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Recent progress in natural fiber reinforced composite as sound absorber material

Majid Mohammadi [a], Ebrahim Taban [b,**], Wei Hong Tan [c], Nazli Bin Che Din [d], Azma Putra [e], Umberto Berardi [f,*]

[a] Department of Material Science and Engineering, Imam Khomeini International University, Qazvin, Iran
[b] Department of Occupational Health Engineering, School of Health, Mashhad University of Medical Sciences, Mashhad, Iran
[c] Department of Mechanical Engineering & Technology, University of Malaysia Perlis (UniMAP), 02600, Arau, Perlis, Malaysia
[d] Department of Architecture, Faculty of Built Environment, University of Malaya, 50603, Kuala Lumpur, Malaysia
[e] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, Durian Tunggal 76100, Melaka, Malaysia
[f] Department of Architectural Science, Toronto Metropolitan University, Toronto, ON, M5B 2K3, Canada

A R T I C L E I N F O

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A B S T R A C T

In today's modern society, an emerging field that has garnered notable attention pertains to the management of sound. Effective control measures are needed because of the increase in noise pollution from urbanization and industrial growth. Effectively regulating the level of noise across all areas of engineering is imperative. The development of acoustic materials with exceptional absorption efficiency is a frontier area of study for acousticians and architects alike in the acoustic industry. This field has garnered the attention of material scientists owing to the multiple noteworthy characteristic properties it offers. Sound absorption materials commonly consist of conventional chemical and synthetic constituents that require replacement for various justifiable reasons, so substitution of these materials with natural materials is very important. The employment of sustainable, cost-effective, recyclable, and reproducible natural materials instead of conventional materials plays a crucial role in addressing a myriad of environmental concerns. These concerns include, but are not limited to, increasing greenhouse gas emissions (CO_2 levels), potential health risks, pollution of air and natural ecosystems, increasing the temperature (global warming), reduction of fossil fuels and raw materials, and the attainment of modern and ecologically sound cities. The main purpose of this review is to draw attention to the most promising natural sound fibers. Thus, the focus will primarily be on current trends in acoustic natural fibers, recycled materials, and fibers from agricultural wastes. Today, these acoustic fibers are very popular and also drive future directions, particularly by providing the next generation of researchers with considerable opportunities.

1. Introduction

In light of the rapid progress in transportation, industrialization, and urbanization, noise pollution has emerged as an increasingly significant concern [1]. It is evident that the human population across the entire planet is experiencing exposure to the detrimental

* Corresponding author.
** Corresponding author.
E-mail addresses: Tabane@mums.ac.ir (E. Taban), uberardi@torontomu.ca (U. Berardi).

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effects of noise pollution. The World Health Organization reported that a noise level exceeding 65 dB is classified as noise pollution. WHO's recent findings indicate that individuals residing in developing nations are more susceptible to auditory impairments such as hearing loss, hypertension, tinnitus, psycho-physiological issues, and cardiovascular complications due to either short-term or sustained exposure to excessive noise. Furthermore, the recovery process from prolonged exposure to high noise levels is estimated to take about three months on average [2,3]. In general, using sound absorber materials to reduce noise levels has emerged as a critical concern in addressing the challenges of noise pollution control, spanning across both societal and industrial contexts. Recent advancements in acoustic materials have become increasingly important across diverse domains, including material fabrication, design, and material selection, particularly those that possess high acoustic properties. Accessible commercial sound absorber materials can be divided into two different categories, including resonant and porous materials. Porous materials like polyurethane have ideal properties for the sound having a med and high frequencies [4], whereas resonance materials like Metamaterials and micro-perforated panels (MPPs) have better sound absorption coefficient (SAC) for low frequencies [5]. To achieve sound absorption for a wide range of frequencies, composite structures made of sound-absorbing materials must be fabricated, since a single construction cannot provide superior sound absorption [6].

Porous materials can be classified into synthetic materials (organic and inorganic) and natural materials [7]. Synthetic fibers have been put into practical use as conventional sound absorbing materials in various applications, but it is known that they have a negative impact on the environment despite their good sound absorbing effect. The exploration and development of eco-friendly products has grown very rapidly over the last decade with the global awareness of eco-friendly materials. Studies on natural fiber reinforced composites (NFRCs) for acoustic purposes show that many materials have similar acoustic properties to conventional materials and have a lower environmental impact [8]. Natural sound absorbers like eco-friendly and biodegradable materials are used in consumer awareness, such as optimal properties (mechanical, thermal, acoustic), recyclability, renewability, permeability, etc. It has several important properties, such as a significantly lower carbon footprint and lower energy production. Extraction requirements, high stability, ease of processing, availability, low cost, low density and no allergy issues make it a prospective alternative to synthetics in polymer composite reinforcements [9–16]. Despite their benefits, natural fiber composites have several disadvantages, including high moisture content, low flame resistance, weak surface adhesion, low resistance to microbial attack, and a requirement for agar processing temperature [17]. The presented review paper illustrates a critical overview of current developments and emerging natural fibers in acoustic materials. The initial section concentrates on the fundamental mechanism of sound absorption and the acoustic parameters associated with sound absorber materials. In essence, it delves into the primary mechanism and underscores the significance of factors influencing the sound absorption capabilities of these materials. The second segment comprehensively addresses various types of natural fibrous materials, encompassing seeds, leaves, fruits, shells, and other forms. This review culminates by outlining significant challenges and proposing future research plans aimed at enhancing the development of superior sound-absorbing

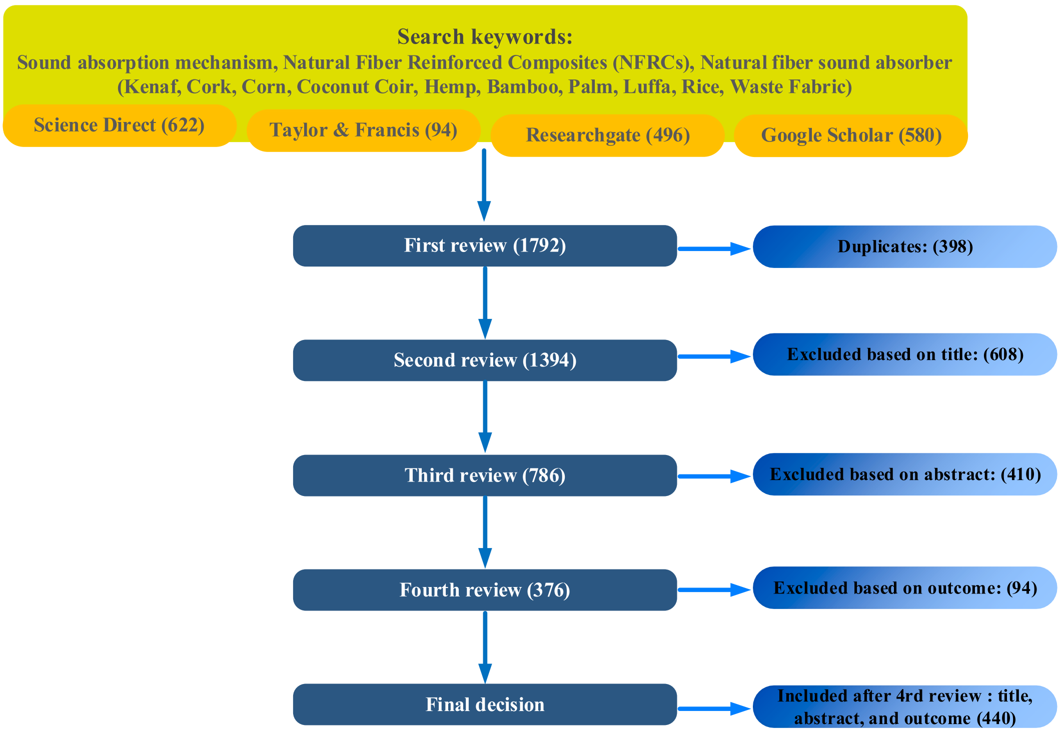


Fig. 1. Flow chart depicting the screening and review process of selecting the relevant sample articles according to the Science Direct, Taylor & Francis, Researchgate, and Google scholar.

materials. The article employed a bibliometric analysis, incorporating both keyword co-occurrence and author co-citation networks. Furthermore, an examination of the number of publications per year and country was conducted. Manual analysis of the search results was undertaken to identify noteworthy findings. The documents were sourced from reputable platforms such as Google Scholar, Science Direct, ResearchGate, Taylor, among others. Using the search query "natural fiber, sound absorption, natural fiber reinforced composite (NFRCs), and natural fiber sound absorber" on Google Scholar, 580 documents were retrieved. From Science Direct, a total

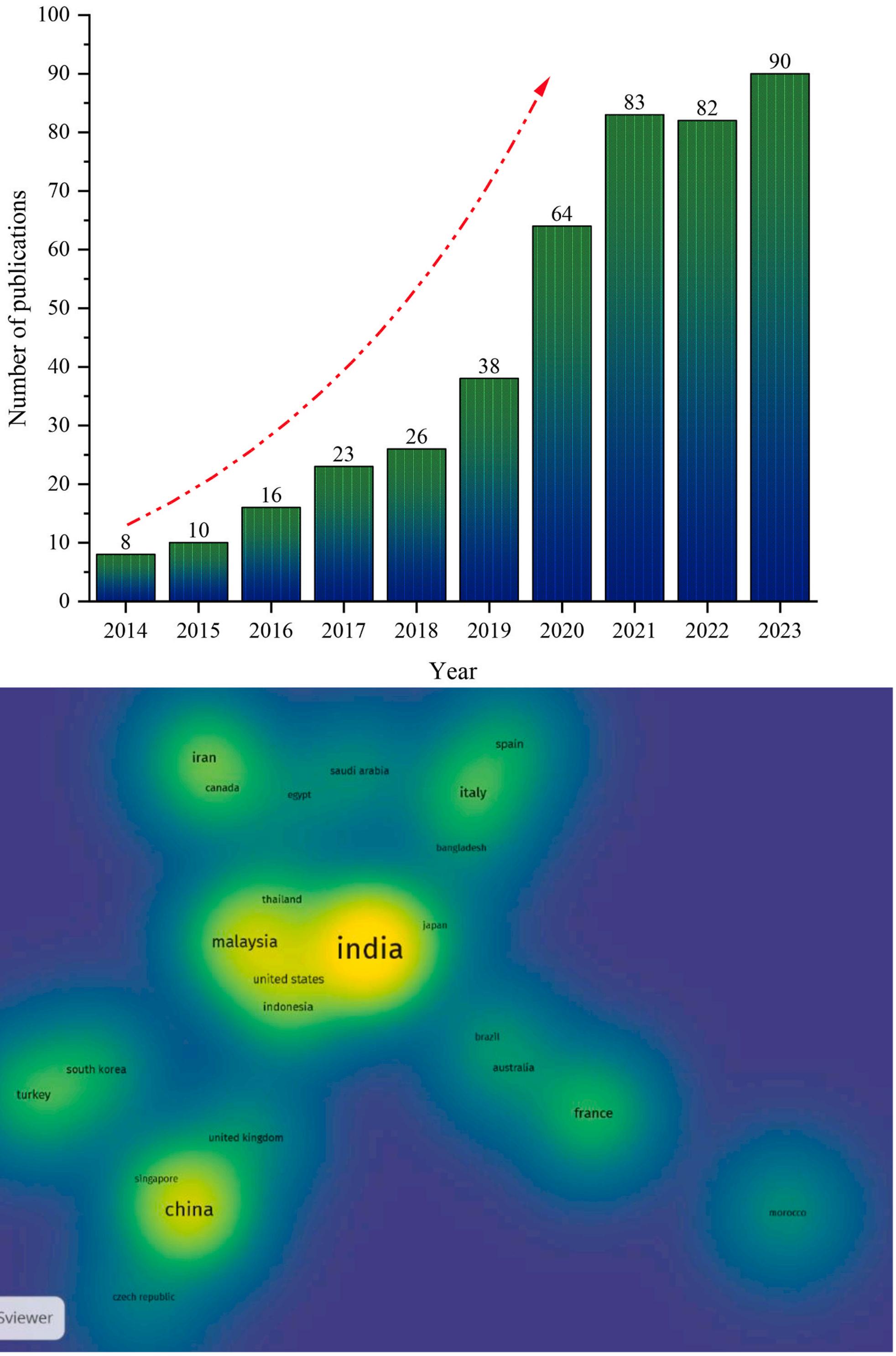


Fig. 2. Numbers and distributions of publication output by countries in the field of sound absorption of natural fibers.

of 12,269 results were identified, with a subsequent focus on the first 622 results for in-depth assessment. An additional 496 documents were gathered from ResearchGate, and 94 articles were sourced from Taylor and other reputable outlets. The document selection process is delineated in Fig. 1. Ultimately, 440 documents were chosen for inclusion in the study.

For the analysis and visualization of recurring keywords and the author co-citation network, VOS Viewer (version 1.6.18), a free and open-source visualization computer program, was utilized. The examination of publication output by country unveiled that South and Eastern Asian nations, including India, Malaysia, China, and Iran, exhibited the highest publication output in this field. Fig. 2 offers a comprehensive overview of the number and distribution of publication output by countries, focusing on those with more than five outputs. Countries with only five outputs are not represented in the graph.

Keyword analysis is instrumental in unveiling research trends within a specific study area. In this investigation, VOS Viewer served as the tool for visualizing the density of keyword occurrences in the selected documents. A minimum threshold of five occurrences was established for the keywords, leading to the identification of 45 keywords out of the total 180 initially recognized. Notably, keywords with the highest occurrences, starting from the minimum threshold of five, include: fiber, noise reduction, absorption (acoustic), acoustic, natural fiber, attenuation coefficient, and noise reduction. For a graphical representation of the keyword density, please consult Fig. 3. The figure provides a visual depiction of the density of the identified keywords.

To enhance comprehension of the conceptual structure within the research area, a country co-citation analysis was executed. The primary objective of this analysis was to pinpoint the interconnections among the most co-cited publications across the retrieved documents. Fig. 4 showcases the country co-citation network, elucidating the relationships between the most co-cited publications. To maintain the relevance of the network, a minimum threshold of five citations for a cited reference was established for this mapping. This visualization of the network offers valuable insights into the relationships and interconnectedness of the cited publications within the research area.

2. Sound absorption mechanism

The processes related to vibration damping and acoustic absorption can be ascribed to distinct physical mechanisms. Vibration damping is a phenomenon that transpires when sound energy is transmitted through direct contact between two solid bodies [18]. The phenomenon of sound absorption properties pertains to the dissipation of acoustic energy as it traverses the atmospheric medium and interacts with a solid physical object. Acoustic energy operates by inducing repetitive displacement of air, resulting in intermittent alterations in air pressure. A pressure wave denotes a spatial region characterized by pressure variations propagating through a given medium. An exemplification of this phenomenon is the conversion of fluid kinetic energy into heat due to viscous stresses arising from fluid shearing. The transfer of thermal energy from a fluid to a solid structure can be achieved through the process of heat conduction.

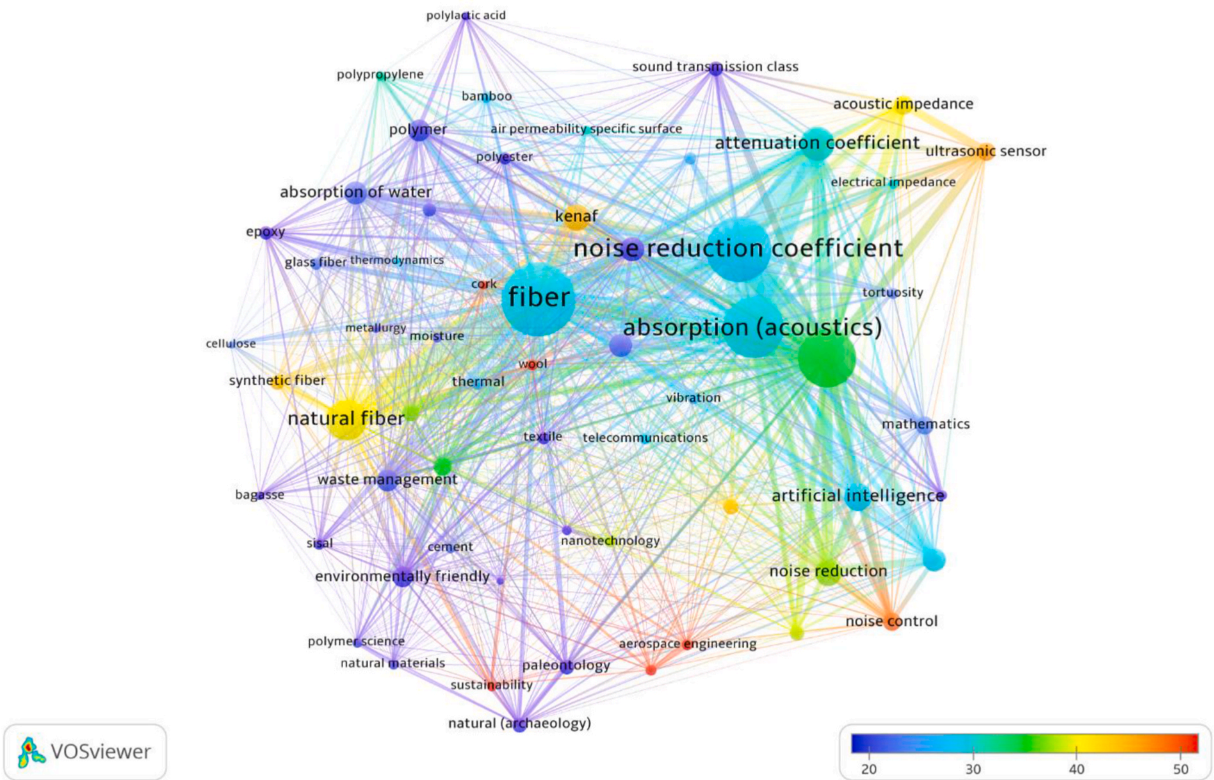


Fig. 3. The density visualization of the identified keywords.

