



## RESEARCH ARTICLE

# Physical Properties and Sound Absorption Performance of Durian (*Durio* spp.) Peel-Based Particleboard with Cold-Water Soaking and Density Variation



Dina Setyawati\*<sup>ORCID</sup>, Nurhaida<sup>ORCID</sup>, Catherine Priscilla Buulolo<sup>ORCID</sup>

Faculty of Forestry, Universitas Tanjungpura, Pontianak, Indonesia

\* Corresponding author: [dina@fahatan.untan.ac.id](mailto:dina@fahatan.untan.ac.id)

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## ABSTRACT

Durian (*Durio* spp.) peel waste has potential as a lignocellulosic raw material, offering a sustainable pathway for wood-based panel production and acoustic applications. This study evaluates the effects of board density and cold-water soaking pretreatment on the physical properties and sound absorption performance of particleboard manufactured from durian peel particles. Boards were produced at target densities of 0.40 and 0.50 g/cm<sup>3</sup> using 15% urea-formaldehyde adhesive, with particle soaking durations of 0, 12, and 24 h. Physical properties were assessed according to JIS A 5908, while acoustic performance was measured using a two-microphone impedance tube across 64–6400 Hz. Results showed that board density significantly influenced moisture content, thickness swelling, and acoustic behavior, whereas cold-water soaking primarily affected dimensional stability and water absorption. Lower-density boards exhibited higher sound absorption due to increased porosity, with the highest absorption coefficient ( $\alpha = 0.87$ ) obtained at 0.40 g/cm<sup>3</sup> after 12 h cold-water soaking at 3150 Hz. All panels met JIS requirements for density, moisture content, and thickness swelling. Sound absorption was generally greater at medium to high frequencies, while higher-density boards demonstrated improved sound insulation but reduced absorption efficiency. According to the ISO classification, the panels ranged from class D to class B, indicating sound absorption capabilities from normal to high. These findings demonstrate that durian peel-based particleboard can serve as a viable, sustainable material for interior acoustic applications while supporting efficient biomass utilization.

## 1. Introduction

The high demand for wood as a building material, for construction, decoration, and furniture, continues to grow alongside population growth. This situation can lead to the overexploitation of forests and ultimately have negative environmental impacts, such as global warming, flooding, and landslides. The development of panel products, such as particleboard, from non-wood materials is expected to serve as an alternative to reduce the use of solid wood, thereby alleviating pressure on forests (Birniwa et al., 2023; Kariuki et al., 2020; Okeke et al., 2024; Prabhu et al., 2021). One abundant but underutilized non-wood material is durian (*Durio* spp.) peel waste (Morasilp et al., 2025; Savitri et al., 2023). Durian is a popular seasonal fruit in Indonesia. Durian production in Indonesia is projected to reach 1.98 million tons in 2024 (BPS, 2025). Assuming durian peel waste accounts for 50% of the total fruit mass, the accumulation of durian peel waste has the potential to pollute the environment if not managed effectively. Making particleboard from durian peel waste represents an effort to utilize waste as a raw material solution for the wood industry while reducing environmental impact. Durian peel has a high cellulose content, so it has the potential to be used as a raw material in various material technology applications, including as a sound-dampening material (Indrayanti et al., 2024; Putra et al., 2022; Tang and Nguyen, 2025).

The use of materials with sound-absorbing properties is crucial for reducing noise levels, particularly in interior applications such as walls and ceilings. Excessive noise levels can cause

discomfort and adverse health impacts, including hearing loss, tinnitus, and psychological stress. Occupational and environmental noise exposure has been linked to noise-induced hearing loss and non-auditory effects such as increased stress in the general population (Hahad et al., 2025). Research on sound-absorbing materials continues to grow in line with the need for environmentally friendly materials (Hou et al., 2024; Rakesh et al., 2021; Yang et al., 2020). Natural fibers have higher porosity and amorphous structure than synthetic fibers, so they have the potential to be used as raw materials for soundproofing.

Several factors, including density, influence the quality of particleboard. Particleboard density is defined as the ratio of weight to volume and represents the degree of compaction of the particles in the formed board sheet. Mechanically, increasing density generally increases the modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IBS) due to tighter interparticle contact and more effective adhesive bonding (Tarigan et al., 2025). However, density also directly affects acoustic performance. Rao et al. (2025) studied the effect of particleboard density from coconut fiber, rice straw, bagasse, and wheat straw on thermal, acoustic, and mechanical properties. They stated that higher density improves mechanical properties but reduces sound absorption effectiveness due to reduced porosity. Putra (2020) examined the sound absorption coefficient of particleboard made from oil palm frond waste with density variations of 0.40 g/cm<sup>3</sup>, 0.60 g/cm<sup>3</sup>, and 0.90 g/cm<sup>3</sup>. The results showed that the highest sound absorption coefficient was obtained at a density of 0.40 g/cm<sup>3</sup>, while the lowest value was observed at 0.90 g/cm<sup>3</sup> in the frequency range of 500–1200 Hz. These findings indicate that density variations affect the material's sound absorption capacity.

