Investigation of the Performance of Pistachio Husks as a Sustainable Sound-absorbing Material

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There are ongoing efforts to use eco-friendly sound-absorbing materials to reduce noise pollution. Various sustainable sound-absorbing materials, including agricultural by-products, have been examined in previous research. This study focuses on using pistachio husks as a sustainable sound-absorbing material. To assess the performance, the sound absorption coefficient was determined by filling impedance tubes with pistachio husks to heights of 40, 60, 80, and 100 mm. The sound absorption peak was observed at 0.523 at 1,296 Hz at a fill height of 40 mm, and 0.736 at 532 Hz at a fill height of 100 mm. As the amount of pistachio husks in the impedance tube increased, the sound absorption performance at low frequencies improved. The noise reduction coefficients (NRCs) were 0.456 at 80 mm and 0.428 at 100 mm. This corresponds to a KS F 3503 grade of 0.5M, which shows that pistachio husks have sound absorption properties. However, the sound absorption performance of pistachio husks was inferior to that of other natural materials. Therefore, future research is required to improve the porosity of pistachio husks through various physical and chemical treatments.

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INTRODUCTION

Noise pollution complaints have increased in urban areas (Tong and Kang 2021), and it poses a severe threat to human health. According to the World Health Organization's (WHO's) report on 'Disease Burden due to Environmental Noise' published in 2011, noise pollution can cause cardiovascular disease, sleep disturbance, tinnitus, as well as cognitive impairment (WHO 2011). Accordingly, interest in potential noise pollution solutions is growing (Toki *et al.* 2021).

The COVID-19 pandemic changed many aspects of our daily lives; foreign travel was restricted, and direct contact between individuals was reduced (Douglas *et al.* 2020; Haryanto 2020). More time spent indoors has resulted in more noise disputes between neighbors (Lee and Jeong 2021; Yildirim and Arefi 2021). In the UK, tweets about noise complaints more than doubled in 2020 compared to before the COVID19-related lockdown which began in 2019 (Lee and Jeong 2021). In Mexico, 42% of disputes caused by lockdown were related to noise (Hoehn-Velasco *et al.* 2020). The COVID-19 pandemic has highlighted the importance of reducing indoor noise and has likely increased public demand for sound-absorbing materials (Jang and Kang 2022b).

Glass, mineral wool, and polyurethane foam are the primary raw materials used in sound absorption materials, though each of which is accompanied by environmental (recycling) concerns. Accordingly, interest in eco-friendly sound-absorbing materials, which are usually fabricated from agricultural by-products, has increased (Yang *et al.* 2020; Gboe *et al*. 2024). These agricultural by-products can include rice straw (Kang *et al.* 2018), kenaf fiber (Lim *et al.* 2018), coconut fiber (Bhingare and Prakash 2021), and peanut husk (Jang *et al*. 2022).

Recently, as a sustainable and eco-friendly sound-absorbing material, wood material has also attracted attention. A hole in a wood panel acts as a resonance absorber. In a previous study, optimum sound absorption peak changed in response to changes in the diameter and distribution of the hole in perforate plate (Peng *et al.* 2018). Hardwood cross-sections with well-developed vessels can also act as a porous sound absorber. The sound absorption performance was excellent in species of hardwood with high through-pore porosity, because the sound wave loses energy as it hits the walls inside the vessels. Accordingly, diverse physical and chemical treatments have been employed to increase the porosity of wood and enhance its sound absorption properties (Jang and Kang 2021e, 2021b, 2021d, 2021a, 2021c, 2022b, 2022a, 2022c).

Wood bark can also be used as a sustainable and eco-friendly sound-absorbing material. Kang *et al.* (2019) investigated the sound absorption performance of six types of wood bark particles and found that the noise reduction coefficient (NRC) varied from 0.24 to 0.82 depending on the particle's size, density, and thickness.

Jang and Park (2025) reported that the sound absorption performance of shredded paper waste increases with material thickness, showing particularly high absorption at 80 to 100 mm. They observed that the material significantly improves low-frequency absorption while maintaining effectiveness across a broad frequency range. Their findings suggest that shredded paper waste is a sustainable and acoustically efficient option for building applications.

In addition, tree fruit stone waste can be used as a sound-absorbing material. Borrell *et al.* (2020) examined the absorption coefficients of four types of fruit stone waste. They found that sound absorption traits depend on the fruit stone's shape and size, as thicker samples demonstrated higher sound absorption coefficients at low frequencies.