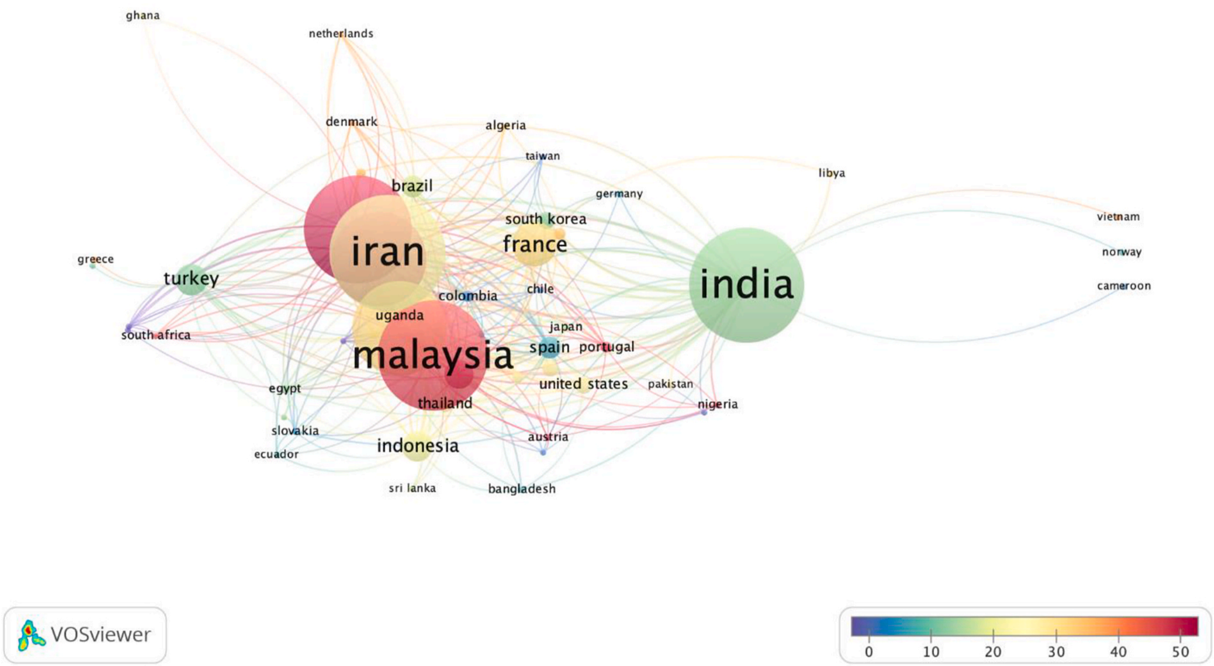


Fig. 4. Co-occurrence distribution of countries in sound absorption studies with natural fibers.

The generation of heat, stemming from friction between the fluid and the solid, may facilitate its transfer from the solid to the fluid. Energy dissipation resulting from the interaction between the sound pressure wave and the rigid structure can occur through the bending process of the rigid frame [19]. In cases where the object's surface is non-porous, incident energy reflects back into the surrounding environment, leading to energy dissipation. Conversely, if the surface under consideration exhibits high porosity, a substantial portion of the pressure wave can infiltrate the material before encountering a solid surface. The above-described process is analogous, occurring within a configuration where the likelihood of reflected energy coming into contact with another component of the solid structure prior to dissipating into the surrounding environment is significantly high.

Effective sound absorption by a solid structure is facilitated through frictional losses resulting from numerous internal reflections. Materials such as polymer foam rely on scattering phenomena to function as effective sound absorbers. To achieve a substantial number of interactions and prevent immediate reflection into the surrounding air, it is crucial for the pressure wave to effectively penetrate the material. It is noteworthy that certain highly porous substances may not be suitable for serving as acoustic absorbers [20]. If the average distance traveled by air molecules between collisions is comparable to the typical separation distance between the walls of pores in a given material, the propagation of pressure waves through the material will be impeded. The phenomenon of the poroelasticity has also been observed in certain absorptive materials. The solid matrix material in a poroelastic medium exhibits both porosity and elasticity, whereas the fluid that pervades it is characterized by its viscosity. Poroelastic materials entail the participation of the solid matrix material in the energy transmission mechanism, allowing for the support of transverse waves as well as two variations of longitudinal (compressional) waves. Foams can be considered as an exemplary porous material that finds multifarious applications as effective sound absorbers in diverse industries [21].

Several factors, including material porosity, the density of the solid matrix, and the density of the gas occupying the pore space, collectively influence foam density. Open-cell foams, characterized by interconnected pores formed by gas bubbles, lack barriers within these pores. The connections between air bubbles take the form of solid structures. In essence, for a material to demonstrate high efficiency as an acoustic absorber, it is crucial for it to have a structure capable of efficiently transferring energy. Additionally, possessing an appropriate range of porosity is essential to enable sound waves to effectively penetrate the material, undergoing multiple interactions with the structure. The sound absorption mechanism involves various parameters categorized into two major

Table 1
Illustration of characteristics, techniques and relevant standards between three diverse impedance tube devices.

Type	Parameter	Technique	Standard
Impedance tube with 2 Microphones	SAC, R, and Zs.	Standing wave ratio method and transfer function method	ASTM E1050, ISO 10534-1 and ISO 10534-2
Impedance tube with 3 Microphones	SAC, R, Zs, and TL.	Transfer function method and two-load method	ASTM E1050 and ASTM E2611 ISO 10534-1 and ISO 10534-2,
Impedance tube with 4 Microphones	SAC, R, Zs, TL, dynamic density, and dynamic bulk modulus.	Two-land method	ASTM E1050 and ASTM E2611, ISO 10534-2

groups: material properties and sample preparation. The selection of the base material and additives to form a sound-absorbing structure is a pivotal factor that significantly influences the effectiveness of sound absorbers. Key parameters in this category include the sound absorption coefficient (α) of base and additive materials, airflow resistivity (σ), sound wave transmission loss (TL), air permeability (κ), density (ρ_b), and tortuosity (α_∞). The second category thickness, single or multilayer (for example FGMs [22]), preparation of sample (surface of sample), weight or volume percentage of the reinforcing phase, manufacturing process, appearance characteristics of the reinforcing phase (size and shape), fiber orientation (parallel, vertical, random) etc. are other important factors. The sound absorption coefficient and some other factors can be derived from impedance tubes devices. Table 1 provides details on some common impedance tubes, along with relevant acoustical parameters mentioned in the following.

2.1. Sound absorption coefficient (SAC)

The Sound Absorption Coefficient (SAC) is intricately linked to both the frequency of sound and the direction of sound propagation. It leverages the average value of sound absorption across all directions, and the absorbed sound frequencies must be clearly defined. The six specified frequencies for SAC evaluation are 125, 250, 500, 1000, 2000, and 4000 Hz. While all materials possess some degree of sound absorption capability, the distinguishing factor lies in the substantial variation in their absorption capacities. A material is considered sound-absorbing if its average sound absorption coefficient at the six specified frequencies (α) is greater than 0.2 [23]. In essence, SAC serves as a metric for the release of sound energy within a permeable substance, gauged by the ratio of absorbed sound energy to the total incident energy. This metric can be calculated using any of the two equations (1) and (2) provided. Refer to Fig. 5 for a schematic representation of the SAC.

$$\alpha = 1\text{-}|R|^2 \tag{1}$$

$$\alpha = 1 + E\alpha/Ei = (Ei\text{-}Er\text{-}Et)/Ei \tag{2}$$

where:

α: Sound absorption coefficient
R: Sound reflection coefficient
Eα: Absorbed sound energy
Ei: Total incident sound energy
Er: Reflected sound energy
Et: Transmitted sound energy

2.2. Airflow resistivity (AFR)

The airflow resistivity is a physical parameter specific to fibrous or porous materials, measuring the material's ability to impede the movement of air particles per unit length. This property is widely acknowledged for its significance in elucidating the acoustic performance of such materials in diverse applications. Two measurement methods are commonly employed for airflow resistance: (a) steady flow and (b) fluctuating flow, as outlined in ISO 9053 and ASTM C-522 standards. The AFR signifies the resistance encountered by air as it traverses through a material. To assess how easily air can penetrate porous structures and the resistance encountered within these structures, it is imperative to establish whether a material possesses Sound Absorption Coefficient (SAC) or sound transmission properties. Regardless of the material's area or thickness, determining the flow rate through the material and the resulting pressure on its components is essential. The airflow resistance of the material influences both characteristic impedance and propagation constant. A lower value indicates less resistance to airflow through the material, suggesting wider pores that allow for efficient airflow and, consequently, enhanced sound absorption. Airflow resistivity can be calculated with two different equations below (equations (3) and (4));

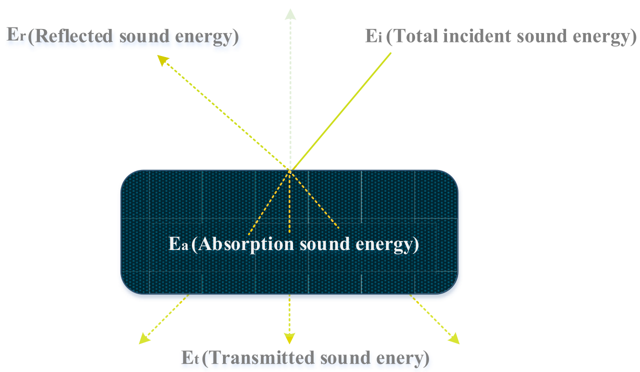


Fig. 5. Schematic of sound absorption coefficient (SAC).

$$R = \Delta p / qv \ [Pa.s.m^{-3}] \quad (3)$$

$$\sigma = R_s / h \ (R_s = R_f A \text{ and } R_f = \Delta p / Q) \quad (4)$$

where:

Δp: Air pressure difference across the sample with respect to the atmosphere (Pa)
q_v: Airflow rate through the sample ($m^3 s^{-1}$)
R: Flow resistance (Pa·s/m^3)
ΔP: Pressure difference across the sample (Pa)
Q: Volumetric flow rate through material (m^3/s)
$R_{s:}$ Specific flow resistance (Pa·s/m)
A: Cross sectional area of material perpendicular to the flow (m^2)
H: Thickness of material (m)

2.3. Sound wave transmission loss (TL)

Sound wave transmission loss (TL) can be quantified using ASTM impedance tubes E1050-12 and ISO 10534. TL represents the reduction in power, measured in decibels, when sound waves traverse through the foam. The equation below (5) is utilized for calculating TL, where I_1 and I_2 denote the sound intensity before and after the waves encounter and pass through the acoustic wall.

$$TL = 10 \ Log \ I_1 / I_2 \quad (5)$$

2.4. Air permeability (κ)

Air permeability (κ) is a measure of the extent to which air can traverse a porous material, and it is influenced by the material's micro-geometry. Defined as the inverse of air resistance according to Darcy's law, air permeability (κ) can be calculated using the following equation (6):

$$\kappa = dQ/S\Delta P = \eta/\sigma \quad (6)$$

where, Q represents volumetric flow per section, S denotes the cross-sectional area, ΔP is the pressure drop across the material, and η is the fluid viscosity. This equation provides a quantitative measure of how easily air can permeate through the material, shedding light on its air permeability characteristics.

2.5. Density

The SAC properties of sound absorber materials are predominantly influenced by their density, which is a critical factor for porous materials. An increase in SAC properties at middle and high frequencies is observed when surface friction rises, leading to higher density and greater energy loss. Contrarily, lower frequencies (500 Hz) can be absorbed by less dense and more open structures, while denser structures prove effective in absorbing sounds above 2000 Hz. Bulk density, defined as the ratio of vacuum mass to the bulk volume of the porous aggregate, plays a pivotal role. Excessive density can diminish porosity, heighten drag, and create a barrier to the penetration of sound waves into the material. As the density decreases, porosity increases, allowing more sound waves to be captured within the material. The bulk density (ρ_b) can be calculated using the equation below (7):

$$\rho_{b=} M / V_t \quad (7)$$

here, ρ_b represents bulk density, M is the vacuum mass, and V_t is the bulk volume of the porous aggregate.

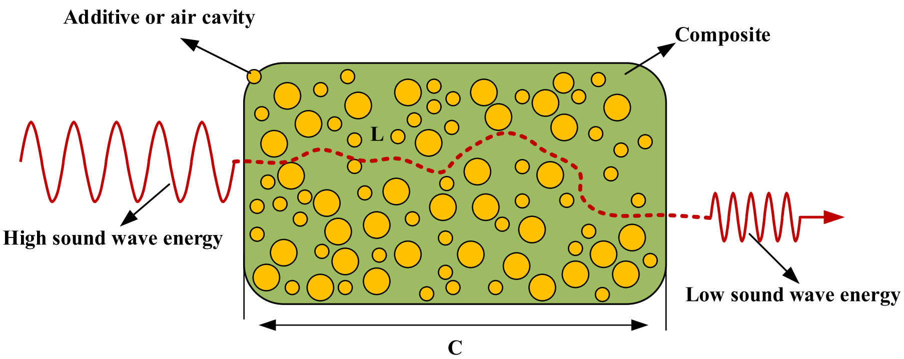


Fig. 6. A schematic of tortuosity.

2.6. Tortuosity (α_∞)

Tortuosity is a parameter associated with higher porosity, leading to an increased distance traveled by sound waves and, consequently, a higher Sound Absorption Coefficient (SAC) due to greater sound energy loss. It quantifies how much the passage through the pore has stretched compared to the thickness of the sample. Tortuosity can be expressed as the ratio of the square of the actual pore length (L') to the material body length (L). It can also be defined as the ratio of the arc or curve length to the distance between its endpoints. The internal structure of the material is influenced by tortuosity, and an increase in tortuosity corresponds to an increase in SAC towards higher frequencies. The tortuosity can be calculated with equation below (8), where L is channel length and C is the distance from the starting point to the end point. Fig. 6 shows a schematic of tortuosity.

$$\alpha_\infty = L/C \quad (8)$$

3. Natural material as sound absorber

Natural fibers derived from plants and animals are gaining popularity as sustainable materials for sound wave absorption. Their appeal lies in their renewable nature, the ability to be reused multiple times, and compatibility with similar materials. These natural fibers are abundantly found in three main categories: plants, animals, and minerals [24]. The classification of natural fibers as sound-absorbing materials is depicted in Fig. 7. Vegetable fibers, containing components such as lignin, cellulose, pectin, and hemicellulose, are considered the optimal choice for sound-absorbing materials. They offer excellent acoustic properties and are derived from sustainable sources. Animal fibers, composed of protein, serve as the second natural source of fibers for reinforcing synthetic materials after plant fibers. They are readily available and non-toxic, though they are generally less durable than vegetable fibers. Mineral fibers, such as asbestos and basalt, fall into the category of fibers derived from minerals. However, their usage is limited due to health concerns. Asbestos, in particular, is banned in some countries due to its detrimental effects on human health. The acoustic properties of these fibers are significantly influenced by their geometry, encompassing factors like diameter, length, cross-sectional shape, and homogeneity. These attributes play a crucial role in determining the effectiveness of natural fibers as sound-absorbing materials. In addition, the properties of natural fibers are determined not only by crop types, cultivation methods, soil conditions, growing location, climate changes, crop maturities, extraction methods used, but also fiber organizations, fiber diameter, microfiber angles, it also depends on the chemical composition [25]. Accordingly, some natural fibers are considered important due to their high sound absorption properties, durability, low cost, environmental compatibility and other important factors, which can be used in many industrial applications as sound absorbing materials, so some of them are discussed below. Fig. 8 shows distribution of papers in the last decade (2014–2023) based on natural fiber reinforced composites (NFRCs) published in the Science Direct.