Another factor affecting particleboard quality is the pre-treatment of the raw materials (Hartono et al., 2018). Cold-water soaking is one of the simplest processing methods for improving the quality of natural fibers. This process helps remove dirt and contaminants from the fibers. Cold-water soaking can cause some extractive substances in the particles to dissolve, thereby improving the adhesion quality in the particleboard production process, such as in particleboard from jatropha fruit peel (Iswanto et al., 2018), sengon (Marwanto et al., 2018), and wood chip recovery (Dafni et al., 2022). Cold-water soaking also increases the porosity of the wood, thereby improving the sound absorption capacity of the particleboard (Rao, 2025). Iswanto et al. (2021) stated that the type of biomass will affect the properties of the particle board produced. However, information on the use of durian peel as a raw material for particleboard with various cold-water soaking times and densities, as a soundproofing material, remains limited and warrants further research. Therefore, this study aims to analyze the effects of density and cold-water soaking on the physical properties and sound absorption coefficient of durian peel-based particleboard.

## 2. Materials and Methods

This study was conducted at three facilities. Material preparation was carried out at the Woodworking and Forest Products Craft Laboratory, Faculty of Forestry, Tanjungpura University. Particleboard manufacturing and physical properties testing were performed at the Biomaterials Laboratory, Faculty of Forestry, Tanjungpura University. Sound absorption measurements were conducted at the Vibration and Acoustics Laboratory, Bandung Institute of Technology (ITB). The research was completed over a period of nine months, encompassing material preparation, board fabrication, testing, and data analysis.

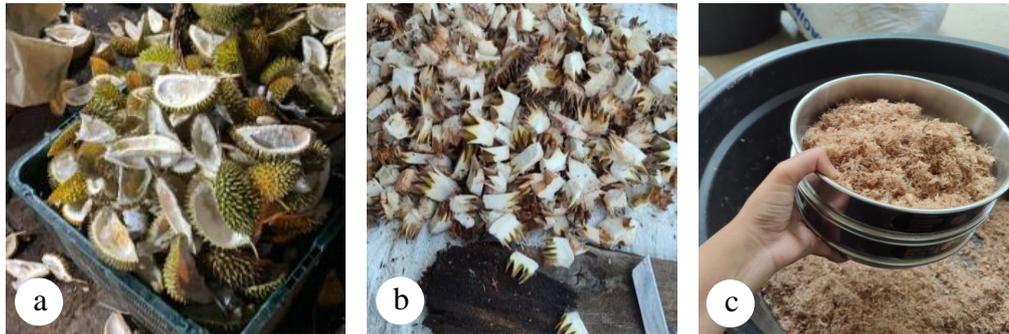
### 2.1. Research Material and Tools

The primary materials used in this study were durian peel waste, urea–formaldehyde (UF) adhesive with a solid content (SC) of 52%, liquid paraffin (SC 40%), and a catalyst (SC 25%), all supplied by PT SAL Sambas. The main equipment included a 30 cm × 30 cm × 1 cm board mold, an analytical balance, calipers, a hot press machine, a hammer mill, an electric oven, and a two-microphone impedance tube.

### 2.2. Material Preparation

Durian peels were chopped into smaller pieces and sun-dried until reaching air-dry moisture content. The dried material was then ground using a hammer mill and sieved to obtain particles passing through an 8-mesh sieve and retained on a lower mesh. The particles were soaked in cold water for 0, 12, and

24 h to remove extractive substances, drained, and then air-dried. Subsequently, the particles were oven-dried at approximately 60°C to a moisture content of about 5% and stored in sealed plastic bags to maintain constant moisture content. The preparation process of durian peel particles is shown in **Fig. 1**.



**Fig. 1.** Preparation of raw materials: (a) durian peel waste, (b) chopped durian peel, and (c) durian peel particles.

### 2.3. Particleboard Production

Particleboards were manufactured with dimensions of 30 cm × 30 cm × 1 cm and target densities of 0.40 and 0.50 g/cm<sup>3</sup>. The composition of raw materials for each density level and cold-water soaking treatment is presented in **Table 1**. Urea–formaldehyde (UF) adhesive was applied at 15% based on oven-dry particle weight (Putra, 2020). The adhesive and particles were manually mixed until a homogeneous mixture was obtained, and then uniformly distributed into the mold. After pre-pressing, the mold was carefully opened, and steel plates (1 cm thickness) were placed on both sides to maintain board thickness during hot pressing. Hot pressing was conducted at 140°C for 10 min under 25 kg/cm<sup>2</sup> pressure. A total of 15 boards were produced and conditioned for one week to release residual stresses before being cut into test specimens.

