ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE September 2026. Vol.22(3):635-651
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
https://doi.org/10.63958/AZOJETE/2026/22/03/007
www.azojete.com.ng

REVIEW ARTICLE

VALORISATION OF AGRICULTURAL WASTES TO BIOCOMPOSITE MATERIALS FOR INDUSTRIAL APPLICATION: A REVIEW

D.M. Ayuba*[1,2], I.S. Aji[1], M.A. Abba-Aji[1], S. Shodiya[1]

[1]*Department of Mechanical Engineering, University of Maiduguri, Maiduguri, Nigeria*
[2]*National Centre for Technology Management (NACETEM), Yola, Nigeria*
**Corresponding author's email: davidayubamshelia@yahoo.com*

ARTICLE INFORMATION

Received: 9th June 2026
Revised: 29th July 2026
Accepted: 30th July 2026

Keywords:
Acoustic
Agricultural wastes
Automobile
Bio-composite
Fibre board
Hybridisation
Natural fibre
Particle board
Thermoplastics

ABSTRACT

In recent years, the market has seen a gradual movement towards a circular economy model that uses materials efficiently, minimises waste and focuses on reuse and recycling, which has contributed to the emergence of interest in finding sustainable alternatives to traditional synthetic materials made from petroleum. This review attributes evidence on the viability and sustainability of hybrid bio-composite materials from agricultural wastes as an alternative to synthetic materials. Along with this, valorisation of these easily obtainable, cheap by-products like rice husk, sugarcane bagasse, coconut coir, etc., as reinforcement fibres embedded in a polymer matrix is highlighted. The review highlighted the latest knowledge regarding the chemical composition of natural fibres, surface modification methods for enhancing the fibre-matrix compatibility and selection of polymer matrices (thermosets and thermoplastics). In addition, the sound-absorbing characteristics of these biocomposites are extensively discussed, with particular focus on their porous structure and ability to absorb sound energy, which is crucial for their use in various applications, including the automotive and construction industries. Also, the review encompassed the formulation techniques, characterisation (physical, mechanical, acoustic and thermal) and new industrial applications in automotive, construction, furniture and packaging industries. A total of 100 journal papers and conference proceedings were sourced from Science Direct, Research Gate, Google Scholar, and Semantic Scholar, mostly published between 2021 and 2025, were reviewed using the inclusion/exclusion criteria method. This study included peer-reviewed journal articles, conference proceedings, review papers, and technical publications that reported pertinent experimental results. For this purpose, publications were excluded if they did not provide sufficient methodological details or if they were not related to the valorisation of agricultural waste for bio-composite materials development. Finally, it identified major challenges such as moisture absorption and fibre inconsistency and outlined future research directions, including the optimisation of hybrid composites and advanced manufacturing processes, to improve the performance of agricultural waste as an eco-friendly material, such as rice husk-palmyra fruit fibre reinforced in a thermoplastic matrix, such as polypropylene.

1.0 Introduction

As environmental stressors have risen around the globe, sustainability has become an important principle for innovation in all industries (Bhuvaneswari *et al.*, 2022). This has resulted in a paradigm shift in materials science, shifting from a linear petroleum-based economy to a circular economy with renewable resources and valorisation of waste. The conversion to this is based on the creation of green composites, especially those using natural fibres and agricultural waste. These materials provide an important route to reduce dependence on synthetic polymers, decrease CO2 emissions and convert agricultural by-products from an environmental liability to a valuable industrial feedstock (Jabu *et al.*, 2025; Phiri *et al.*, 2023). Traditional composites can be flexible and strong, but they are also a major environmental issue due to their long-term use. They are made in large quantities by using the fuels obtained from non-renewable fossil fuels. Additionally, they are not biodegradable, and they pollute the environment for years, leading to clogged landfills and the presence of microplastics in the environment (Manickaraj *et al*., 2025). As a result, there has been a need to seek sustainable alternatives in the context of a circular economy. Biocomposites are generally manufactured by using natural fibres (as reinforcement) with a polymer matrix. The use of renewable resources to produce materials with desirable mechanical properties is used in biocomposites (Nkomo & Alugongo, 2024). They can reduce environmental footprint without sacrificing performance by using materials from nature instead of synthetic fibres, and in some cases even fossil-based polymers, which paves the way to a break from dependency on fossil fuels.