Jung *et al.* (2021) proposed using air-dried leaves of evergreen trees as an eco-friendly sound-absorbing material. In their study, the average sound absorption of air-dried *Dendropanax morbiferus* and *Fatsia japonica* ranged from 0.288 to 0.575, depending on the thickness and size of the leaves. Jang (2022a) investigated the use of wood pellets as a granular sound-absorbing material. He also introduced wood and forest by-products such as pine pollen corns, hinoki cubes, and *Acanthopanax senticosus* wastes as an environmentally sound-absorbing material (Jang 2022b). Their sound absorption performance was relatively good.

This study introduced pistachio husk as a sustainable and eco-friendly material. The pistachio nut (*Pistacia vera* L.) of the Anacardiaceae family is consumed for its nutritional and sensory properties (Grace *et al.* 2016). The world's major producers of pistachio are in Iran, the United States, Turkey, China, and Syria (Karacan and Ceylan 2020). Iran alone generates at least about 520,400 tons of pistachio hull waste annually (Taghizadeh-

Alisaraei *et al.* 2017). Pistachios consist of a rigid hull and nutmeat. Pistachio husk is a sustainable agricultural by-product.

Pistachios' by-products, obtained after de-hulling, have been mainly considered as an adsorbent for wastewater treatment (Igwegbe *et al.* 2021) and in biofuel production (Taghizadeh-Alisara *et al.* 2017). However, few studies have investigated the use of pistachio husks as a sound-absorbing material. Although pistachio husks are not highly porous, their naturally curved, bowl-like geometry may enable them to trap incident sound energy within the husks. Therefore, this study evaluates the performance of pistachio husks and considers their potential application as a sustainable and eco-friendly sound-absorbing material.

EXPERIMENTAL

Sample Preparation

Figure 1 shows pistachio husk samples. Pistachios were sourced from the U.S.A., and supplied by Seum Co. Ltd. (Ansung, Korea). Since the primary purpose of this study was to evaluate the sound absorption performance of pure pistachio husks, grains, and husks were separated. The width and height of the pistachio husks were measured using a vernier caliper and were 12 ± 2 mm and 20 ± 2 mm, respectively.

Fig. 1. Pistachio husk samples

Scanning Electron Microscopy (SEM) Observation

The external and internal surfaces of pistachio husks were observed at 500× magnification using a scanning electron microscope (SEM: Genesis-1000, Emcraft, Gwangju, Korea). Interior and exterior images of the surface of the pistachio husks were each taken three times.

Measurement of the Sound Absorption Coefficient

Sound absorption was measured using the transfer function method in an impedance tube (model: 4206, Brüel and Kjær, Denmark). Figure 2 shows a schematic diagram of two impedance tubes used to measure the absorption coefficient of pistachio husk; a "large tube" with a diameter of 99 mm, and a "small tube" with a diameter of 29 mm. After filling both impedance tubes with pistachio husks, each was shaken up and down 5 to 10 times to ensure a random arrangement. The pistachio husks were filled inside the impedance tube to respective heights of 40, 60, 80, and 100 mm.

Before filling, the empty cylinder was weighed. The husks were then poured into the cylinder without applying external pressure, and the surface was leveled to match the target height. After filling, the cylinder was weighed again. The bulk density was determined by comparing the mass of the husks with the known volume of the cylinder corresponding to the filling height, and the resulting bulk density was approximately 0.3 g/cm³.

A power amplifier generated a plane wave sound ranging from 100 to 1,600 Hz in the large tube and 100 to 6,400 Hz in the small tube. The sound absorption curves were obtained by measuring the sound absorption coefficient three times for each pistachio husk filling height, and averaging the results.

The sound absorption performance of pistachio husks was evaluated using Korean Industrial Standard KS F 3503 (KSA 2012). Table 1 divides the sound absorption performance of materials into four grades according to NRC values (average sound absorption coefficient at 250, 500, 1,000, and 2,000 Hz), as stated by KS F 3503.