**Table 1.** Composition of raw materials

Density (g/cm <sup>3</sup> )	Soaking time (minutes)	Weight (g)			
		Particle	UF adhesive	Catalyst	Paraffin
0.4	0	325.58	97.65	1.24	3.16
	90	325.58	97.65	1.24	3.16
	120	325.58	97.65	1.24	3.16
0.5	0	406.97	122.25	1.55	3.95
	90	406.97	122.25	1.55	3.95
	120	406.97	122.25	1.55	3.95

### 2.4. Performance Evaluation

Particleboard performance was evaluated through physical and acoustic testing. Physical properties, including density, moisture content, water absorption, and thickness swelling, were measured in accordance with JIS A 5908 (2003). Sound absorption performance was determined using a two-microphone impedance tube (BSWA SW477) (**Fig. 2a**). The measurement system consisted of a signal generator (A) connected to a loudspeaker (B) installed inside the tube, producing acoustic waves that propagated toward the test specimen (C). When the incident sound waves interacted with the specimen, part of the energy was reflected while the remainder was absorbed or transmitted through the material. The sound pressure signals were captured by two microphones (D) and analyzed using computer-based frequency analysis to calculate the sound absorption coefficient. Measurements were conducted over a frequency range of 64–6400 Hz, divided into three bands: low frequency (64–250 Hz), medium frequency (500–1000 Hz), and high frequency (>2000 Hz). The test specimens used for acoustic measurements are shown in **Fig. 2b**.



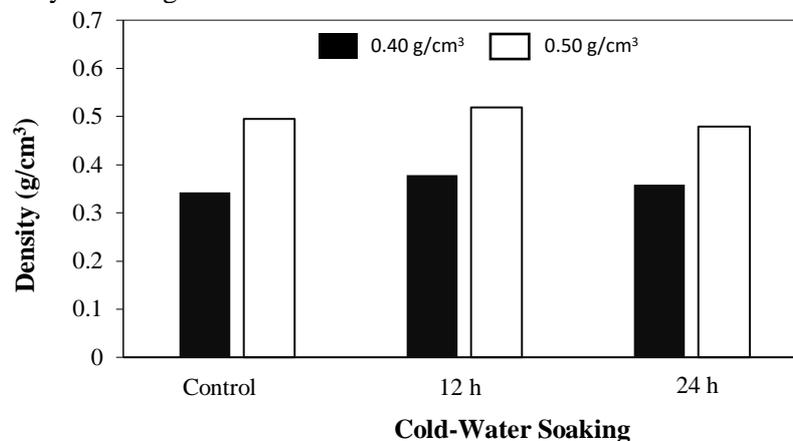
**Fig 2.** (a) Schematic of the sound absorption measurement using a two-microphone impedance tube, (b) test specimen. Notes: A = signal generator, B = loudspeaker position, C = test specimen position, D = microphones.

### 3. Results and Discussion

#### 3.1. Physical Properties of Particleboard

##### 3.1.1. Density

The measured density of the durian peel particleboards ranged from 0.34 to 0.52 g/cm<sup>3</sup> (**Fig. 3**), corresponding closely to the target densities of 0.40 and 0.50 g/cm<sup>3</sup>. Boards manufactured at the higher target density exhibited significantly greater measured density than those at the lower target density. The highest density (0.52 g/cm<sup>3</sup>) was obtained from boards with a target density of 0.50 g/cm<sup>3</sup> subjected to 12 h cold-water soaking, whereas the lowest density (0.34 g/cm<sup>3</sup>) occurred in untreated boards with a target density of 0.40 g/cm<sup>3</sup>.



**Fig. 3.** Average density values of particleboard based on density variation and cold-water soaking.

Analysis of variance indicated that density variation had a highly significant effect on board density (**Table 2**), while soaking duration and the interaction between factors were not statistically significant. This suggests that compaction level during pressing primarily determines board density, whereas cold-water soaking does not substantially alter particle packing or compression behavior. Similar findings were reported for particleboards produced from other lignocellulosic residues, where target density was the dominant factor influencing final board density ([Marwanto et al. 2018](#)). Variations between target and measured densities may be attributed to manual mat formation, which can produce non-uniform particle distribution and localized differences in compression ratio. Such variability has been previously observed in laboratory-scale particleboard manufacturing. [Karlinasari et al. \(2012\)](#) reported that the manual board manufacturing process can cause uneven particle distribution during sheet formation or particle release during pressing. According to JIS A 5908, boards with densities around 0.50 g/cm<sup>3</sup> are classified as medium-density particleboard, whereas those near 0.40 g/cm<sup>3</sup> fall into the low-density category.