3.1. kenaf fiber

kenaf fiber, scientifically known as Hibiscus cannabinus, is a type of plant material widely utilized as a natural fiber in various fields. Researchers have shown keen interest in exploring its unique properties. European car manufacturers, in particular, have incorporated kenaf fiber to reduce noise in different components of vehicles. Moreover, the building and construction industry has found applications for this material. The fibrous structure of kenaf features a network of channels and gaps. When a sound wave encounters this structure, the particles on the fabric's surface and within the pores are compelled to vibrate, dissipating their original energy. The loss of acoustic energy, attributed to heat and viscous effects within the walls of internal voids and channels, results in

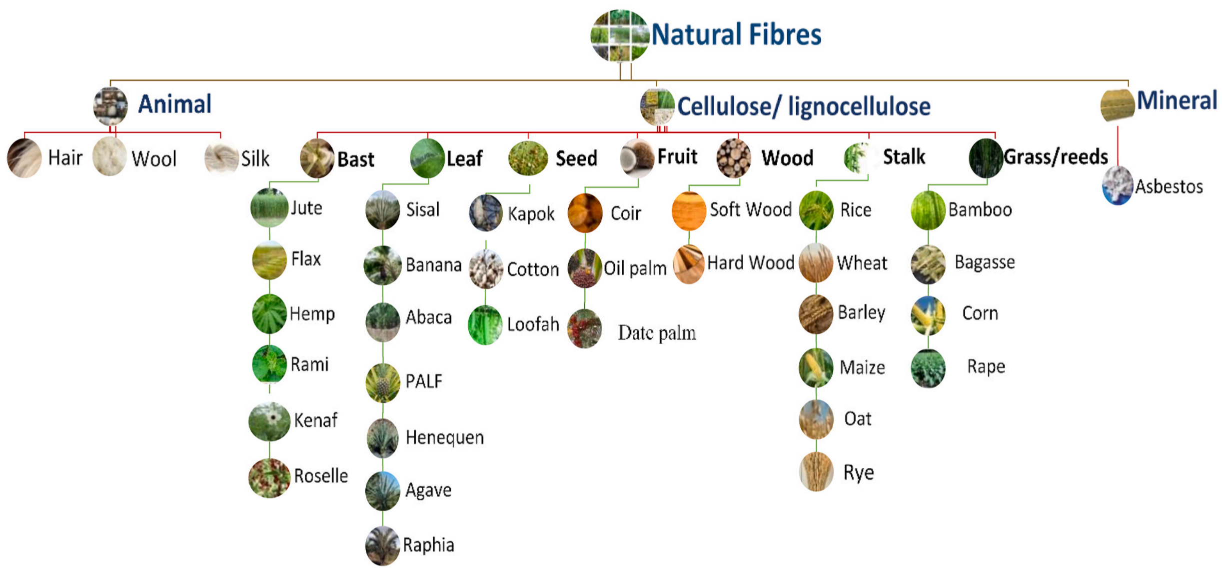


Fig. 7. Classification of natural fibers as sound-absorbing materials based on three different categories, animal, plant, and mineral [26].

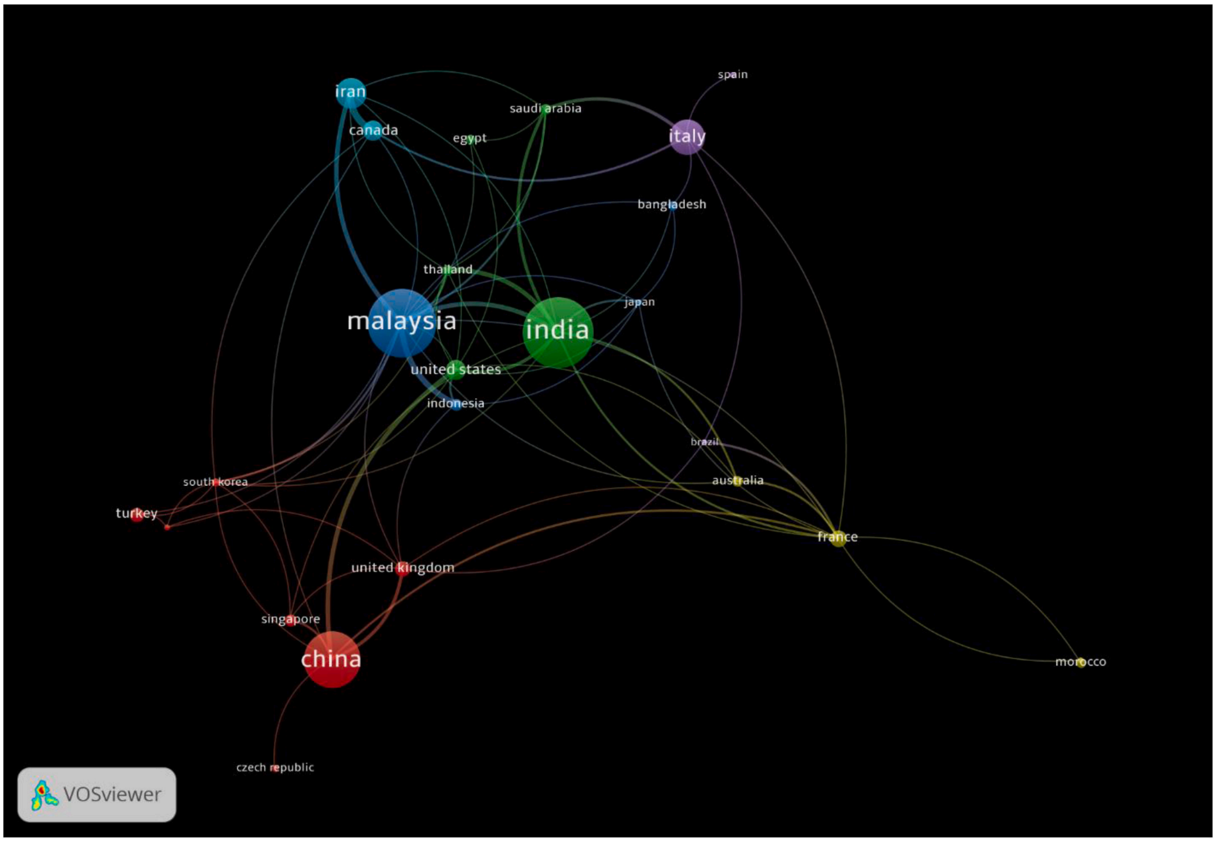


Fig. 8. Distribution of countries.

sound absorption. This distinctive property makes kenaf fiber a valuable material for mitigating noise in various applications.

Despite the desirable properties of kenaf fiber, there are limitations and drawbacks that hinder its widespread use as an alternative to synthetic fibers in the fabrication of noise control composites. Notably, natural fibers, including kenaf, undergo significant decomposition when exposed to fire or heat sources. This characteristic renders them unsuitable for applications involving high temperatures in industrial settings. To enhance the utility of kenaf fiber for sound absorption, it is crucial to address its vulnerability to fire and improve its resistance to damage. One effective approach involves applying a coating layer to the fiber's surface. Strengthening the surface of wood materials against fire using inorganic (mineral) materials is considered a promising and cost-effective method. Surface modification plays a pivotal role in overcoming the limitations and weaknesses of kenaf fibers, including poor fiber-matrix interactions due to the hydrophilicity of natural fibers and their wetting ability.

Surface modifications are frequently conducted through chemical treatments, with soda (NaOH) being a common agent. Notably, treatment with NaOH significantly improves the mechanical properties of fibers by eliminating the amorphous surface layer. This treatment also results in a reduction in fiber diameter and a change in fiber surface morphology. Various fiber surface treatments, including alkali, peroxide, acetylation, benzoylation, isocyanate, permanganate, salt, acetylation, methylation, and cyanoethyl solution, have been employed. These treatments serve to reduce fiber moisture, enhance fiber surface roughness, promote effective fiber-matrix surface bonding, and augment the mechanical properties of cellulose-based materials [27].

Taban et al. [28] have studied on Measurement, modeling, and optimization of sound absorption performance of kenaf fibers for building applications. In this study, specimens were fabricated with thicknesses of 10–40 mm at two diverse bulk densities of 150 and 200 kg/m^3, and their sound absorption coefficient (SAC) was determined by standing wave sound impedance tube at different air gap cavities. In addition, A hybrid numerical-mathematical model was also proposed to investigate the acoustic behavior of the samples so that a code was developed to simulate the 3D virtual structure of samples, and flow resistivity was calculated by numerically solving the flow of air in the structures. Tortuosity and two characteristic lengths were obtained using an inverse method programmed in MATLAB®, then, these parameters were then imported into the Johnson-Champoux-Allard (JCA) model to predict SACs at different frequencies. Consequently, the acoustic behavior of the optimized acoustic panels was investigated in the reverberation room in terms of reverberation time and random absorption coefficient. The result shows that the SAC at low, mid, and high frequencies increases significantly with increasing the bulk density and they reported that a perfect consistency was observed between the predicted and experimental data and the results of the statistical analysis suggested a thickness of 33 mm and a bulk density of 150 kg/m^3 for the optimized panels. the results of this study are depicted in Fig. 9.

Nasidi et al. [29] experimentally analyzed the effect of alkali treating kenaf fibers with sodium hydroxide on the sound-absorbing properties. The authors believe that there are still limited studies on the effects of different concentrations of NaOH treatment on the improvement of the sound-absorbing properties of kenaf fibers, so the percentage of NaOH solution is different. The entire preparation of composites and results is shown in Fig. 10. The findings showed that sodium hydroxide treatment significantly altered the surface morphology of the kenaf fibers, reduced fiber diameter, and showed that a significant increase in sound absorption occurred on the treated fibers compared to the untreated fiber (Fig. 10-A). Moreover, the reduction in diameter enabled the treated samples to achieve the same volume and thickness, increasing the number of fibers per unit area. This, in turn, augmented the surface friction area per

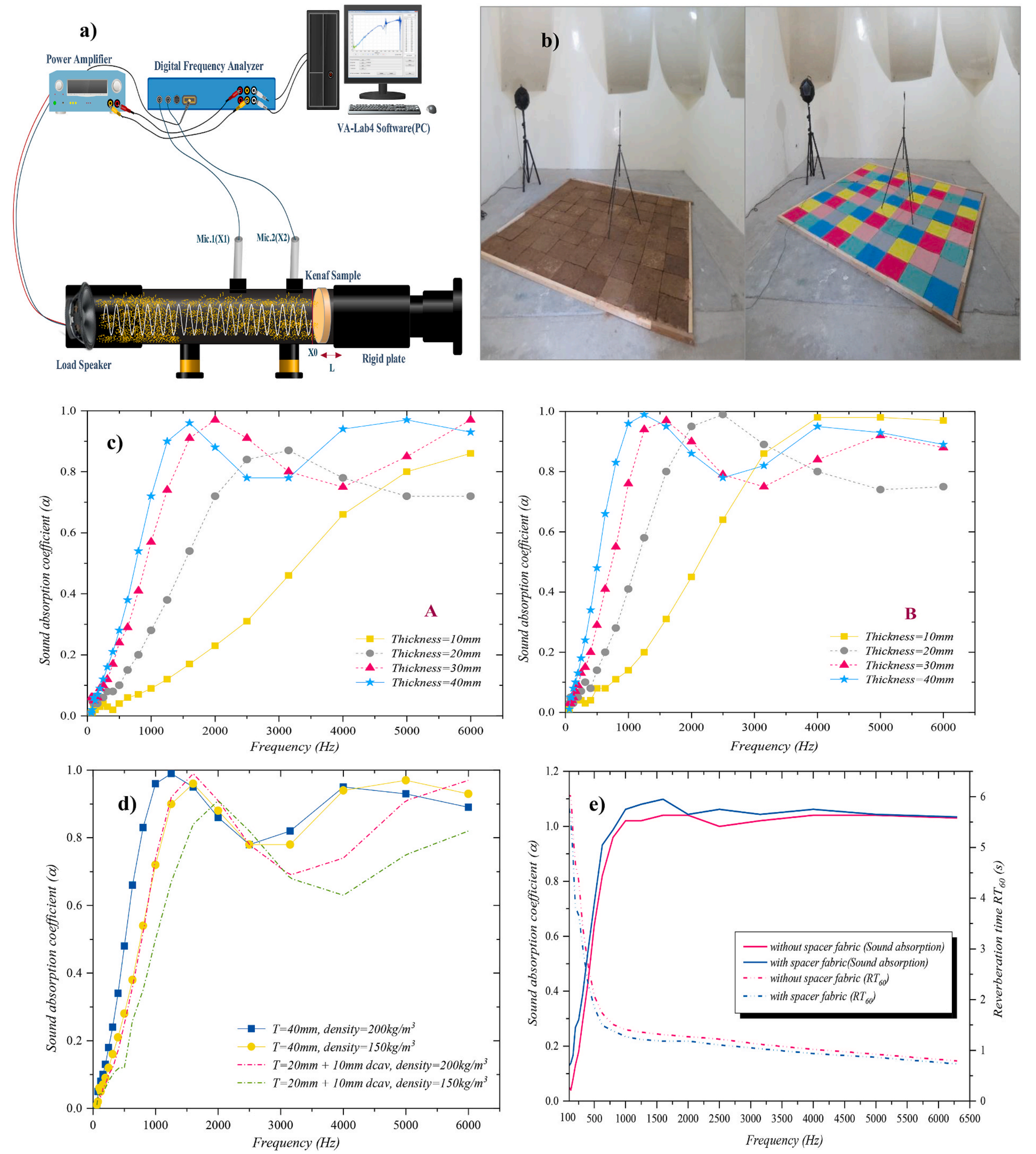
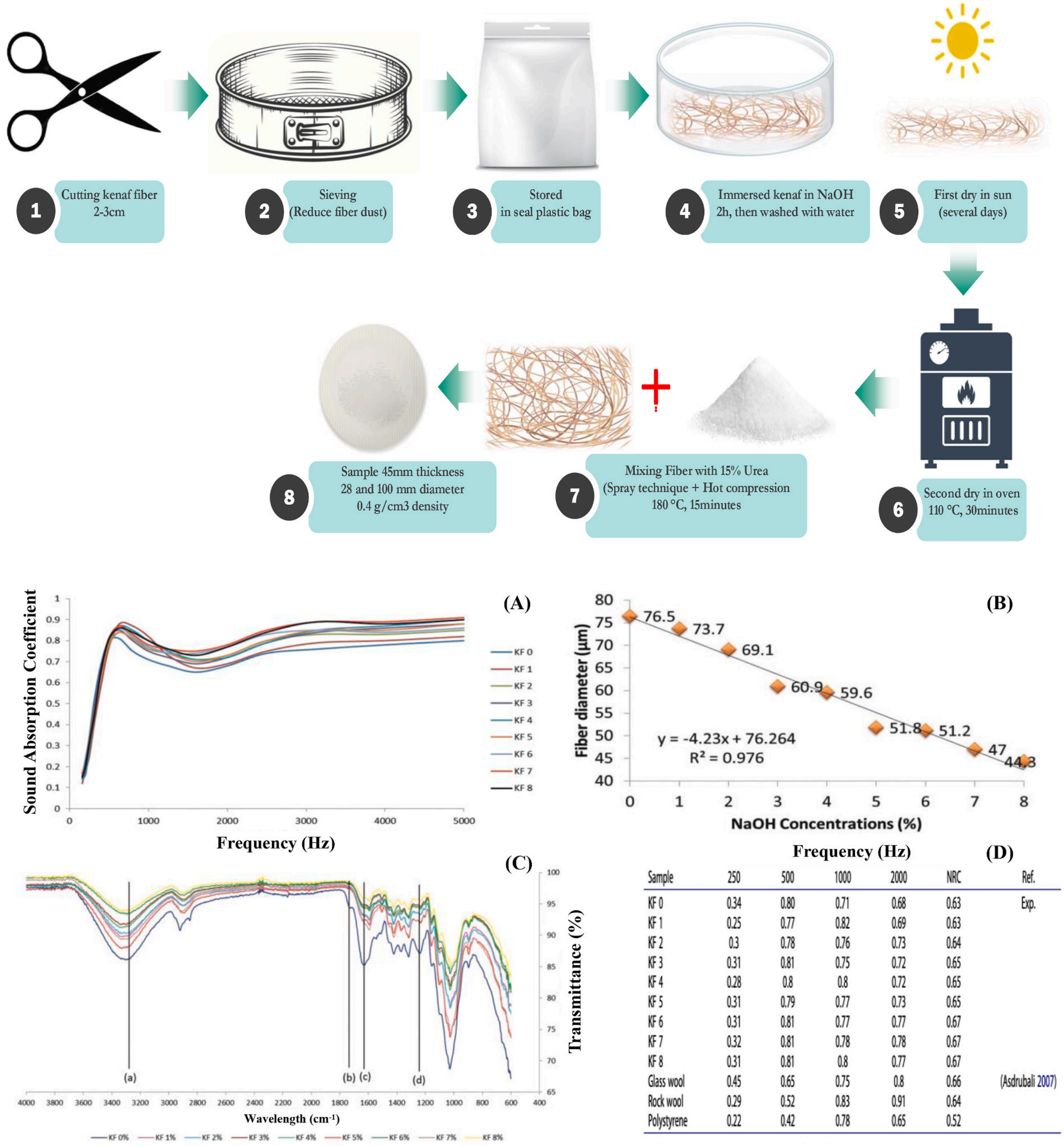


Fig. 9. a) Schematic diagram of the two-microphone impedance tube, b) Acoustic panels fabricated of kenaf natural fibers in the reverberation room, left) without spacer fabric, right) with spacer fabric, c) Effect of bulk density and thickness on SAC of kenaf fiber samples (A) Density of 150 kg/m^3, B) Density of 200 kg/m^3), d) Comparison of SACs of samples with thickness of 40 mm with rigid backing and those of samples with thickness of 20 mm and air gap of 10 mm, e) SAC and reverberation time of kenaf fiber acoustic panels with and without spacer fabric [28].