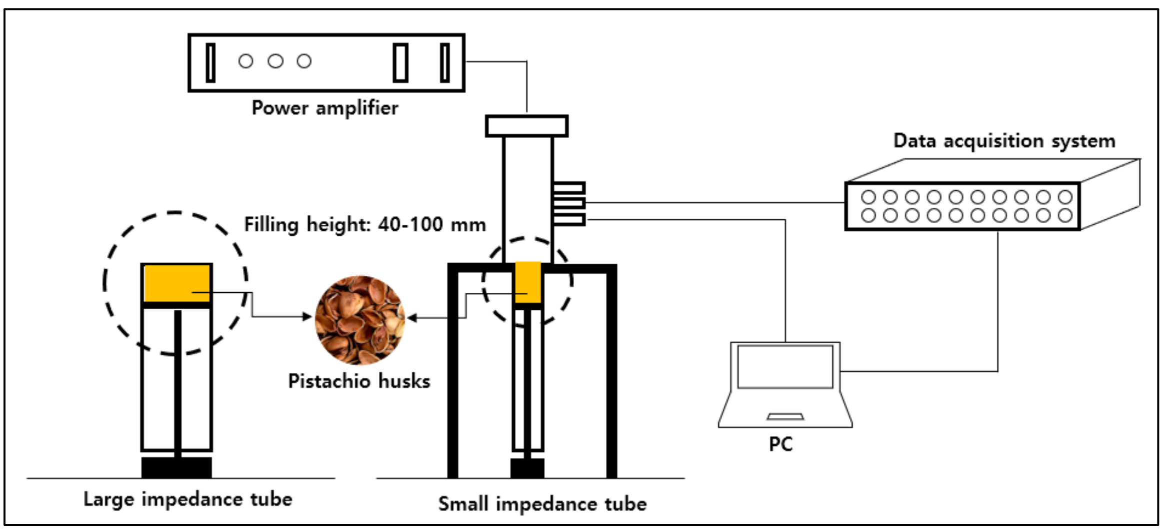


Fig. 2. Pistachio husk samples

Table 1. Sound Absorption Capability of Sound-absorber KS F 3503 (2012)

Class	NRC
0.8M (M)	Above 0.81
0.7M (M)	0.61 to 0.80
0.5M (M)	0.41 to 0.60
0.3M (M)	0.21 to 0.40

Note: If the sound-absorbing material is close to the wall, "M" must be marked after the grade mark. And if the sound-absorbing material does not adhere to the wall (when the airbag cavity is applied), "S" must be marked.

RESULTS AND DISCUSSION

SEM Images

Figure 3 shows SEM images of the outside and inside surfaces of a pistachio husk. Overall, the outside surface had a dense structure, and some pores were observed on the surface.