The research methodology involves a systematic approach to assess the development of the agro-waste natural fibre composites and their acoustic properties. A detailed literature survey is carried out to gather the existing research work that has been done on using agro-waste natural fibre composites along with advanced manufacturing technologies and their acoustics, with a specific consideration of the parameters that impact the sound absorption and insulation of agro-waste natural fibre composites. Depending on material composition and manufacturing, the review compares experimental results based on the consistency of results from many studies. The review also highlights the areas which are lacking in the literature and recommends directions for future research. This review has been conducted on 100 (open access) papers from various journal publications and conference proceedings from Science Direct, Research Gate, Google Scholar, Elsevier, SpringerLink and Semantic Scholar with the following keywords: agricultural waste, hybrid, bio-composite, acoustic properties, fibre/particle boards, natural fibre, multi-purpose, eco-friendly materials and polymers. The date of publication of the paper is an inclusion/exclusion criterion from 2021 to 2025. Research that was published before 2021 was not included to make sure that the literature is up-to-date and relevant. Furthermore, after a careful review of the content of some of the publications, it was decided to exclude them because their content and scope were not directly related to the aims and thematic focus of the present study.

1.1 Objectives of this Review

The primary objective of this paper is to review how hybrid biocomposites derived from agricultural waste are developed, processed, characterised, and applied, with particular focus on their mechanical, thermal, and acoustic.

1.2 Scope of this Review

The scope of this review covers the types and properties of agricultural waste fibres used as reinforcement, the selection of polymer matrices, including thermosets, thermoplastics, and biopolymers, an overview of fabrication methods, a summary of performance evaluation metrics, including mechanical, thermal, and acoustic properties, and an exploration of current industrial applications and future research directions. This review begins by examining the foundational component of the agricultural waste fibres that provide good reinforcement and strength.

2. Agricultural Waste as Reinforcement Materials

The rising environmental issues and restrictions on synthetic materials have driven the need for alternative materials in the field of sound insulation. Natural fibres and agro-waste are lightweight, renewable, biodegradable and low-cost reinforcement for polymer composites, thus reducing the reliance on energy-consuming synthetic fibres (Hosseini *et al*., 2023).

A study conducted by Lekshmi *et al.* (2023) shows the interconnected pore network, high sound absorbing coefficient of between (0.72–0.83) and optimum airflow resistivity of coir–rice husk panels in the frequency range of 100–1000 Hz were due to their highly porous structure. Additionally, the synergetic effect of the coir fibres and rice husk particles led to enhanced sound wave scattering, increased viscous and thermal energy dissipation and the multiple internal reflections. This enabled the effective absorption of sound at low frequencies for use in practical sound insulation applications. Mustafa *et al.* (2024) reported that sugarcane bagasse had the highest sound absorption coefficient value of 0.95 at 1600 Hz, which was explained by sugarcane bagasse having a highly porous structure, a well-connected pore network, and a sound absorption coefficient that favoured viscous and thermal dissipation of the acoustic energy. Coconut fibre and groundnut shell, on the other hand, showed lesser peaks of sound absorption coefficient of 0.84 and 0.73, respectively, at 4000 Hz, due to their relatively dense structure and low porosity, which necessitated higher frequencies for sound absorption.

2.1 The Chemical Composition of Natural Fibres

The behaviour of natural fibres is determined by their chemical composition, which is mainly cellulose, hemicellulose and lignin. This structure gives strength but also causes the major problem of hydrophilicity. This is because the cellulose and hemicellulose have many hydroxyl (-OH) groups that can easily form hydrogen bonds with water molecules, resulting in absorption of moisture by the fibres. However, they are not suitable for most polymer matrices, which are very little water-attracting, because they are hydrophobic. This difference leads to poor interfacial adhesion, which is a major disadvantage to be solved to produce high-performance composites (Rahman *et al*., 2025b).