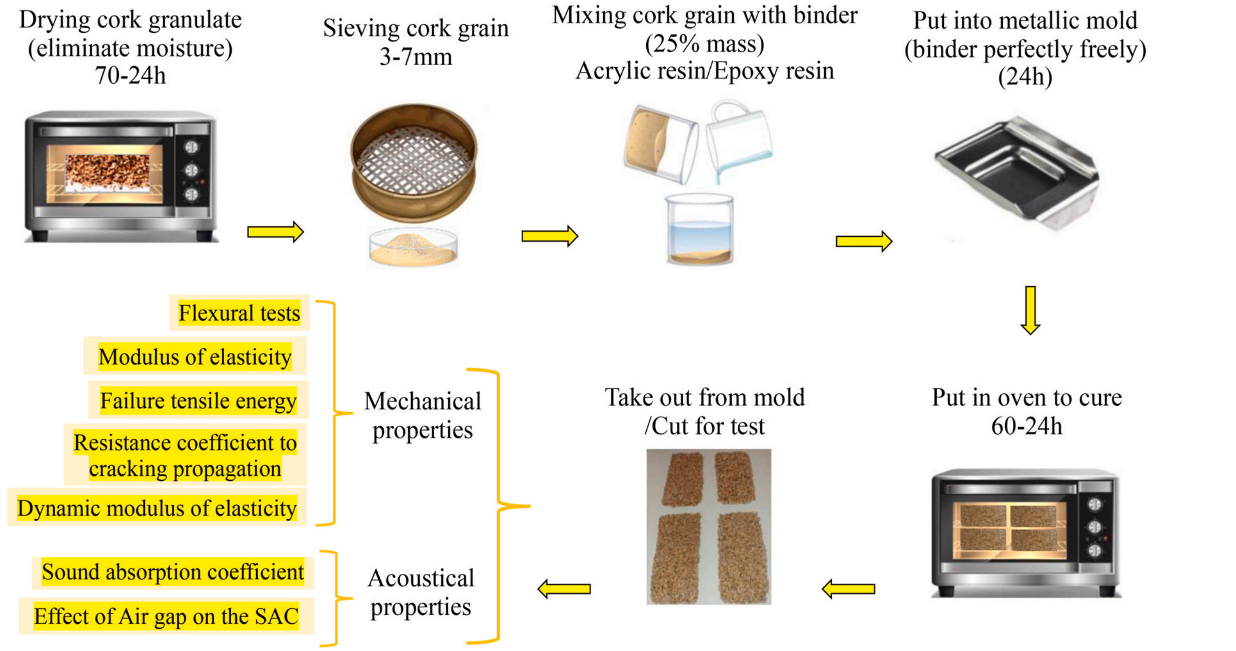
Sample	250	500	1000	2000	NRC	Ref.
KF 0	0.34	0.80	0.71	0.68	0.63	Exp.
KF 1	0.25	0.77	0.82	0.69	0.63	
KF 2	0.3	0.78	0.76	0.73	0.64	
KF 3	0.31	0.81	0.75	0.72	0.65	
KF 4	0.28	0.8	0.8	0.72	0.65	
KF 5	0.31	0.79	0.77	0.73	0.65	
KF 6	0.31	0.81	0.77	0.77	0.67	
KF 7	0.32	0.81	0.78	0.78	0.67	
KF 8	0.31	0.81	0.8	0.77	0.67	
Glass wool	0.45	0.65	0.75	0.8	0.66	(Asdrubali 2007)
Rock wool	0.29	0.52	0.83	0.91	0.64	
Polystyrene	0.22	0.42	0.78	0.65	0.52	

Fig. 10. Preparation of kenaf fiber composites, A) SAC values of composites containing untreated and treated kenaf fiber, B) kenaf Fiber diameter, C) FTIR spectra of treated and untreated kenaf fiber composites, D) NRC properties of kenaf samples and synthetic sound absorber [29].

sample, resulting in higher values of the sound absorption coefficient across all tested frequencies (Fig. 10-B). The analysis suggested that treating kenaf fiber with a 6% NaOH concentration yielded maximum absorption efficiency. This concentration not only altered the fiber surface significantly but also facilitated the dissipation of sound effectively (Fig. 10-D).

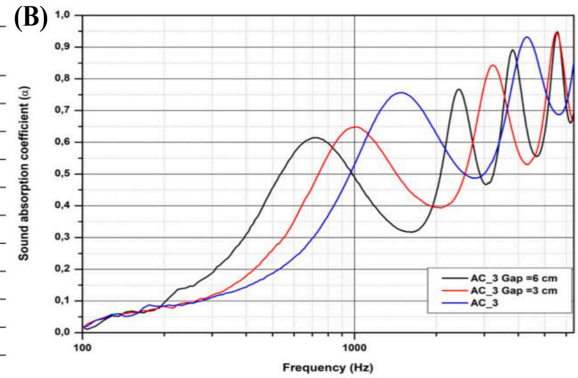
Samaei et al. [11] conducted an investigation into the impact of nanoparticles ($ZnO–TiO_2$) on the acoustic properties and flammability of natural kenaf fibers. The researchers aimed to enhance the acoustic properties and flammability resistance of kenaf by coating its surface with a mineral material. The synthesis of $ZnO–TiO_2$ nanoparticles was accomplished through co-precipitation, and these nanoparticles were subsequently coated onto kenaf fibers. The study employed XRD, EDAX, cone calorimeter, and impedance tube techniques to analyze the phase, morphology, flame resistance, and sound absorption properties. The results indicated that the $ZnO–TiO_2$ coating was uniformly distributed around the kenaf fibers, with a size ranging from 80 to 200 nm. The SAC properties of the composites increased following the coating process. Furthermore, the flame-retardant properties of the samples exhibited a twofold increase, extending from 8 to 17 s. An interesting finding was the elevated levels of carbon monoxide and carbon dioxide in the coated sample.

Saad et al. [30] studied the effect of kenaf fiber on the sound absorption ability of the core chipboard as an insulation board. They



(A)

Sample	σ_f (MPa)	ε_f (mm mm^{-1})	E_f (MPa)	Porosity	F_L (Hz)	E_d (MPa)	G (N mm)	R (mm)
AC_3	0.04	0.10	0.61	0.803	435	0.92	251.28	10.66
AC_4	0.04	0.09	0.59	0.793	429	0.94	176.17	7.69
AC_5	0.05	0.07	0.70	0.788	412	1.39	154.36	6.02
AC_6	0.05	0.08	0.61	0.781	435	1.02	187.10	7.68
AC_7	0.04	0.07	0.71	0.782	447	1.07	166.20	7.82
EP_3	0.02	0.06	0.33	0.850	387	0.79	57.73	3.55
EP_4	0.02	0.06	0.38	0.853	356	0.65	59.23	5.26
EP_5	0.03	0.08	0.66	0.854	407	0.84	134.74	6.53
EP_6	0.04	0.10	0.55	0.854	387	0.76	122.19	5.22
EP_7	0.04	0.11	0.43	0.857	408	0.83	128.99	4.47



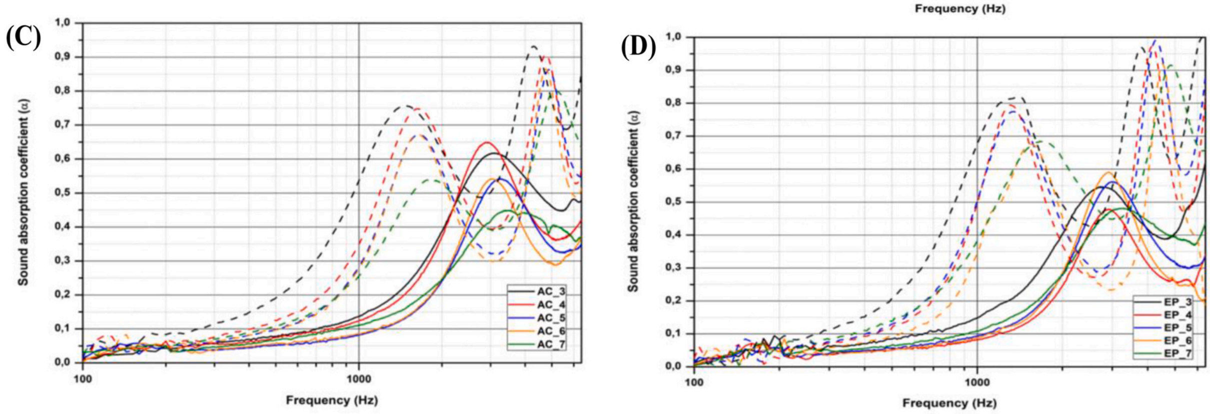


Fig. 11. The method used to create bio-based composites from cork granules and epoxy and acrylic resin. (a) Flexural tests of the samples, porosity, resonance frequency, dynamic modulus of elasticity, rupture energy, and resistance coefficient to cracking evolution of the samples; (b) The effect of the air-gap on the sound absorption spectra for sample AC_3 (grain size 3 mm, density 162Kg/m^{-3}, porosity 78.1%); (c) The sound absorption spectra for acrylic samples having thickness of 2 cm (solid line) and 4 cm [33].

mixed the kenaf cores with the resin and preliminarily pressed them in a cold press at 35 kg/cm^2 and then pressed them in a hot press to a thickness of 12 mm at 1700 °C for 6 min. Two different circular diameters are cut from kenaf chipboard and used to cover the entire frequency range. A sample with a diameter of 100 mm is used to measure the frequency range from 125 to 1600 Hz and a sample with a diameter of 28 mm is used to measure the frequency range from 1200 to 6000 Hz. They investigated the effects of resin and kenaf loading on the characteristics of the sample's sound absorption coefficient. The results demonstrated that cardboard NAC containing 8% and 10% exhibited superior noise absorption compared to a 12% UF load. This superior performance was observed across low, middle, and high-frequency ranges. Panels with a density of 350 kg/m^3 displayed enhanced noise absorption, possibly attributed to their improved porous properties, contributing to noise reduction.

Prabhu et al. [31] fabricated glass (300gsm)-kenaf (40–70 μm)-waste tea leaf fiber (27–35 μm)-reinforced hybrid epoxy resin composites which are alkali treated with 5% sodium hydroxide and studied the mechanical (tensile, flexural, impact, and interlaminar shear strength tests) chemical and sound absorption properties of composites. In this research, the hybrid composite was fabricated using the compression molding technique. The findings revealed that a hybrid composite containing 25 wt% of waste tea leaf fiber and 5 wt% kenaf fiber exhibited a significant enhancement in sound absorption coefficient (SAC) properties, reaching 0.56 with the alkali-treated combination.

3.2. Cork

Cork, derived from the bark of oak trees predominantly found in southwestern Europe and northwest Africa, stands out as a natural material that embodies environmental sustainability. Harvesting cork involves a meticulous, handcrafted process that does not harm the trees or contribute to pollution, ensuring the renewal and reuse of this eco-friendly resource. Known for its remarkable properties, cork exhibits excellent resistance to impacts, effective insulation against heat and sound, vibration reduction capabilities, and fire resistance. However, integrating cork into polymer composites poses challenges, particularly in achieving strong adherence between cork and certain polymers, especially those with hydrocarbon matrices like polyethylene. The challenge lies in the insufficient transfer of stress from the matrix to the filler under mechanical stress. To address this, coupling agents, such as certain polymers containing maleic anhydride groups, can be added to enhance the bond between cork and nonpolar polymers. Additionally, treatments like silanization, plasma treatment, and exposure to hot water or hydroxide-based solutions can be employed to improve the compatibility between the filler and polymer. These treatments help modify the surfaces of cork and the polymer, promoting better adhesion. Due to its unique physical and mechanical properties, including low-speed sound transmission, thermal conductivity, and low acoustic impedance, cork is a preferred material for the production of sound, heat, and vibration insulation products [32].

Maderuelo et al. [33] investigated mechanical and acoustical behavior of bio-based composites designed for ceiling tiles. These composites were composed of cork granulates with a grain size ranging between 3 and 7 mm and featured thicknesses of 2 and 4 cm. The fabrication process and the characterization of sample properties are detailed in Fig. 11. The study utilized two types of polymers, namely water-based acrylic resin (AC) and water-based epoxy resin (EP), to manufacture the acoustic panels. The findings indicated that as the sample thickness increased, the first absorption maximum shifted to lower frequencies, as illustrated in Fig. 11-c and d. Additionally, smaller cork grain sizes resulted in slightly higher sound absorption coefficients compared to larger grain sizes. The study also explored how the spacing between objects impacts sound absorption. The air space between the tested object and the wall behind it contributed to enhanced sound absorption, particularly at lower frequencies (Fig. 11-b). This phenomenon is evident in the absorption coefficient spectrum, where the peak absorption points shifted to lower frequencies, leading to lower sound absorption values.

In the investigation by Vasconcelos et al. [34], the focus was on creating a polymer matrix using polyethylene, cork powder (74 μm), and HDPE adhesive. The study aimed to explore the thermal and acoustic properties of polyethylene/cork composites designed for civil construction applications, particularly for enhancing thermal comfort in ceilings. Prototypes made of PVC, GHDPE, GHDPE/5CP, and GHDPE/15CP with varying compositions were assembled to assess ceiling thermal comfort. The sound absorption characteristics of the samples revealed that GHDPE exhibited a higher sound absorption profile at higher frequencies. Conversely, other composites containing cork demonstrated higher sound absorption coefficients than the matrix at low and medium frequencies, up to 1000 Hz. Interestingly, the study found that adding a compatibilizer (PE-g-MA) did not lead to an improvement in sound absorption within the studied frequency range. The researchers suggested that the addition of PE-g-MA to modified composites might enhance their sound absorption ability by reducing internal friction and porosity in the compound. The results indicated that the GHDPE/15CP eco-composite showed satisfactory and superior performance compared to PVC or GHDPE. This suggests that the use of this material as a ceiling holds promising potential for improved heat and sound insulation in civil engineering applications.

In the study by Uzun [35], the focus was on examining the sound absorption coefficient, mechanical properties (tensile and tear strength), and thermal properties of a textile cork fabric/adhesive resin composite, with lamb leather serving as the reference structure. The findings indicated that composites reinforced with cork exhibited superior opacity and strength properties. Additionally, it was reported that the bulky structure of the nonwoven reinforced cork composite led to enhanced sound absorption values compared to the knitted structure. In a related study by Sair et al. [36], composites were manufactured using gypsum (40%) reinforced with a mixture of cork fiber (60%) and cardboard waste for potential application as thermal insulation in the building industry. The investigation covered mechanical properties (compression strength and flexural strength), water absorption, thermal conductivity, and sound speed propagation properties. The results revealed a significant decrease in the maximum moisture absorption capacity as the cork fiber content increased. Furthermore, the composite with a cork fiber content of 60% demonstrated a thermal conductivity value of 62 mWm−1 K−1, indicating a 300% improvement in insulation performance compared to the pure matrix (cork fiber and waste paper content is 0%). The study attributed the reduction in thermal conductivity to the increase in the size and number of pores in the samples and the poor adhesion between all components.