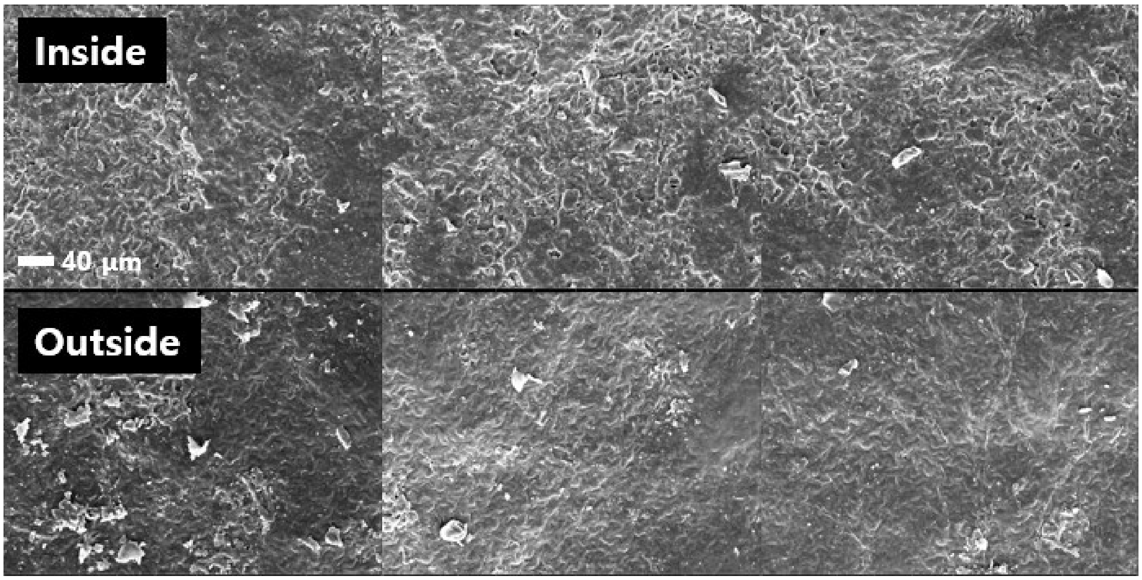


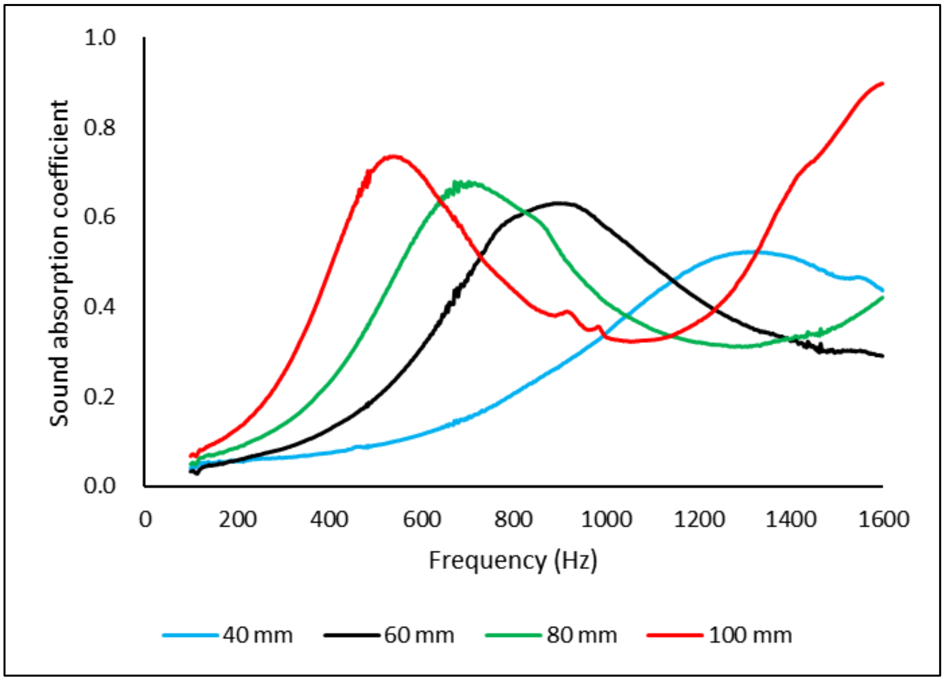
Fig. 3. SEM images of the pistachio husk's surface

Sound Absorption Properties

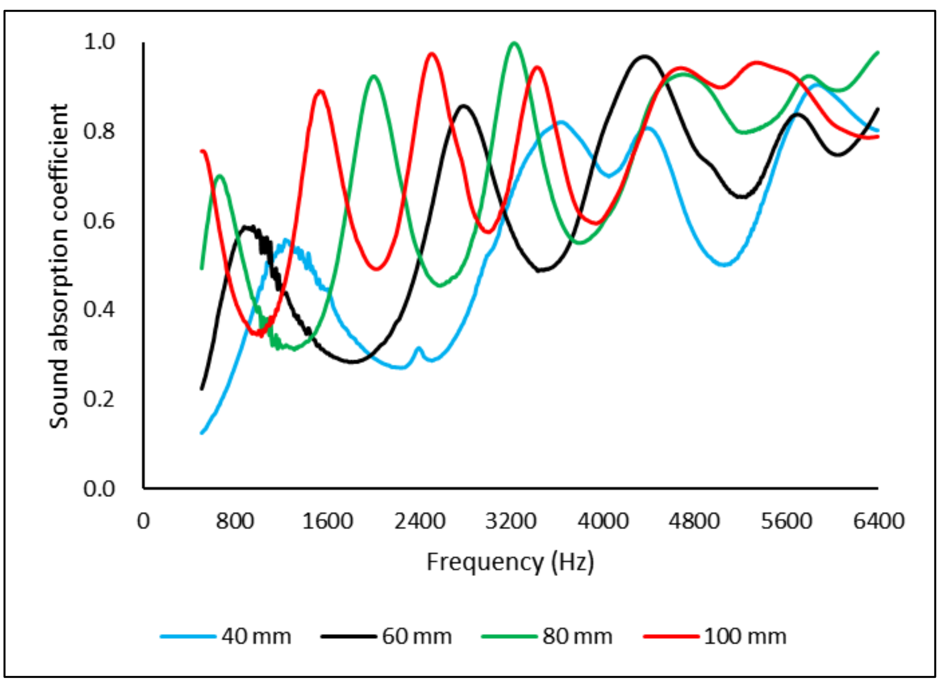
Figure 4 displays the sound absorption coefficient curves of pistachio husk. Figures 4(a) and 4(b) show the sound absorption results from the large and small impedance tubes, respectively. The absorption peaks obtained were as follows: 0.523 at 1,296 Hz at a filling height of 40 mm; 0.629 at 886 Hz at a height of 60 mm; 0.679 at 686 Hz at a height of 80 mm, and 0.736 at 532 Hz at a height of 100 mm (Fig. 4(a)). These results show that the sound absorption performance of pistachio husk at low frequencies increased as the filling height inside the impedance tube rose from 40 to 100 mm. In regards to a porous or granular sound absorber, a thicker material results in increased sound absorption performance at low frequencies (Yang *et al.* 2020; Jang 2022a). At high frequencies, above 500 Hz, the sound absorption peaks were four at the filling height of 40 mm, five at 60 mm, and six at both 80 and 100 mm (Fig. 4(b)).