**Table 2.** Analysis of variance for particleboard density

Source of variation	df	SS	MS	F-value	F-critical	
					5%	1%
Treatment	5	0.09				
Density (A)	1	0.08	0.0857	45.20**	4.75	9.33
Cold-water soaking (B)	2	0.00	0.0018	0.95 <sup>ns</sup>	3.89	6.93
A × B	2	0.00	0.0004	0.20 <sup>ns</sup>	3.89	6.93
Error	12	0.02	0.0019			
Total	22	0.20		CV = 10.17%		

Notes: df = degrees of freedom, SS = sum of squares, MS = mean square, CV = coefficient of variation, ns = not significant, \*\* = highly significant.

Post hoc analysis using Tukey’s Honestly Significant Difference (HSD) test (**Table 3**) confirmed that boards manufactured at 0.50 g/cm<sup>3</sup> were significantly denser than those at 0.40 g/cm<sup>3</sup>. Density strongly influences board performance because it governs interparticle contact area, adhesive distribution, and internal bond formation. Increased density typically improves mechanical strength but may reduce porosity, which is critical for acoustic absorption.

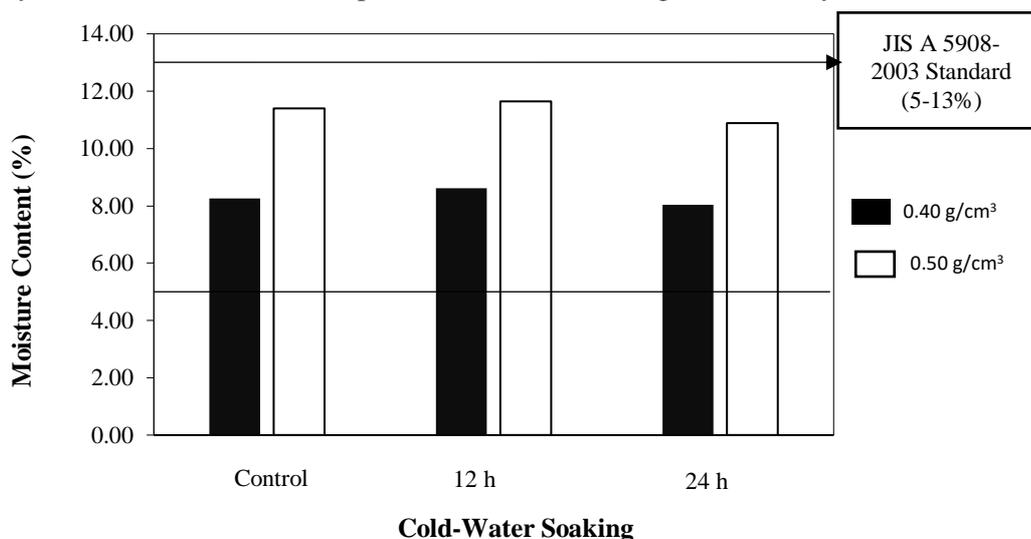
**Table 3.** Tukey’s HSD test results for particleboard density based on density variation

Density variation	Average
0.40 g/cm <sup>3</sup>	0.36a
0.50 g/cm <sup>3</sup>	0.52b
HSD 5% = 0.04	HSD 1% = 0.06

Notes: Means followed by the same letter are not significantly different, whereas means followed by different letters are significantly different.

3.1.2. Moisture content

The moisture content of the particleboards ranged from 8.03% to 11.63%, falling within the limits specified by JIS A 5908 (5–13%) (**Fig. 4**). Cold-water soaking in cold water for 24 h resulted in a lower moisture content for the particleboard compared to the control. This is consistent with research by [Hartono et al. \(2018\)](#), showing that longer cold-water soaking times resulted in lower moisture content in the particleboard. This is because pretreatment of the particles reduces the extractive content, thereby increasing the adhesive’s ability to penetrate cell walls and resulting in better bonding. Therefore, water vapor accessibility can be reduced ([Chaydarreh et al., 2022](#)). In this study, the analysis of variance results showed no significant differences among the pretreatments (**Table 4**). This shows that the soaking time in this study was insufficient to alter the particle structure, resulting in a relatively uniform water content.



**Fig 4.** Average moisture content of particleboard based on density variation and cold-water soaking.

**Table 4.** Analysis of variance for particleboard moisture content

Source of variation	df	SS	MS	F-value	F-critical	
					5%	1%
Treatment	5	42.08				
Density (A)	1	40.67	40.67	40.90**	4.75	9.33
Cold-water soaking (B)	2	1.34	0.67	0.67 <sup>ns</sup>	3.89	6.93
A × B	2	0.07	0.03	0.03 <sup>ns</sup>	3.89	6.93
Error	12	11.93	0.99			
Total	22	96.09		CV =10.17%		

Notes: df = degrees of freedom, SS = sum of squares, MS = mean square, CV = coefficient of variation, ns = not significant, \*\* = highly significant.