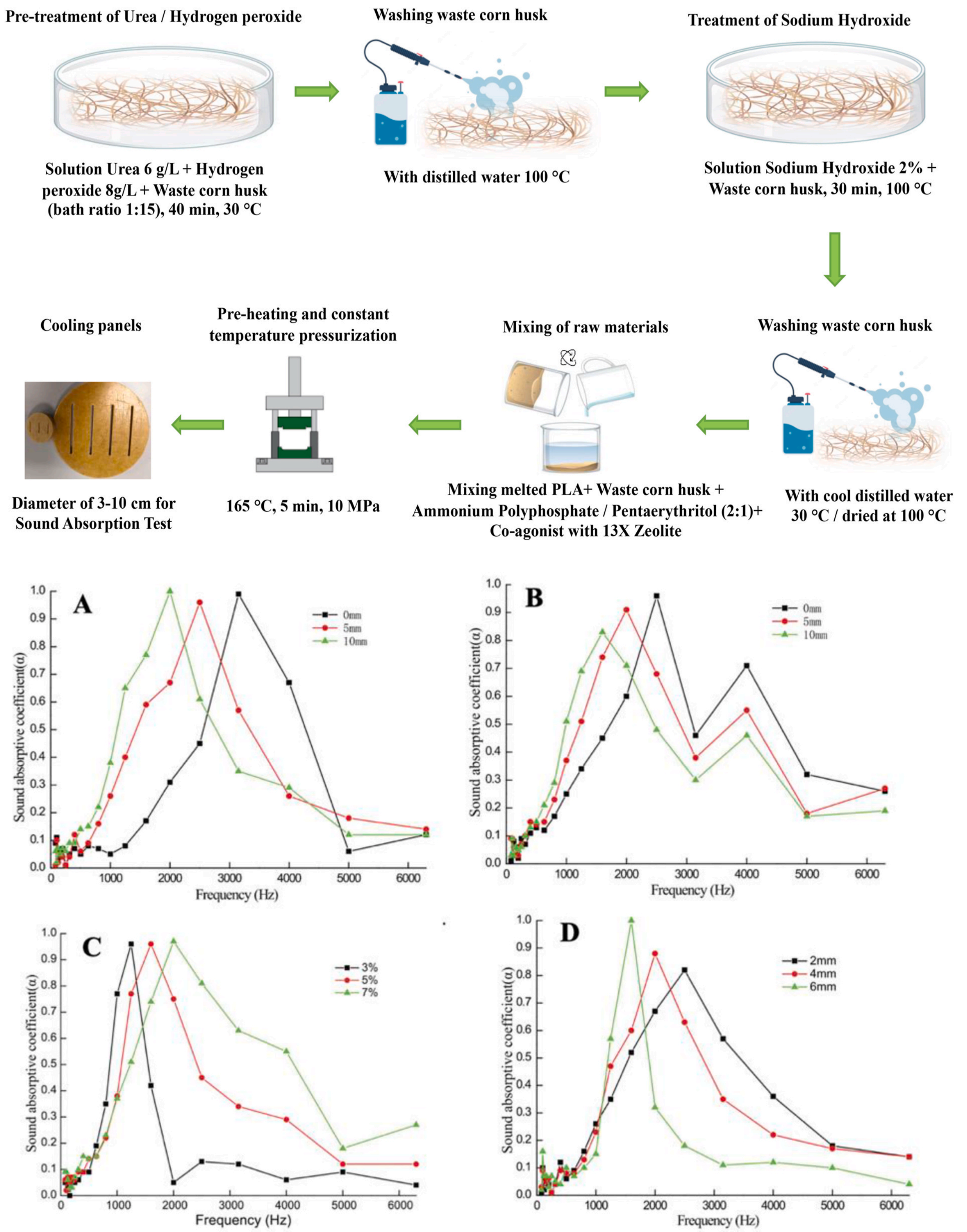


Fig. 12. Schematic of fabrication process of samples, A) Influence of flax felt thickness on SAC properties, B) The effect of air cavity depth on SAC properties, C) Effect of slit rate on sound absorption coefficient, D) Effect of thickness of micro-slit panel on SAC properties [38].

3.3. Corn

Corn, as one of the most prevalent crops globally, generates substantial byproducts, including corn husks, during large-scale cultivation. Traditionally utilized for purposes like animal feed and handicraft materials, corn husk fiber has emerged as a promising reinforcing material for composites. Its cost-effectiveness, sustainable sourcing, and environmental friendliness make it a competitive fiber. Beyond husks, other corn waste components such as stems, leaves, and cobs are commonly generated in household cooking processes. While some of this waste is repurposed as crop compost, many regions witness the accumulation of corn waste in non-agricultural areas, posing environmental and health risks. Corn stalks find applications as agricultural biomass for animal feed, fuel production, and soil fertilization. In recent years, there has been a transformation of corn crop residues into fibers for sound absorption, aligning with environmental sustainability goals. The growing demand in developed nations and the move away from synthetic fibers in various applications have sparked increased interest in natural fibers globally [37]. Several studies have delved into the sound absorption properties of corn, particularly focusing on corn husk.

Lyu et al. [38] explored the SAC values of multi-layered composite materials using waste corn husk fibers. In this study, polylactic acid powders served as the lattice, and corn husk was incorporated as a reinforcing agent. The composites were fabricated through a hot-press technique and shaped into micro-slit panels. The researchers successfully created multi-layered sound-absorbing composites featuring micro-slit panels, air cavities, and flax felt. The composite fabrication process and relevant results are illustrated in Fig. 12. The analysis revealed that the thickness of the flax felt had minimal impact on SAC characteristics in the high-frequency band, with a small effect on the maximum sound absorption coefficient (Fig. 12-A). Furthermore, as the depth of the cavity increased from 0 mm to 10 mm in 5 mm increments, the peak value of the sound absorption coefficient shifted to the lower frequency side and decreased. Increasing the cavity depth from 0 to 10 mm in 5 mm increments significantly improved the low-frequency sound absorption properties of the multilayer composites (Fig. 12-B). The peak sound absorption coefficient decreased with the increasing cavity depth, from 0.96 at 2500 Hz to 0.83 at 1600 Hz (Fig. 12-C). The authors also demonstrated that the creation of air voids had the effect of increasing the material's thickness in the mid- and low-frequency bands (Fig. 12-D).

Yahya et al. [39] employed waste corn husks, both treated and untreated, with mass fraction variations of 30% and 50%, and thicknesses of 2 mm and 4 mm as acoustic absorbers using latex adhesive. The study aimed to investigate the acoustic properties of latex and corn husk fiber content in the composites, considering both treated and untreated fibers with NaOH 5%. The authors found that the incorporation of latex as an additive provided technical advantages in terms of layer stiffness and membrane resonance control, leading to more effective dissipative damping of the vibrating fiber structure. Additionally, alkali treatment did not significantly impact the acoustic performance when treated fibers were combined with latex as a composite matrix. It was emphasized that careful consideration of the percentage of latex in the composition is essential to avoid excessive latex build-up in the bottom layer of the composite, preventing cavity resonances due to the harder and denser layers.

Prasetiyo et al. [40] conducted an assessment utilizing corn husks (moisture content less than 5%) and water-soluble chitosan (6%, 8%, and 10%wt.) as an adhesive in chipboard manufacturing. The study aimed to investigate the effects of water-soluble chitosan content and variations in pressure and temperature on the properties of chipboard as a separator material. The research findings indicated that the physical and mechanical properties of particleboard were enhanced with an increase in water-soluble chitosan content, reaching a maximum improvement at 8%. Additionally, the composites exhibited the capability to absorb sound at middle to high frequencies and reflect sound at low frequencies.

Buot et al. [41] conducted an analysis involving three different natural fibers—corn, coconut, and banana—combined with synthetic materials such as fiberglass and wool fibers. The goal was to fabricate sound-absorbing panels using local biomass materials and assess their potential properties as acoustic sound absorbers. The study findings indicated that the sound absorption coefficient (SAC) properties of the panels made from local biomass materials exhibited significant characteristics. However, these panels were not able to compete with synthetic panels in terms of the SAC properties. The SAC properties of panels made from corn and banana showed higher values at frequencies 750 and 1000 Hz, although slightly lower than synthetic rockwool materials like conventional panels.

3.4. Coconut coir

Coir fiber, derived from the outer shell of coconuts, is a significant natural fiber available as a by-product and agricultural waste. It stands out due to its high lignin content, contributing to enhanced durability, elongation, and cost-effectiveness. These qualities make coir a preferred fiber, particularly for non-apparel applications. With inherent porosity and high lignin content, coco coir proves suitable for sound absorption applications. When mixed with binders, coir fibers are utilized in building boards to enhance functionality and surface properties. Notably, coir offers customization options, allowing the creation of panels that absorb specific frequencies based on consumer needs. Additionally, coir fibers find applications in tin roofs, light-absorbing panels, cement boards, rubber fibers, and textiles. Over the past few decades, researchers have explored the use of coconut fiber to create acoustic layers. Taban et al. [7] compared the acoustical properties of composites made with coir fiber with those of suggested empirical models for approximating sound absorption. They crafted samples in three different thicknesses—25mm, 35 mm, and 45 mm—with diameters of 3 cm and 10 cm. The Sound Absorption Coefficient (SAC) of coir fiber exhibited a noticeable increase with sound frequency, resulting in a relatively low absorption coefficient at lower frequencies and a significant rise at higher frequencies. The researchers emphasized the critical role of material thickness, particularly at low frequencies, in dissipating acoustic energy. Notably, the 45 mm thick sample demonstrated a higher absorption coefficient compared to the 25 mm and 35 mm thick samples at a constant density and frequency of 1000 Hz (0.97, 0.34, and 0.11, respectively). The effectiveness of a sound-absorbing material in dissipating sound wave energy at low frequencies was found to be directly correlated with its thickness. Introducing an air gap (up to 3 cm) by moving the sample further away from the rigid support increased the absorption coefficient at frequencies under 1000 Hz. However, the

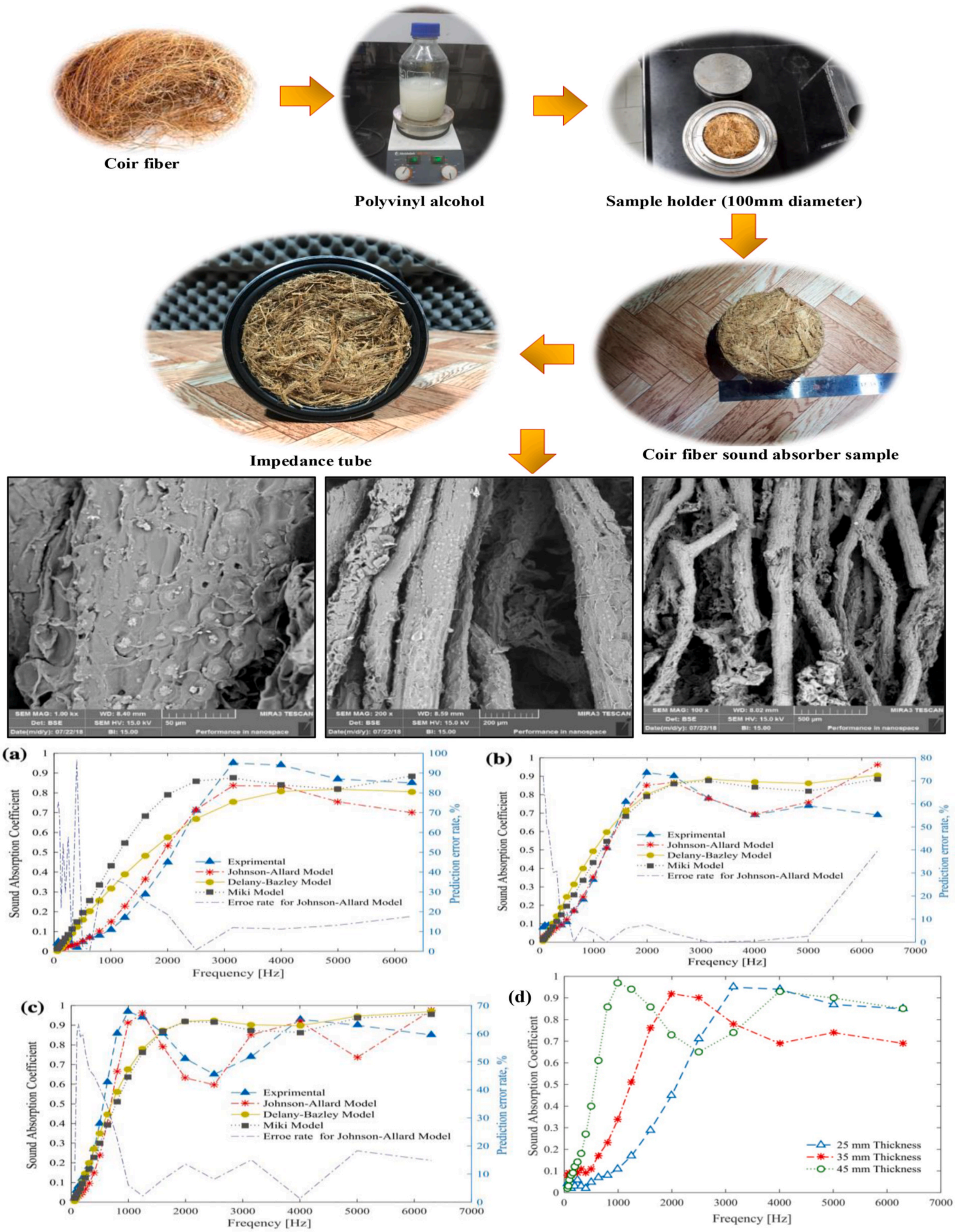


Fig. 13. The process of fabricating coir husk fiber with PVA, the SEM of the coir composite, and comparison of the experimental versus empirical models for sound absorption coefficient of coir fiber, a) 25 mm, b) 35 mm, C) 45 mm thickness, and d) Sound absorption coefficient of coir fibers with different thickness [7].

Johnson-Champoux-Allard model exhibited fair accuracy in predicting absorption coefficients at various thicknesses when compared to the Delany-Bazley and Mito models. The Johnson-Champoux-Allard model proved suitable for the lower frequency range and thicknesses of 25 mm, 35 mm, and 45 mm, achieving prediction accuracies of 12%, 9%, and 11% in higher frequency ranges. The predicted values exceeded the results of experimental tests. Furthermore, increasing sample thickness or introducing an air gap resulted in higher values for the noise reduction coefficient. The fabrication process of samples and corresponding results are depicted in Fig. 13. Rusli et al. [42] delved into the Sound Absorption Coefficient (SAC) characteristics of three distinct natural fibers—coconut coir, oil palm fruit bunches, and pineapple leaf—across thicknesses of 10 mm and 20 mm. The study revealed that fabric density had a more significant impact on the absorption coefficient than the thickness of the pattern. As density and thickness increased, the absorption coefficient characteristics improved, and the frequency peak shifted towards lower frequencies. Furthermore, an increase in fiber content led to the trapping of additional sound stress energy within the composite. The absorption analyses indicated that specimens with a thickness of 20 mm and a density of 0.1978 g/cm^3 exhibited the highest sound absorption, absorbing 90% of sound at a frequency of 3000 Hz. Notably, the results highlighted that the pineapple leaf fiber pattern demonstrated the highest sound absorption coefficient among the three types of fibers.

Putra et al. [43] introduced the SAC properties of multilayer coir fiber (three different sizes, 10, 20, and 30 mm) and kapok fiber (as an auxiliary layer element for coconut fiber) composites. Unlike traditional composite fabrication methods involving mechanical pressure, this study applied mild pressure to eliminate air gaps between the sandwich layers during assembly. The research examined the impact of thickness and the position of kapok fiber on the SAC properties of the samples. The findings indicated that the coir-kapok composite performed comparably to thicker natural coir fiber samples, and the density of kapok fibers could be controlled to enhance sound absorption properties. Moreover, placing kapok layers between the coir layers demonstrated improved absorption. Conversely, placing kapok fibers in the front layer slightly enhanced the low-frequency range, while the air gap showed no distinct effect on enhancing sound absorption.

Muralidharan [44] conducted a study on the Sound Absorption Coefficient (SAC) properties of coir mat, multilayer, and hybrid structure coir natural fibers. The nonwoven mats, with a thickness of 16 mm, were treated with 20% latex and cured in a hot press at 110 °C and 150-ton pressure for 15 min to ensure proper binding of the fibers for structural integration. Various densities of coir nonwovens were layered to create a multilayer structure, and a hybrid structure was developed by layering a panel-like hybrid face layer with the multilayer gradient structure. The research aimed to investigate the impact of the gradient structure, snippets, and the hybrid face layer on the sound absorption properties of the composites. The results indicated that the multilayer structure enhanced SAC properties at mid and high frequencies compared to a homogeneous layer of the same thickness. However, the gradient structure alone was not sufficient for low-frequency sound absorption. Additionally, the addition of a snippet layer on the surface of the coir sheet increased the surface area of the composite, leading to greater vibrational loss of sound waves by the face layer.