While the dense surface of the pistachio husks was not advantageous for sound absorption, the empty spaces between the pistachio husks absorbed sound energy. In particular, the irregular arrangement of pistachio husks created a more complicated path for sound to travel. The intrinsic geometric characteristics of packed pistachio husks may induce phenomena such as negative refraction and acoustic cloaking, thereby enhancing their overall sound absorption performance (Cao *et al.* 2018; Wu *et al*. 2026).

Table 2 shows the sound absorption coefficients at 250, 500, 1,000, and 2,000 Hz, as well as NRC values. The sound absorption coefficient at 250 and 500 Hz improved as the filling height of pistachio husks increased. When the filling height of pistachio husks was increased 2.5 times, from 40 to 100 mm, the sound absorption coefficients at 250 and 500 Hz rose by 2.9 and 7.8 times, respectively. In addition, 80 mm filled pistachio husks had an optimum sound absorption coefficient of 0.922 at 2000 Hz. As the human ear is sensitive to noise at frequencies above 2,000 Hz (Aybek *et al.* 2010), at 80 mm pistachio husk height may prevent hearing loss in those exposed to noise.



(a) Large impedance tube



(b) Small impedance tube

Fig. 4. Sound absorption curves of pistachio husk

Table 2. The Sound Absorption Coefficient and NRC

Thickness (mm)	Sound Absorption Coefficient at Various Frequencies (Hz)				NRC
	250	500	1000	2000	
20	0.061	0.091	0.342	0.294	0.197
	(0.002)	(0.001)	(0.035)	(0.033)	(0.018)
40	0.071	0.195	0.576	0.303	0.286
	(0.005)	(0.003)	(0.023)	(0.035)	(0.016)
60	0.108	0.386	0.410	0.922	0.456
	(0.002)	(0.017)	(0.015)	(0.008)	(0.010)
80	0.176	0.711	0.333	0.493	0.428
	(0.010)	(0.026)	(0.007)	(0.036)	(0.020)

Note: The values in parentheses are the standard deviations

Improved NRC values were observed as the filling height of pistachio husks increased, and the optimal sound absorption performance was found at a filling height of 80 mm. The sound absorption performance of pistachio husks was slightly lower than that of the authors' previous studies which evaluated peanut husks (NRC: 0.533 at 90 mm) and pine pollen cones (NRC: 0.513 at 100 mm). Nonetheless, KS F 3503 grade 0.5M was evaluated at the same level. In summary, this study shows that pistachio husks have a sound-absorbing effect.

Figure 5 presents a comparison of sound absorption performance between pistachio husks and various other natural materials proposed in previous studies. At equal material height, pistachio husks exhibited relatively lower sound absorption capability. This is presumed to result from their low surface porosity and the fact that sound absorption occurs primarily through the void spaces between individual husks rather than within the material itself. The present findings highlight the importance of internal microstructure and surface porosity in determining sound absorption capability. Materials with interconnected pores and complex internal geometry tend to dissipate sound energy more effectively (Egab *et al.* 2014; Yang *et al.* 2020; Jang 2023). Given that pistachio husks primarily absorb sound through inter-husk gaps, future optimization may involve physical or chemical surface treatments to enhance porosity or combining them with other fibrous materials to improve overall performance.

Beyond the present findings, pistachio husks may be applied as eco-friendly sound-absorbing materials in building acoustics, interior finishing, and noise control panels. Their utilization not only contributes to sustainable waste management but also diversifies the portfolio of agricultural by-products used in acoustic engineering. Future studies should focus on enhancing porosity through physical and chemical treatments, pulverization, or hybridization with fibrous materials to improve absorption efficiency. It is proposed that the findings of this study will diversify the potential applications of pistachio husks.

Fig. 5. Comparison of NRC values of various eco-friendly materials (Berardi and Iannace 2015) and SPW sound-absorber depending on the thickness

CONCLUSIONS

1. As the filling height of pistachio husks increased, sound absorption performance improved.
2. The pistachio husks filled to 80 mm and 100 mm heights had a 0.5 M (KS F 3503) grade. These results suggest that pistachio husks can be used as a sustainable sound-absorbing material.
3. The sound absorption of pistachio husks was lower than other natural materials. Future studies will aim to enhance porosity through physical and chemical treatments, grinding, or mixing, and optimize their structure to improve sound absorption.

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