Fig. 3: FFT analysis tuned C4 (= 264 Hz) bar of MA in nature

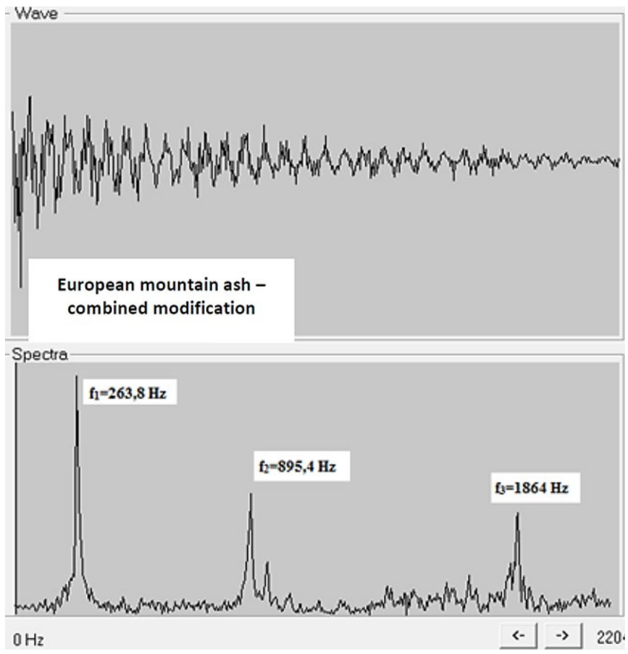

Fig. 4: FFT analysis tuned C4 (= 264 Hz) bar of MA after combined modification

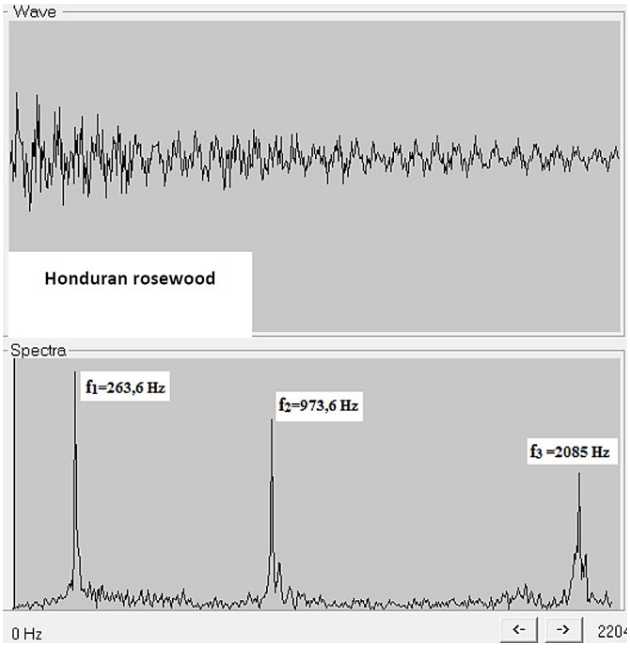

Fig. 5: FFT analysis tuned C4 (= 264 Hz) bar of HR

4. CONCLUSION

Wood used in the production of idiophonic musical instruments – xylophones (e.g., Honduran rosewood) need to have high density and high modulus of elasticity, yet a low acoustical constant. The properties of hardwood species cause that the radiated sound decay slower, due to the lower lose energy. Moreover, the wood must meet also certain aesthetic requirement.

The combined modification (mechanical densification and thermal modification), the physical, mechanical and vibrational characteristics of wood were changed, and they correspond to the requirements of wood for the xylophones bar. Thermal modification also causes a change in the colour of wood, which is welcome from an aesthetic point of view.

Following the experiment results it can be stated that the wood of the European mountain ash, after combined modification, can be used as an alternative to the Honduran rosewood for the xylophones of lower quality.

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