3.5. Hemp

Hemp stands out as an environmentally friendly natural fiber with a unique structure, featuring various shapes of voids, spiral patterns, holes, and cracks connected to the longitudinal surface. Scientists, both domestically and internationally, have taken interest in utilizing hemp fibers for acoustic research. The tiny holes in hemp allow sound waves to penetrate, creating gas flow and friction. This phenomenon converts some of the sound energy into heat energy, resulting in effective sound absorption. When sound waves impact hemp, the viscous effect between cavities attenuates some of the sound energy, transforming it into heat. Moreover, the strength between the warp segments, the distinctive hollow structure, and the large specific surface area of hemp rods contribute to

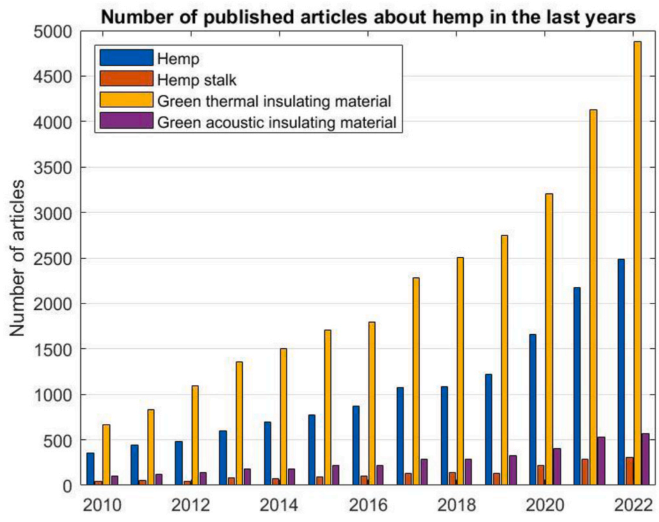


Fig. 14. Number of articles published in the Science Direct and MDPI on hemp and green insulating materials [45]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Some research papers of hemp-reinforced composites for acoustic properties.

Materials	Purpose	Tests	Findings	Ref.
Hemp + Sunflower pith +4 diverse Binders	Investigation of the relationships between hydrothermal and geometrical properties.	SAC and TC Water vapor permeability Moisture behavior	1- Connection between thermal conductivity and inter-particle porosity. 2- Exponential relationship between water vapor and air permeability. 3- Sample acoustic characterization shows a wide range of air resistivity values.	[46]
Hemp fiber + NaOH solution + Unsaturated polyester resin	Developing automotive interior materials sound absorption.	SEM SAC FTIR	1- The STL result was 61.91 dB up to 68.52 dB for the frequency 630 Hz–125 Hz. 2- The presence of surface impurities, lignin and waxy coatings effect on SAC properties.	[47]
Woven Hemp fabric + Bio-epoxy resin	Investigation of STL for two diverse types of sandwich structures realized in HFRP.	STL Mechanical test: (Tensile, Compression, Shear, Young modulus)	1- Comparison of experimental and numerical values illustrated perfect agreement. 2- The STL of the woven hemp sandwich structure is comparable to the honeycomb structure.	[48]
Hemp fiber + Clay soil	Investigation of transmission loss of hemp clay composites and modelling.	STL Sound attenuation Modelling	1- A modeling approach shows that performing lightweight can be well predicted of the wall configuration by a transmission matrix method with isotropic elastic and porous layers.	[49]
Hemp + Clay + Binder + Water	Study on acoustical, thermal and mechanical properties of hemp clay building materials.	SAC TC Compressive strength Flexural strength	1- Density values are not linear with thermal conductivity values. 2- Due to the low mechanical properties of composites, one way to improve compressive and flexural strength is to stabilize the composition of hemp and clay with other binders.	[50]
Hemp fiber + Polylactic acid (PLA)	Relationship between microstructure and sound absorption performance of hemp fiber waste.	XRD SEM SAC Acoustic impedance	1- When acoustic energy applies to the waste fiber from hemp, the friction effect of the oxygen-rigid hexagonal ring structure of the hemp waste fiber polymer, the macromolecular interactions, the thermal conductivity of the polymer chain segment and unique hollow structure of waste hemp fiber, waste hemp fiber creates a sound-absorbing effect, because the unevenness of the fiber absorbs sound energy and dissipates heat and energy mechanics.	[51]
Cotton and Hemp fibers + Polypropylene (PP) fiber	Evaluation of the acoustic properties of thermoplastic composites reinforced with hemp and cotton fibers.	SAC STL	1- Reducing the thickness of the composite does not significantly affect the SAC properties of the material, as the density increases at the same time. 2- Hemp fiber composite structures have considerably higher levels of sound insulation than cotton fiber and cotton/hemp fiber reinforced composites and can be used for high frequency sound insulation applications.	[52]
Hemp stalks + Polycaprolactone powder	Investigation of the SAC properties of waste hemp stalk/polycaprolactone.	SAC NRC XRD SEM FTIR	1- The SAC properties of hemp stalks are closely related to their microstructure. 2- The hemp stalk has a hollow tubular structure, the rough surface causes gas flow and friction, so that part of the sound energy is converted into heat energy, absorbing sound waves. 3- As the hemp stalk length increases, the SAC capacity initially increases and then decreases 4- By reducing the density of the material accordingly, the overall SAC properties can be improved. 5- As the thickness increased, the SAC properties first increased and then decreased.	[53]
Review paper	Investigation of the SAC properties of hemp fibers based on nonwoven fabrics and composites.	Microstructures SAC	1- Hemp natural fiber can be used for sound control and good mechanical strength. 2- multi-layer or multi-component structures offer a wide range of applications for sound absorbers.	[54]
Review paper	Investigation of mechanical, thermal, and SAC properties of the hemp.	SAC, Thermal, mechanical properties	1- Hemp fibers are porous, which affects the acoustic impedance of the material. 2- The use of hurd and hemp fibers in polymer composites encourage a bioeconomy by using waste biomass to fabricate developed environmentally friendly materials.	[55]
Review paper	Industrial hemp fiber-reinforced/ hybrid composites and application.	Thermoplastic and Thermoset Polymeric Matrices, Surface Modifications, Fiber Dispersion,	1- Industrial hemp is utilized in many applications such as textiles, automotive, composites, insulation, concrete, soundproofing, as well as sporting goods and musical instruments, or products. It is also used as a reinforcing agent for applications for brake pads.	[56]

sound energy attenuation and conversion to heat. These properties give hemp yarn a unique sound-absorbing function. Additionally, hemp boasts excellent thermal insulation properties inherent in its stem. Affordability and insulating capabilities make hemp stalks an advantageous choice. However, ensuring long-term stability and chemical compatibility with various binders is crucial. Beyond sound insulation, hemp stalks exhibit high insulation and thermal conductivity. The remarkable properties of hemp have garnered significant attention from both academia and industry in recent years, leading to a notable increase in related publications. Fig. 14 depicts the number of academic papers published in the last decade [45], and Table 2 provides an overview of research papers on hemp-reinforced composites for acoustic properties.

3.6. Bamboo

Bamboo emerges as a remarkable natural material with the distinction of being the fastest-growing and highest-yielding among renewable resources. Its rapid growth, resistance to bending and breaking, and carbon dioxide sequestration make it a sustainable and promising material. Unlike some plants, bamboo does not require annual rooting and replanting, and it achieves optimal mechanical properties within a few years. Bamboo possesses several advantages over other plant fibers, such as its high growth rate and robust mechanical properties. It has the ability to fix carbon dioxide, contributing to green space recovery. The plant cells in bamboo contain cellulose embedded in hemicellulose and amorphous lignin. This natural material is widely utilized for creating sound-absorbing materials, comparable to commercial fiberglass. Bamboo has been employed in the development of fiberboard, a resonant sound-absorbing material, and has demonstrated excellent sound insulation performance in furniture like tables, chairs, and floors. However, bamboo powder, a biomass product with high hydrophilic properties that easily absorbs water, requires modification when used as a composite filler. This involves treating the filler matrix or surface with a compatibilizer or binder. Given the widespread availability of bamboo in several countries, the scientific promotion of modern bamboo structures holds the potential to achieve sound-absorbing, mechanical, and thermal insulation properties. Zhihua et al. [57] conducted an analysis on the dispersion of bamboo

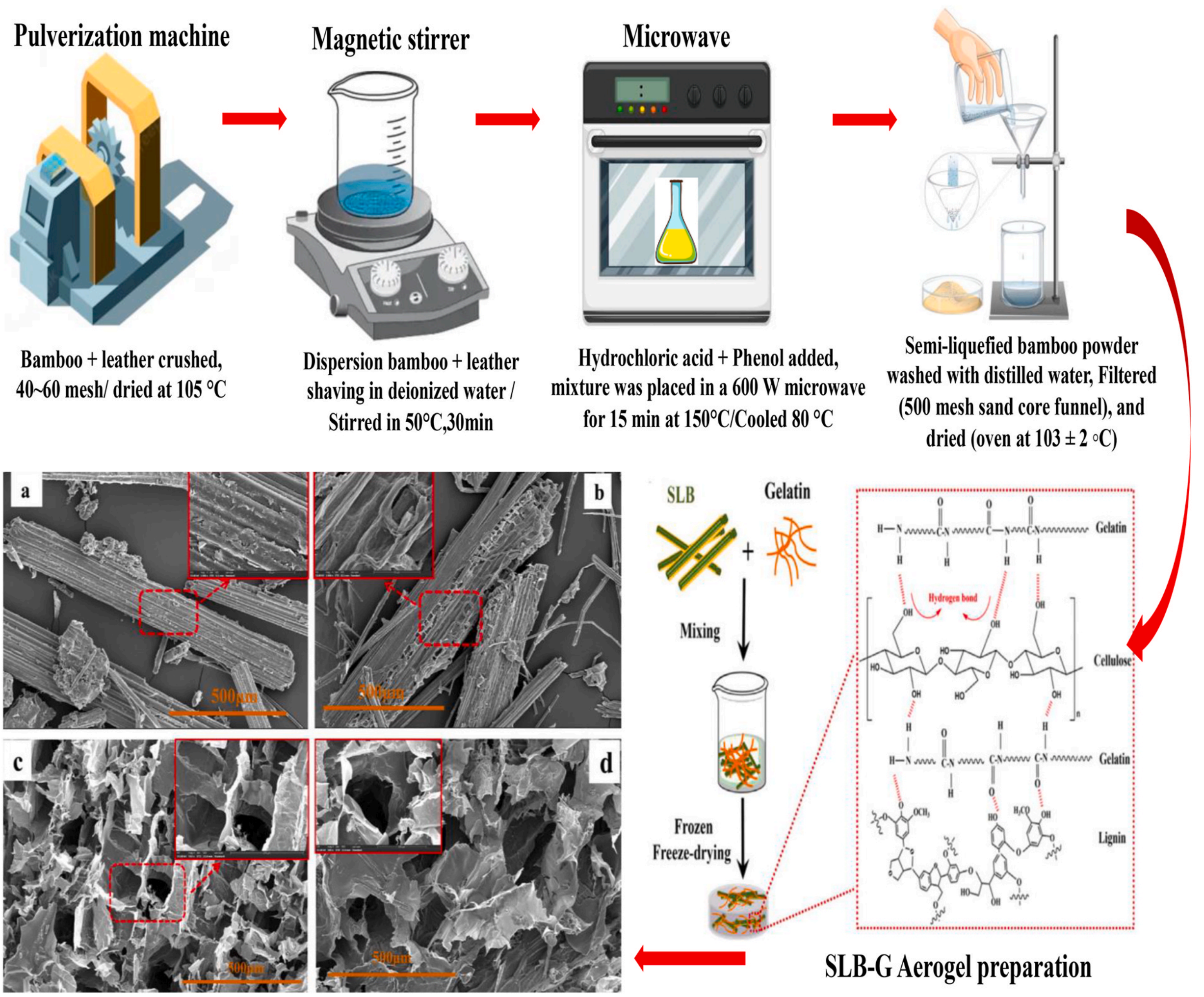


Fig. 15. The process of fabrication SLB-G Aerogel, and the scanning electron microscopy of waste bamboo (a) without liquefaction, (b) with semi-liquefaction, (c) Cross-section of the SLB-G aerogel, (d) surface [57].

natural fiber in gelatin solutions to enhance the physical and chemical properties of aerogels. This study covered aspects such as microstructure, mechanical properties, sound absorption coefficient (SAC), and thermal insulation properties. The manufacturing process of the semi-liquefied bamboo gelatin composite is illustrated in Fig. 15. The study found that the addition of semi-liquefied bamboo improved the mechanical properties of aerogels. Semi-liquefied bamboo gelatin aerogels exhibited excellent sound absorption and thermal insulation properties owing to their low density and high porosity. This functional aerogel, based on degradable and volatile gas-free biomass materials, holds potential for replacing synthetic foams as interior materials, particularly in outdoor

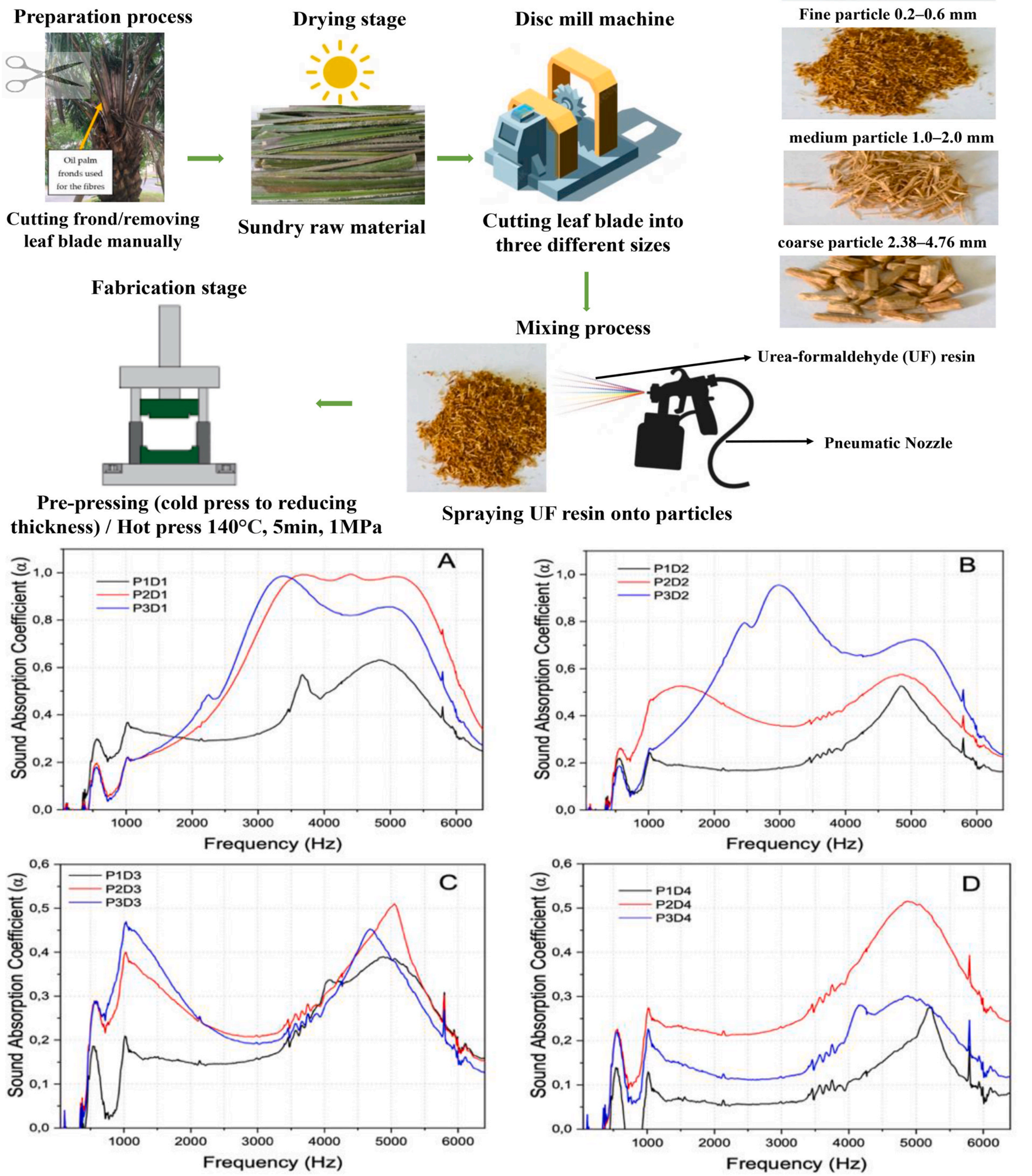


Fig. 16. The process of fabrication oil palm frond-reinforced composites and the SAC properties of samples with the same density of OPF fibers with diverse particle size, A) density 0.3 g/cm^3, B) density 0.4 g/cm^3, C) density 0.5 g/cm^3, D) density 0.6 g/cm^3 (P1 = fine particle size, P2 = medium particle size, P3 = coarse particle size) [63].

construction sites.