Boards manufactured at higher density exhibited significantly higher moisture content (**Table 5**). This behavior can be attributed to the hygroscopic nature of durian peel particles, which contain high proportions of hemicellulose capable of absorbing water vapor from the environment. [Gamay et al. \(2024\)](#) stated that durian peel contains high levels of cellulose (57–64%) and hemicellulose (30%). Higher-density boards contain more lignocellulosic material per unit volume, increasing the number of accessible hydroxyl groups and thus the equilibrium moisture content. The moisture content of particleboard in this study meets the standards set by JIS A 5908-2003, which requires particleboard water content to range from 5–13%.

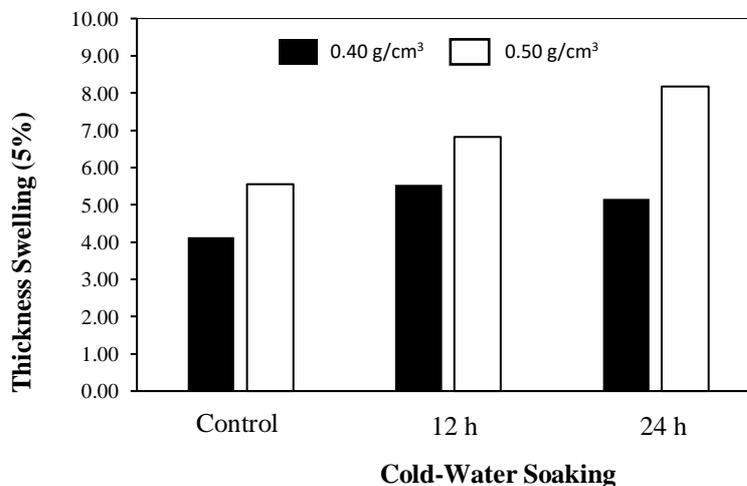
**Table 5.** Tukey’s HSD test results for particleboard moisture content based on density variation

Density variation	Average
0.40 g/cm <sup>3</sup>	8.30a
0.50 g/cm <sup>3</sup>	11.31b
HSD 5% =1.02	HSD 1%= 1.43

Note: Means followed by the same letter are not significantly different. whereas means followed by different letters are significantly different.

3.1.3. Thickness swelling

Thickness swelling after cold-water soaking ranged from 4.13% to 8.17% (**Fig. 5**), well below the maximum limit specified by JIS A 5908 of 12%. Both density variation and soaking duration had highly significant effects on thickness swelling. Boards with higher density exhibited greater swelling due to increased water uptake associated with the larger amount of hygroscopic material. These results align with those of [Maraghi et al. \(2018\)](#), who stated that boards with higher densities absorb more water than particleboards with lower densities. Reducing the board density reduces the amount of wood material per unit volume, thereby reducing the water that can be absorbed by the material particles. In addition, cold-water soaking increased thickness swelling, likely because extractive removal enhanced particle porosity and created additional void spaces that could facilitate water penetration during soaking.



**Fig 5.** Average thickness swelling of particleboard based on density variation and cold-water soaking.

The analysis of variance for particleboard thickness swelling shows that the interaction between the two factors had no significant effect on moisture content, whereas the density variation factor and cold-water soaking treatment had highly significant effects (**Table 6**).

**Table 6.** Analysis of variance for particleboard thickness swelling

Source of variation	df	SS	MS	F-value	F-critical	
					5%	1%
Treatment	5	29.85				
Density (A)	1	16.36	16.36	33.55**	4.75	9.33
Cold-water soaking (B)	2	10.71	5.35	10.98**	3.89	6.93
A × B	2	2.79	1.39	2.86 <sup>ns</sup>	3.89	6.93
Error	12	5.85	0.49			
Total	22	65.55		CV =11.85%		

Notes: df = degrees of freedom, SS = sum of squares, MS = mean square, CV = coefficient of variation, ns = not significant, \*\* = highly significant.

Post hoc analysis using Tukey's HSD test further clarified the effects of density variation and cold-water soaking on thickness swelling (**Table 7** and **Table 8**). Table 7 shows that particleboards with a target density of 0.50 g/cm<sup>3</sup> exhibited significantly higher thickness swelling than those with a density of 0.40 g/cm<sup>3</sup>. This result indicates that higher board density increases susceptibility to dimensional instability under cold-water soaking. Although denser boards generally possess stronger interparticle bonding, they also contain a greater amount of hygroscopic lignocellulosic material per unit volume, leading to higher water uptake and swelling. In addition, the higher compression ratio in dense boards generates greater internal stresses during pressing. Upon water exposure, these stresses are released, resulting in thickness recovery and increased swelling.

**Table 7.** Tukey's HSD test results for particleboard thickness swelling based on density variation

Density variation	Average
0.40 g/cm <sup>3</sup>	4.94a
0.50 g/cm <sup>3</sup>	6.85b
HSD 5% = 0.72	HSD 1% = 1.00

Notes: Means followed by the same letter are not significantly different. In contrast, means followed by different letters are significantly different.

**Table 8** demonstrates that cold-water soaking significantly increased thickness swelling compared with untreated boards, while no significant difference was observed between the 12 h and 24 h soaking treatments. This is in line with [Dafni et al. \(2022\)](#) and [Maraghi et al. \(2018\)](#), who state that the longer the cold-water soaking time, the greater the increase in particleboard thickness. The increase in swelling after soaking can be attributed to the removal of extractive substances during pretreatment, which enhances particle porosity and water accessibility. Extractives often act as hydrophobic components; their removal increases the particle surface wettability and promotes water penetration into the cell wall structure. This is consistent with the research by [Marwanto et al. \(2018\)](#) on sengon particleboard treated with cold-water soaking, which found that soaking in cold water for 24 h results in some extracts leaching from the wood particles, increasing porosity and creating additional voids. The absence of significant differences between 12 h and 24 h treatments suggests that most extractive removal occurred within the first 12 h of soaking.

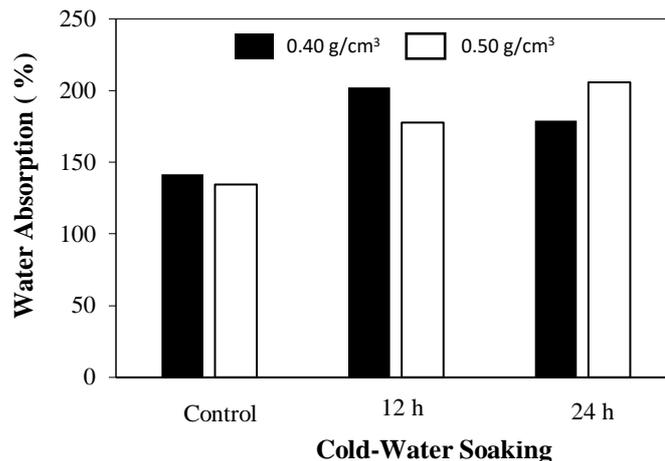
**Table 8.** Tukey's HSD test results for particleboard thickness swelling based on cold-water soaking

Duration of cold-water soaking	Average
Control)	4.84a
12 h	6.18b
24 h	6.67b
HSD 5% =1.07	HSD 1%=1.43

Notes: Means followed by the same letter are not significantly different. whereas means followed by different letters are significantly different.

### 3.1.4. Water absorption

Water absorption ranged from 134.68% to 205.62% (**Fig. 6**). Cold-water soaking significantly increased water absorption, whereas density variation did not have a statistically significant effect. Cold-water soaking treatments remove extractives that normally contribute to hydrophobicity, thereby increasing the accessibility of cell wall polymers to water. Consequently, treated boards exhibited greater water uptake. These results are consistent with the research by [Iswanto et al. \(2018\)](#) and [Marwanto et al. \(2018\)](#), who found that higher density and longer soaking time were associated with higher water absorption values. These results are consistent with the previously reported thickness expansion values. This is in line with the research by [Chaydarreh et al. \(2022\)](#), which states that the air absorption value is determined by porosity.



**Fig. 6.** Average water absorption values of particleboard based on density variation and cold-water soaking.

Analysis of variance revealed that cold-water soaking had a significant effect on water absorption, whereas density variation and the interaction between factors were not statistically significant (**Table 9**). This indicates that pretreatment played a more critical role than board density in determining the water uptake behavior of the particleboards. The absence of a density effect suggests that, within the tested density range, water absorption was primarily governed by changes in particle surface chemistry and pore structure rather than compaction level alone.

**Table 9.** Analysis of variance for particleboard water absorption

Source of variation	df	SS	MS	F-value	F-critical	
					5%	1%
Treatment	5	13252.20				
Density (A)	1	11.31	11.31	0.01 <sup>ns</sup>	4.75	9.33
Cold-water soaking (B)	2	11243.48	5621.74	5.28*	3.89	6.93
A × B	2	1997.41	998.71	0.93 <sup>ns</sup>	3.89	6.93
Error	12	12774.97	1064.58			
Total	22	39279.37		CV = 18.81%		

Notes: df = degrees of freedom, SS = sum of squares, MS = mean square, CV = coefficient of variation, ns = not significant, \*\* = highly significant.