Mahesh [58] researched the effects of thermoplastic polymer matrix jute-bamboo hybrid composites with different lamination sequences on thermomechanical properties in automotive usage. The Polypropylene (PP) was utilized as the matrix, with bamboo and jute serving as natural fiber reinforcements for both non-hybrid and hybrid composites. The findings highlighted several important points:

- **Matrix-Fiber Bonding**: Increasing the matrix-fiber bonding enhanced the interlaminar shear strength.
- **Impact Strength:** Non-hybrid composites exhibited lower impact strength compared to hybrid composites.
- **Moisture Absorption:** Moisture absorption was inversely proportional to tensile properties. The hybridized bamboo/jute/jute/bamboo (B.J.J.B) showed lower absorption properties than comparable market composites.
- **Void Filling:** Pre-filling voids during the manufacturing process limited moisture accumulation within the composite.
- **Thermal Stability:** The sample containing bamboo fibers in both the inner and outer layers demonstrated slightly better thermal stability due to its higher cellulose content and crystalline structure.

Another study by Jie et al. [59] focused on sound absorption properties of glued laminated bamboo and spruce-pine-fir (SPF). Thin-strip glubam, thick-strip glubam, and SPF samples were created with specific orientations to minimize sound leakage. The research revealed that thin-strip glulam had similar sound absorption coefficient (SAC) properties in directions y and z but was significantly weaker in direction x. This type of investigation contributes to understanding the acoustic performance of different materials, essential in applications like automotive interiors where sound management is crucial. Dita et al. [60] determined the SAC and STL of thick and thin bamboo woven panels as well as the combination of them. The SAC is a crucial parameter as it indicates the material's ability to absorb sound energy before it is reflected back into the space.

The key findings and recommendations from their research include:

- **SAC Properties:** The study found that bamboo material, in its natural state, has a relatively small sound absorption coefficient, measuring below 0.5. This observation is attributed to the material's thin dimensions, especially when considering the thickness.
- **Improvement Strategies:** To enhance SAC properties, the researchers suggest implementing a multilayer structure on the back of the bamboo panels or combining them with other materials. For instance, adding a layer of lime on the exterior is proposed as a method to potentially increase the sound insulation capability.

These recommendations highlight the potential for optimizing bamboo panels for improved sound absorption, making them more effective in sound management applications.

3.7. Palm

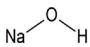
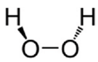
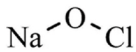
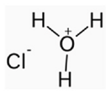
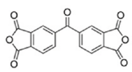
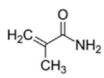
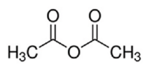
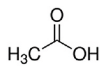
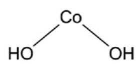
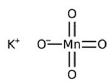
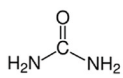
The oil palm, thriving in tropical and subtropical regions, stands as one of the earliest domesticated trees. Extracted from hollow fruit bunches, oil palm fibers (OPF) serve as effective reinforcement for various synthetic materials. The fibrous characteristics of OPF make them versatile, contributing significantly to applications in sound and thermal insulation, aligning with green technology initiatives [61]. Notably, OPF's acoustic qualities are comparable to wood, influenced by factors such as anatomical structure, density, humidity, and ambient temperature. These fibers are readily accessible in numerous countries, offering a straightforward alternative to wood as they can be easily processed into fibrous or granular chips. Additionally, OPF is a renewable, abundant, and cost-effective resource, posing fewer health and safety risks during processing. The abundance of date palm fiber in North Africa and the Middle East presents an opportunity for environmentally friendly material sourcing, promoting cost-effective development. With excellent insulation properties allowing date palms to thrive in temperatures exceeding 50 °C in the shade, OPF emerges as a promising material for various applications. The by-product of the steam sterilization process, empty fruit pods constitute 22–25% of fresh oil palm fruit, with fiber extraction achieved through roasting these empty bunches. It is crucial to note that maximizing the potential of OPF may involve specific processing techniques and treatments tailored to the desired application. Researchers and industries continue to explore innovative ways to harness the benefits of OPF, contributing to sustainable and eco-friendly practices across diverse sectors. Various roasting methods, including mechanical or hammering, chemical, steam, and water, can be employed to extract fibers from oil palm trees. The abundant and advantageous properties of palm trees position them as a promising subject for researchers exploring their potential as sound-absorbing and insulating materials, as well as reinforcing additives in composites. This has spurred considerable research efforts in recent years [62]. Batan et al. [63] studied the effects of particle size and bulk density on the sound absorption coefficient (SAC) properties of composite particleboards reinforced with oil palm leaf were investigated. The study utilized urea-formaldehyde as a binder, oil palm leaf as reinforcement, and ammonium nitrate as a hardening agent. The fabrication process and results are illustrated in Fig. 16, where three types of samples were created with fine-grained, medium-grained, and coarse-grained particles, featuring grain sizes of 0.2–0.6 mm, 1.0–2.0 mm, and 2.38–4.76 mm, respectively. The findings revealed that fiber-reinforced oil palm fiber (OPF) composites generally exhibit a notable sound absorption capacity. The bulk density and particle size of OPF composites play a crucial role in influencing their sound absorption performance across a broad frequency range, effectively absorbing mid-to high-frequency sounds (Fig. 16-A to D). Particularly, medium- and coarse-grained particles demonstrated superior sound absorption performance, highlighting the significance of these factors in optimizing the acoustic properties of oil palm-based composites.

Ali et al. [64] innovatively produced biodegradable thermal insulation composites using agricultural waste materials, specifically date palm tree leaves and wheat straw fibers, for potential applications in building insulation. The fabrication involved creating ten fiberboard samples, with three as loose leaves and the rest as bound boards. The binding agents used were cornstarch or wood adhesive for leaves and fibers, respectively. Mechanical, acoustical, and thermal analyses were conducted on the samples. The outcomes revealed that the hybrid samples exhibited an average thermal conductivity ranging from 0.045 to 0.065 W/m K within the temperature range of 10–60 °C. Moreover, the sound absorption coefficient (SAC) properties exceeded 0.6 for frequencies ranging from 900 Hz to 2000 Hz. Additionally, the mechanical properties of the boards indicated that increasing the percentage of both date palm leaves and the polymerized binder could enhance the flexural stress of the hybrid boards. Dasari et al. [65] investigated the mechanical, moisture, sound, alkali, water, and absorption properties of composite panels made with oil palm fiber. For this study, a water-based acrylic resin served as the binding agent, and fly ash, along with other metal oxides, was used for reinforcement. The process involved the removal of hemicellulose and other impurities to a certain percentage, thereby improving the roughness of the palm fibers' surface. SAC studies demonstrated that palm fibers enhance SAC characteristics, especially in the frequency range of 1000–3000 Hz. This is significant as conventional rigid panels made of gypsum and magnesia showed no absorption. Additionally, composite panels without reinforced fly ash exhibited superior damping characteristics compared to panels with fly ash up to temperatures of 70 °C.

3.8. *Luffa*

Luffa, a member of the Cucurbitaceae family (cucumber), finds versatile applications, with its ripe fruit serving as a natural cleaning sponge and its immature fruit being consumed as a vegetable. Widely distributed from South Asia to East Asia and Central Asia, it is notably present in countries like Vietnam and China. Luffa fibers exhibit exceptional toughness, strength, and stiffness akin to various metals in the same density range. Characterized by a voluminous structure, soft texture, and high porosity, luffa proves ideal for diverse acoustic applications. Chemically, luffa comprises 10–23% lignin, 8–22% hemicellulose, and 0–55% cellulose, alongside inorganic elements like glycosides, polypeptides, amino acids, and proteins. The flake-like structure of luffa fibers endows them with remarkable tensile strength, making them an excellent choice for reinforcement in composites to enhance strength. In the realm of eco-

Table 3
Some chemical materials used for treatment of natural luffa fiber.

Material	Reason	Chemical structure	Ref.
Sodium Hydroxide (NaOH)	Improving the surface roughness and mechanical bonding with matrix material.		[66]
Hydrogen Peroxide (H_2O_2)	The effect of hydrogen peroxide treatment on the structure, moisture absorption and mechanical properties of luffa fiber.		[67]
Sodium Hypochlorite (NaClO)	Improvement of interfacial bonding and to reduce moisture absorption (using 2% of sodium hypochlorite).		[68]
Hydrochloric Acid (HCL)	Surface treatments of the luffa fiber 3%.		[69]
Benzophenone Tetracarboxylic Dianhydride (BTDA)	Improvements in mechanical and thermal properties (2.5gr).		[70]
Methacrylamide (C_4H_7NO)	The treatment with Methacrylamide for copolymerization or grafting (1–3%).		[71]
Acetic Anhydride ($C_4H_6O_3$)	Surface treatments of the luffa fiber (100 °C for 3 h).		[72]
Acetic Acid (CH_3COOH)	To remove the moisture.		[73]
Calcium Hydroxide (Ca $(OH)_2$)	Improvement mechanical and acoustical properties.		[74]
Potassium Permanganate ($KmnO_4$)	Surface modification of luffa fiber.		[75]
Urea (Carbamide $CO(NH_2)$)	Effect of treatment on the micro/nano structures, moisture absorption and mechanical properties of luffa sponge fiber.		[76]

friendly composites, Luffa Natural Fiber Composite (LNFC) holds immense potential for applications in vibration and noise isolation, such as in yachts, automobiles, and aircraft, owing to its high elasticity and damping properties. Pure luffa fibers exhibit excellent Sound Absorption Coefficient (SAC) properties, indicating that thick and pure luffa samples may yield superior acoustic performance. The addition of luffa fibers to the polymer matrix enhances acoustic properties significantly across all frequencies, leading to a four-fold increase in sound insulation at moderate frequency levels. Moreover, the morphological analysis of LNFCs provides insights into the compatibility between luffa fibers and the chosen matrix, revealing the state of fiber-matrix adhesion and identifying internal defects. Chemical treatments are commonly employed to enhance the mechanical, physical, and acoustic properties of luffa fibers. Tables 3 and 4 detail some of the common chemicals used for treating luffa fibers and the thermoplastic and thermoset matrices applied in the fabrication of Luffa Natural Fiber Composites (LNFC) over the past decades.

3.9. Rice

Rice straw stands out as an abundant organic material and a natural residue from rice cultivation, ranking third globally among agricultural residues, following sugar cane bagasse and corn stalks. It encompasses by-products like rice straw, chaff, and bran, resulting from rice production. Notably, unlike wheat straw, which is commonly used as animal feed, rice straw is less favored in this regard due to its limited nutritional value. Instead, it finds applications in various sectors, including as fuel in brick kilns, for animal production, mushroom cultivation, cardboard manufacturing, biomass power plants, and diverse industrial processes. The incorporation of rice husk in materials presents potential advantages, contributing to enhanced thermal performance and reduced environmental impact throughout their life cycle. Utilizing these agricultural wastes represents an innovative approach in the development of sound-absorbing materials, leveraging their favorable mechanical properties, cost-effectiveness, availability, non-toxicity, and environmental friendliness. Consequently, recognizing common agricultural waste types becomes imperative for assessing the acoustic performance of materials through experimental studies and model applications. Numerous research studies have delved into the utilization of rice by-products over the past decades.

Olcay [86] and Wang [87] independently investigated the impact of incorporating rice plant waste into polyurethane composites as acoustic absorption materials. Olcay observed that alkali treatment had a positive effect on the sound absorption coefficients of the composites. The TRW-PU5 composite, in particular, exhibited a higher sound absorption coefficient than PU foam in the 400–3200 Hz range, while the RW–PU5 composite surpassed PU foam in the 2500–6400 Hz range. On the other hand, Wang found that the addition of rice husk improved the polyurethane foam's sound absorption capabilities, particularly at low frequencies. Among the polyurethane-rice husk composites tested, the one with a 5% rice husk content demonstrated the most effective sound absorption performance. The fabrication processes and outcomes of Olcay and Wang's studies are illustrated in Fig. 17. Lekshmi et al. [88] conducted a study to assess the effectiveness of fibro-granular acoustic panels incorporating coir fiber and rice husk for absorbing low-frequency sound waves and providing flame resistance. The coir fiber-rice husk acoustic panel (CFRHAP) exhibited an average sound absorption coefficient of 0.83 in the low-frequency range (500–1000 Hz) and 0.9 in the high-frequency range (1500 Hz–5000 Hz). Notably, CFRHAP performed exceptionally well across the broad frequency spectrum of 500 Hz–5000 Hz. Furthermore, the fibro-granular material used in CFRHAP achieved a V-1 rating for flame resistance, indicating that sustained burning is not observed. The results from the flame resistance test confirm the CFRHAP's suitability as a safe passive acoustic absorber. Taskin et al. [89]

Table 4
Thermoplastics and thermosets chemical matrixes used in luffa natural fiber composite for improving acoustical, mechanical, and thermal properties.

Matrix	Investigation	Findings	Ref
Epoxy resin	Effect of machining on the SAC and mechanical properties of jute and luffa/epoxy resin composites.	SAC properties are reduced by 3–7%, the transmission loss levels increase by 6–11 dB, and the damping levels and young modulus are reduced by 0.1–0.5% and 3–4%, when the samples are machined.	[77]
Polyurethane	Investigation of tensile strength, tear resistance, aging resistance, thermomechanical properties, thermal stability, and mechanical properties of Polyurethane/luffa oil.	The mechanical properties of luffa oil viscoelastic foam gradually improved with the increase in the added amount of luffa oil.	[78]
Polyester	Investigation of the SAC properties of luffa fibers and polyester as the matrix and adhesive.	The sound absorption coefficient of luffa fiber/polyester composite material reaches high-performance sound absorbing (0.645).	[79]
Geopolymer	Physical and mechanical properties of luffa cylindrical fiber/geopolymer composites.	Compressive and flexural strengths of the geopolymer composites increased from 13 MP and 3.4Mpa up to 31Mpa and 14.2Mpa.	[80]
Concrete	Increasing mechanical properties of concrete with luffa fiber as a reinforcement additive.	Concrete reinforcement with the use of luffa aegyptiaca fiber generally shows an increase in the strength gained with time.	[81]
Epoxy resin	Mechanical and Thermal properties of Luffa/Epoxy/Nanosilica Polymer Composite.	The mechanical and thermal behavior of the luffa/epoxy composites can be enhanced through the addition of nanosilica to epoxy resin.	[82]
Potassium iodide (KI)	Photocatalytic properties of BiOI/luffa fiber composite.	The high specific surface area of luffa enhanced the adsorption of contaminants and enabled the separation of recyclable BiOI.	[83]
Polylactic acid	Investigation of dielectric properties of luffa–polylactide quadratic splint composites.	This network is very secure for patients with pacemakers and other medical devices that must not be subject to electronic interference.	[84]
Vinyl ester	Mechanical properties of Sisal-Luffa-Vinyl ester natural composite.	The (20Sisal + 10Luffa) natural fiber reinforced composite specimen has high tensile strength.	[85]