Post hoc comparisons using Tukey's HSD test (**Table 10**) showed that boards subjected to cold-water soaking exhibited significantly higher water absorption than untreated boards, while no significant difference was observed between the 12 h and 24 h soaking durations. Similar findings have been reported by [Dafni et al. \(2022\)](#) and [Marwanto et al. \(2018\)](#). This trend is consistent with the thickness-swelling results obtained in the present study. The increase in water absorption following soaking can be attributed to the removal of extractive substances from durian peel particles, thereby enhancing porosity and increasing the accessibility of hydrophilic cell wall components. Extractives typically provide partial resistance to moisture penetration; therefore, their removal improves wettability and facilitates the diffusion of liquid water into the particle structure. Although JIS A 5908 (2003) does not

specify requirements for water absorption, this property remains important because it directly influences the durability and dimensional stability of particleboard in service conditions.

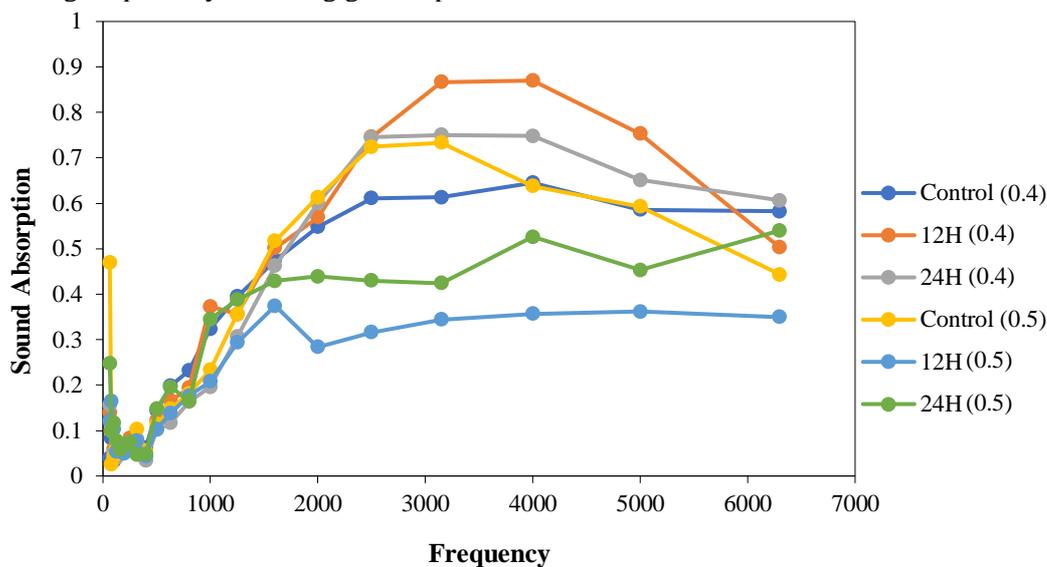
**Table 10.** Tukey’s HSD test results for particleboard thickness swelling based on cold-water soaking

Duration of cold-water soaking	Average
Control	138.17a
12 h	189.93b
24 h	192.37b
HSD 5% = 50.25	HSD 1% = 67.21

Notes: Means followed by the same letter are not significantly different. whereas means not followed by the same letter are significantly different.

### 3.2. Sound Absorption of Particleboard

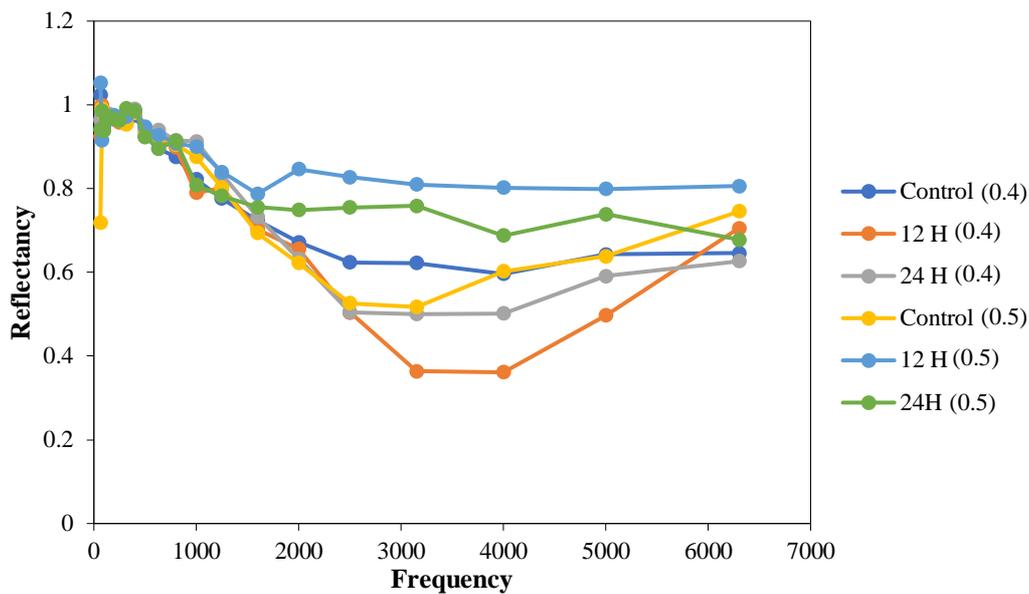
The sound absorption coefficient ( $\alpha$ ) of the particleboards was strongly influenced by density and cold-water soaking treatment (**Fig. 7**). Boards with lower density (0.40 g/cm<sup>3</sup>) consistently exhibited higher absorption coefficients than those with higher density (0.50 g/cm<sup>3</sup>) across the measured frequency range. Maximum absorption ( $\alpha = 0.87$ ) was achieved at 3150 Hz for boards with density 0.40 g/cm<sup>3</sup> after 12 h soaking. In general, sound absorption increased with frequency, with the highest performance observed in the medium- to high-frequency range (>1000 Hz). At low frequencies (<250 Hz), absorption was relatively limited due to insufficient material thickness and airflow resistance. Lower-density boards possess higher porosity, allowing greater penetration of sound waves into the material structure.



**Fig 7.** Sound absorption coefficient values of durian peel particleboard as a function of density and cold-water soaking.

Different soaking durations resulted in variations in the sound absorption performance of the particleboards. In general, boards without cold-water soaking exhibited lower sound absorption coefficients than those soaked for 12 h or 24 h at all density levels. This behavior is primarily associated with changes in material porosity. Increased porosity enhances the interaction between incident sound waves and the internal structure of the board, thereby improving energy dissipation through viscous and thermal losses. Previous studies have demonstrated that particleboard porosity strongly influences acoustic performance (Chaydarreh et al. 2022). Cold-water soaking promotes the dissolution of extractive substances from durian peel particles, which increases pore volume and creates additional cavities within the board structure (Marwanto et al. 2018). The resulting interconnected pore network facilitates air movement inside the material and enhances viscous damping of sound waves (Bakri et al. 2025). Consequently, a greater portion of the incident acoustic energy is absorbed rather than reflected. These findings confirm that pretreatment-induced microstructural changes play a crucial role in

improving the sound absorption capacity of lignocellulosic particleboards. The sound reflectivity results corresponding to these observations are presented in **Fig. 8**.



**Fig 8.** Reflectivity coefficient values of durian peel particleboard based on density variation and cold-water soaking.

Based on **Fig. 8**, particleboards with a density of  $0.50 \text{ g/cm}^3$  exhibited higher sound reflectivity than those with a density of  $0.40 \text{ g/cm}^3$ , particularly in the high-frequency range (2000–4500 Hz). Cold-water soaking also increased reflectivity compared with untreated boards, especially at the lower density level. Higher reflectivity indicates that denser boards tend to reflect more incident sound energy and therefore provide greater sound insulation (transmission loss), rather than sound absorption. This finding is consistent with [Karlinasari et al. \(2012\)](#), who reported that bamboo particleboards with higher density exhibited greater transmission loss than lower-density boards. Increased density reduces porosity and airflow pathways, limiting the penetration of sound waves into the material and enhancing reflection.

**Fig. 7** further shows that sound absorption was generally higher at high frequencies than at low or medium frequencies. This behavior is typical for porous materials, where viscous and thermal losses are more effective at shorter wavelengths. Similar trends have been reported for natural-fiber composites and perforated panels, which exhibit improved performance at higher frequencies due to enhanced interaction between sound waves and the material structure ([Karlinasari et al. 2021](#)). Enhancing low-frequency absorption would require structural modifications such as increased panel thickness or optimized pore architecture. According to ISO 11645 (1997), the absorption coefficients obtained in this study correspond to classes D (0.30–0.55) to B (0.80–0.85), indicating normal to high sound absorption capability. Nevertheless, further investigation of mechanical properties and long-term durability is necessary before practical interior applications can be recommended.

#### 4. Conclusion

Durian (*Durio* spp.) peel waste was successfully utilized as a raw material for particleboard with promising physical and acoustic properties. Board density was the dominant factor influencing performance, where lower-density boards ( $0.40 \text{ g/cm}^3$ ) exhibited higher sound absorption due to greater porosity, while higher-density boards ( $0.50 \text{ g/cm}^3$ ) provided greater sound reflectivity and insulation. Cold-water soaking enhanced sound absorption by removing extractive substances and increasing pore connectivity, although it also led to higher water absorption and thickness swelling. The highest sound absorption coefficient ( $\alpha = 0.87$ ) was obtained for boards with a density of  $0.40 \text{ g/cm}^3$  after 12 h soaking, particularly at high frequencies. All boards met JIS A 5908 requirements for density, moisture content, and thickness swelling, and their acoustic performance fell within ISO absorption classes D to B, indicating normal to high sound absorption capability. These results demonstrate the potential of durian

peel particleboard as an environmentally friendly acoustic material for interior applications, although further studies on mechanical properties and long-term durability are needed to support practical use.

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