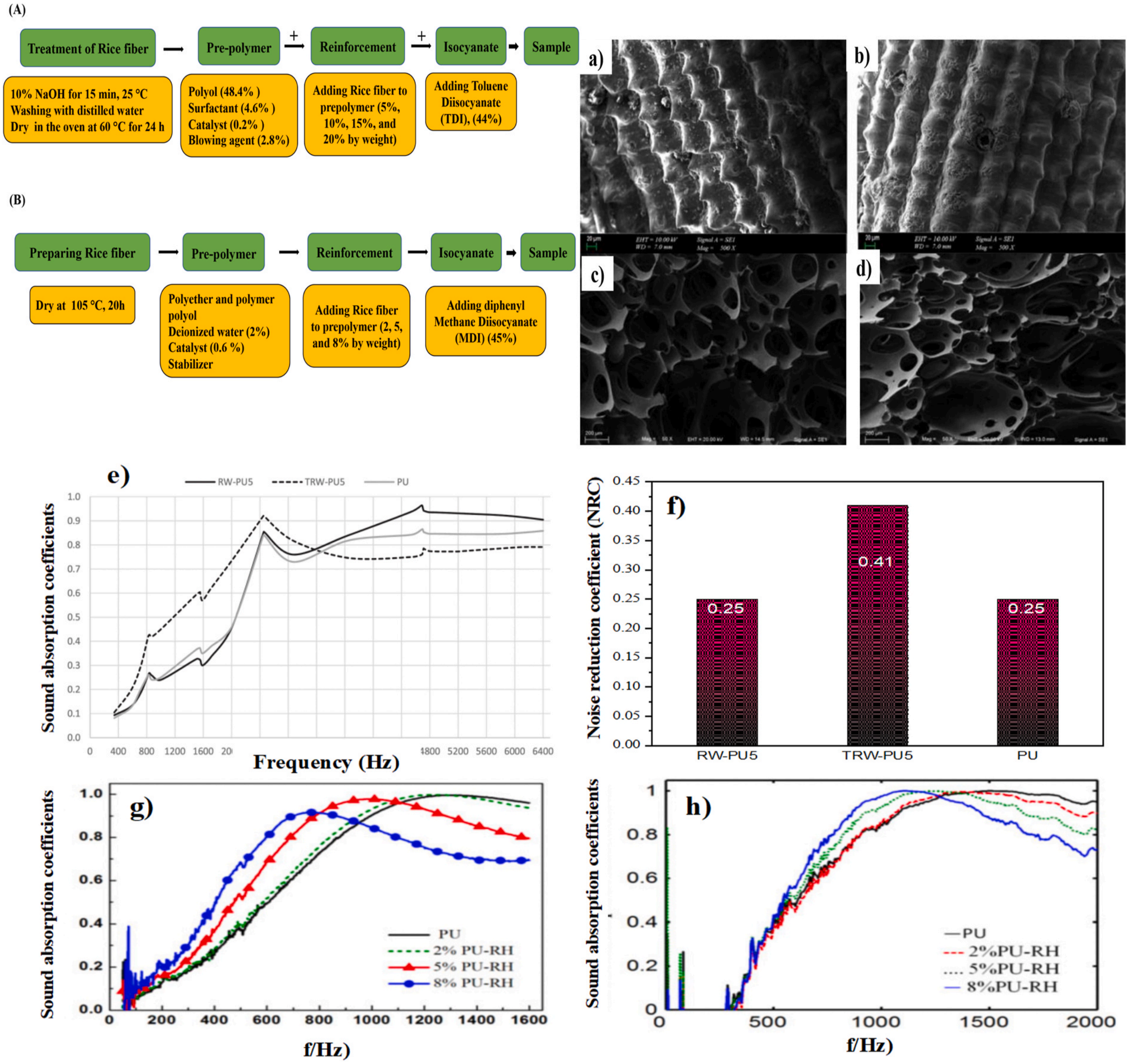
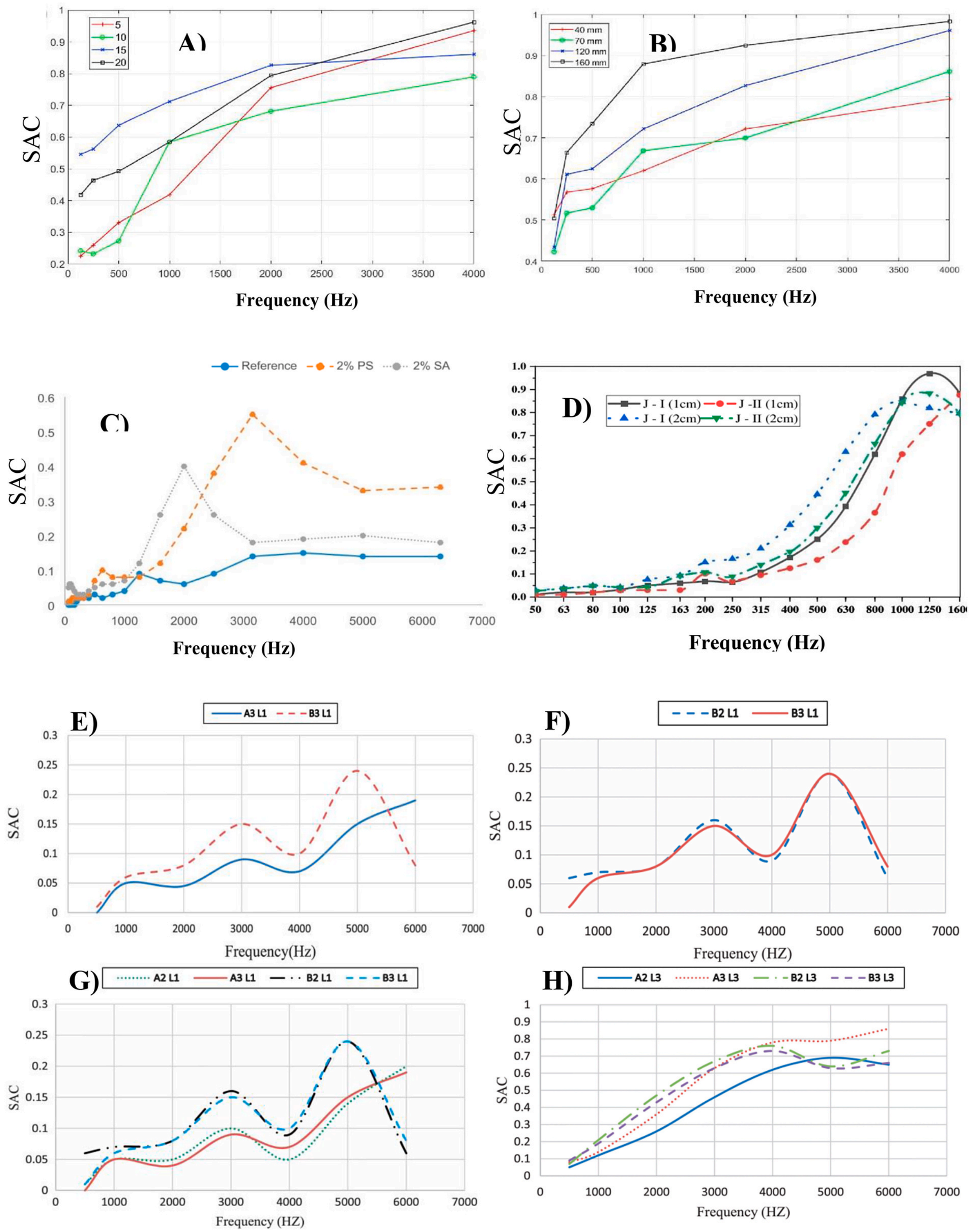


Fig. 17. Fabrication processes and results of Olcay and Wang paper, A) Fabrication process of Olcay work [86], B) Fabrication process of Wang's work [87], a) SEM micrograph of the untreated rice plant waste [86], (b) Treated rice plant waste at diverse magnifications [86], c) SEM micrographs of polyurethane foam [87] d) Polyurethane-rice husk composites with 2% rice husk [87], e) SAC frequency graph for rice plant waste reinforced PU foam composites and PU foam [86], f) NRC properties of rice plant waste reinforced PU foam composites and PU foam [86] g) SAC properties of PU-RH composites, h) SAC properties of PU-RH composites by self-made.

investigated the impact of a bio-composite material comprising rice straw fiber and polylactic acid (PLA) on its thermal conductivity and acoustic properties. Specifically, they utilized a PLA polymer matrix and a nonwoven fabric structure made from rice straw fiber to create composite sheets through the hot press technique. The SEM analysis revealed structures that facilitated bonding to the matrix during composite fabrication without the need for additional chemical inputs to form interfaces. Additionally, FTIR spectra indicated the successful hydrophilization process for rice straw, signifying its appropriate modification. The researchers emphasized that the sound absorption coefficient (SAC) properties exhibit a direct correlation with the material's density. Increasing the material thickness enhances the number of pores per unit, and multilayer composites were observed to inhibit high SAC properties. Moreover, the low thermal conductivity of the PLA/rice straw fiber composite establishes its suitability for thermal insulation applications in industrial settings.

3.10. Waste fabric

Annually, landfills receive millions of tons of textile and clothing waste, causing severe environmental pollution. The fashion industry alone contributes nearly 20% to the global waste production, with 15% of fabric designated for clothing ending up as



(caption on next page)

Fig. 18. Some composites made of fabric have SAC properties. A) SAC characteristics of composites with different pressures (5, 10, 15, 20 Tons on a 4″ Diameter Ram) made of post-industrial textile waste and natural rubber, and B) with different panel thicknesses [90], C) SAC properties of glass fiber fabric epoxy composite with PS and SA inherently without deterioration of main mechanical properties (reference means glass fiber fabric epoxy sample) [91], D) SAC properties for Jute cloths of 1 and 2 cm thickness samples with rigid backing (jute I and II means two different forms of jute cloths) [92], E) The effect of spacing on SAC properties of warp knitted spacer fabrics based on knit structure and nanofiber enhancement (L1″ refers to the results in single layer mode of experiments and the numbers 2 and 3 refer to the underlap movement of connecting yarns in each case, A and B means the samples with 4.5 and 7.5 mm of spacing respectively), F) The effect of connecting yarn angle, G) The effect of knit structure of single layer, and H) The effect of knit structure of three layer [93,94].

discarded remnants on the cutting room floor. Utilizing recycled textiles for soundproofing materials presents an opportunity to mitigate the environmental impact caused by the fashion industry's excessive fiber production through agricultural or extraction methods, which accounts for a significant carbon footprint. It also addresses the adverse effects of textile waste accumulating in landfills. Post-industrial textile waste typically comprises surplus and discarded fabrics, cutting waste, and sewing waste. In countries with a predominant manufacturing industry, the disposal of industrial waste has become a substantial challenge as production escalates. The acoustic properties of textile waste, influenced by factors such as yarn density, nature, fiber, humidity, and pore treatment, are determined by the manufacturing process and the physical characteristics of the textile. The acoustic characteristics of textile waste are shaped by the interaction of sound waves with the porous structure's surface and the connecting yarns between two surfaces. Abrasion during this interaction diminishes the energy of the sound wave, leading to sound absorption as the transformed energy converts into heat. Porous fiber structures exhibit reduced acoustic energy through heat generation, momentum loss, and frictional losses. However, incorporating textile fibers, especially post-consumer fibers, as value-added materials pose challenges. One obstacle involves reducing the length of recycled natural fibers in traditional textiles. Nonwoven technology provides a workaround by effectively utilizing short fibers. Products manufactured through the nonwoven process demonstrate excellent Sound Absorption Coefficient (SAC) characteristics in the medium and high frequency range. Another challenge arises from the irregularity of natural fibers, prompting ongoing research to develop soundproofing materials using recycled fibers. Fig. 18 illustrates sound absorption diagrams of acoustic insulation materials employing recycled textiles [90–94].

3.11. *Other natural material*

There are other natural materials and fibers, some of which have received more attention and use, while others have received less attention in research. Table 5 lists some other natural fibers used for sound absorption applications that have been studied by researchers in recent years.

4. Conclusions

Natural fibers present a promising avenue for replacing synthetic materials in sound-absorbing applications, offering advantages such as excellent acoustic properties, low cost, lightweight characteristics, availability, and biodegradability. However, several challenges persist for the development of next-generation sound-absorbing materials using natural fibers. The following points outline key areas for future research:

Enhancing Heat Resistance and Moisture Absorption: Despite the numerous advantages of natural fibers, issues like low heat resistance and moisture absorption need improvement for practical applications. Research should focus on developing flame-retardant materials to enhance heat resistance and mitigate flammability risks.

Polymer Additives and Interfacial Adhesion: The relationship between additives in the polymer matrix plays a crucial role in determining mechanical, thermal, and acoustic properties. Future research should delve into understanding and improving this relationship, especially addressing the decrease in interfacial adhesion between the polymer matrix and natural fibers.

Surface Treatment of Natural Materials: Surface treatment significantly influences acoustic properties, mechanical properties, flame resistance, and moisture absorption. Exploring various chemical and physical methods, such as alkali, acetyl, silane treatments, and more, can improve matrix-fiber interfacial bonding and surface properties. Further investigation into surface treatment technologies is essential.

Utilizing Modeling and Simulation Software: Computational modeling techniques, including machine learning, deep learning, genetic algorithms, and artificial neural networks, can predict sound absorption properties without experimental measurements. Future research should focus on developing and utilizing such models and simulation software to streamline the selection of fibers for acoustic composites.

Geographical Considerations for Natural Fiber Cultivation: Since some natural fibers are region-specific, researchers should explore cultivating and utilizing fibers indigenous to their regions. This approach supports environmental sustainability, reduces the use of chemicals, and contributes to lowering carbon dioxide production, aligning with global efforts to combat climate change.

Refinement of Processing and Manufacturing Methods: Future studies should concentrate on refining processing and manufacturing methods, particularly understanding fiber-matrix interactions to minimize wastage. Additive 3D manufacturing can be explored to fabricate complex 3D acoustic architectures, reducing manufacturing costs and time.

Intelligent Noise Absorption: There is a current lack of research in intelligent noise absorption that can be modulated by external stimuli. Researchers are encouraged to explore and develop smart devices using natural fibers in response to electric or magnetic fields.

Hybrid Composites for Improved Properties: Mixing different types of natural fibers to create hybrid composites enhances tensile and flexural properties. Future research should focus on developing hybrid composites to optimize sound absorption properties.

Scaling Prototypes for Large-Scale Fabrication: Future studies should aim to transform prototypes into scalable solutions for large-scale fabrication and real-time devices.

Table 5
A summary of studies of other natural fiber composite sound absorbers.

Material	Topic	Results	Ref.
Tea leaf	SAC properties of tea waste/polypropylene and nanoclay bio-composites.	Increasing the amount of tea waste had a special role in SAC properties because of high porosity at a frequency of 1000 Hz and a frequency range of 2500–6300 Hz.	[95]
Banana	Effect of banana frond fiber/polyurethane matrix on composite panels SAC properties.	The best composition for silencers using banana frond fibers/ polyurethane is 80%:20%.	[96]
Flax	Properties of SAC of composites fabricated by flax fiber.	Flax fiber and vermiculite composites have mechanical, SAC, and microbiological stability properties.	[97]
Sisal	Investigation of SAC and mechanical properties of sisal/ Palm/epoxy fiber composites.	A composite of 65% epoxy resin, 20% sisal and 15% palm exhibits the best SAC and mechanical properties (tensile, flexural, and impact strength).	[98]
Wood	NRC and thermal-insulation capabilities of a scalable and high-porosity wood structure.	Insulwood illustrates a high porosity of (0.93), high noise-reduction coefficient (0.37), low radial thermal conductivity (0.038), and high compressive strength.	[99]
Coffee skin	Investigation of the SAC properties of pure coffee grounds.	The optimal NRC properties of coffee grounds is 0.61 at a density of 0.3 g/ cm^3 and thickness of 50 mm.	[100]
Sugarcane Bagasse	The effect of fiber size on SAC properties of sugarcane bagasse wastes fibers.	The airflow resistivity and SAC properties of the sugarcane bagasse waste fibers decreased with increased fiber sizes.	[101]
Charcoal	SAC properties of Charcoal produced from wood waste.	Granular charcoal of 25 mm has a better SAC property compared to wood of the same thickness.	[102]
Pineapple Leaf	Acoustic and mechanical properties, measurement and modeling of pineapple leaf fiber/silica aerogel-filled mortars.	Optimal components are determined from the model, ensuring high sound insulation and at the same time low loss of mechanical strength and future design advantages.	[103]
Clay	Investigation of size and amount of lightweight expanded clay aggregate on SAC properties of concrete at normal incidence.	By substituting lightweight expanded clay aggregate for coarse aggregate in concrete, the normal SAC of lightweight concrete can be significantly improved.	[104]
Wool	SAC and thermal properties of composites with pure and crossbred sheep waste wool.	Waste wool is a potential source of raw material for thermal insulation and sound absorption applications.	[105]
Esparto grass	SAC properties of composites fabricated with 3 different esparto grass fibers.	Esparto Type 1 with 90 mm thickness shows the best SAC properties, with a peak value near unity at 500 Hz.	[106]
Grewia Optiva	Investigation and theoretical modelling SAC properties of grewia optiva fiber composite.	The GOF reinforced epoxy-LC composites have a higher SAC compared to their counterparts because the SAC properties of composites increased as the fiber contents increased.	[107]
Sawdust	SAC properties of rigid polyurethane foam/rubber/wood sawdust as a natural filler.	Composite with a higher amount of rubber-wood sawdust has high SAC at wider frequency range.	[108]
Posidonia	SAC properties and modeling of posidonia fibers.	According to modeling, an intriguing feature of posidonia is that the lignin fibers are prepared for acoustic application as a result of the natural cleaning process of the waves and salt water.	[109]
Ramie	SAC properties of ramie fiber reinforced poly (L-lactic acid [110]) composites.	The SAC properties depicted that the composites with short ramie fiber have better SAC properties than the ramie fabric reinforced PLLA composites.	[111]
Sugarcane bagasse	SAC and thermal insulation of waste fiber for application in sustainable buildings.	SBW provides perfect properties in SAC and thermal insulation fields.	[112]
Yucca	Investigation of the SAC properties of kenaf/yucca composites	Composites with 100% kenaf shows best properties at the low- and mid-frequency.	[113]

In summary, addressing these challenges through comprehensive research efforts will contribute to the advancement of natural fiber-based sound-absorbing materials and their practical applications.

CRediT authorship contribution statement

Majid Mohammadi: Software, Investigation, Data curation, Writing. Ebrahim Taban: Software, Methodology, Validation, Formal analysis, Writing – review & editing. **Wei Hong Tan:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing. **Nazli Bin Che Din:** Conceptualization, Methodology, Validation, Writing – review & editing. **Azma Putra:** Data curation, Writing – review & editing. **Umberto Berardi:** Supervisor, Investigation, Formal analysis, Conceptualization, Methodology, review & editing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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