2.2 Fibre treatments for improved interfacial bonding between fibre and matrix

Hydrophilic fibres and hydrophobic polymer matrices are incompatible, which reduces interfacial adhesion, limits stress transfer, and consequently affects the product's mechanical properties. Many fibre-treatment methods are used to enhance fibre-matrix bonding, particularly alkali treatment. The enhanced tensile strength of alkali-treated jute fibre composites was reported by Valipour et al. (2022) to be due to the improved fibre–matrix interface adhesion, which was achieved by removing the hemicellulose, lignin, waxes and other impurities present on the fibre surface. The treatment also resulted in a slight increase in crystallinity index, as the amorphous parts were removed, thus increasing fibre stiffness. Besides, the obtained modification of fibre morphology (enhancement of surface roughness and porosity) resulted in better acoustic energy dissipation (NRC increased from 0.66 to 0.69).

With careful selection and application of these procedures, the performance of agricultural waste fibres can be greatly improved, allowing for stronger, more durable and water-resistant biocomposites. Such surface modifications are important to enhance the adhesion between the two surfaces as well as to help prevent the dimensional stability issues that could result from water absorption or thickness swelling that could compromise the long-term durability of the material.

3. Principles of Matrix Selection and Hybridisation

The matrix material is an important component that determines the overall performance of the composite, while reinforcement fibres play a crucial role in providing strength. The matrix holds the fibres in place, shares the load applied to the fibres, and shields them from degradation and wear. The matrix distinguishes the composites with respect to their processing, mechanical properties, thermal resistance and end-of-life.

3.1 Polymer Matrix Systems

Polymer matrices are broadly classified into two primary categories based on their response to heat; thermosets and thermoplastics.

Thermosets are resins that start as a liquid and then undergo an irreversible chemical reaction (curing) to create a rigid, highly cross-linked, three-dimensional network. Once cured, they cannot be remelted or reshaped. They offer excellent dimensional stability, superior thermal and chemical resistance, and strong adhesion to reinforcement fibres. Their high performance and rigidity make them the preferred choice for demanding structural applications in the aerospace, automotive, marine, and construction industries(Diniță *et al*., 2024; Edah *et al*., 2025). In the Fibre Reinforced Polymer (FRP) composites industry, the predominant thermoset resins are polyester, vinyl ester, and epoxy, as illustrated in Figure 1.

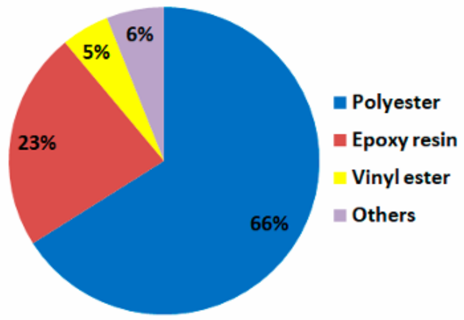

Figure 1: The distribution of thermoset resin in the Fibre Reinforced Polymer Composites (Karim *et al*., 2023)

Polyester dominates the polymer composite market with a 66% share, followed by epoxy at 23% and vinyl ester at 5%. Polyester is favoured for its low cost, ease of use, and fast curing, though its mechanical properties are inferior to epoxy and vinyl ester. Most studies reviewed employed thermoset matrices, including polyester (Lakshmaiya *et al*., 2025), epoxy (Aminah *et al*., 2025; Charles *et al*., 2024), formaldehyde-based resins (Atoyebi *et al*., 2021; Ojewumi *et al*., 2023), and polyurethane(Samaei *et al*., 2023). Few studies used thermoplastics as matrices, including PVC (Anand *et al*., 2025), PE (Ogah *et al*., 2022), PVA (Haghighat *et al*., 2023; Kalasee *et al*., 2025), polypropylene (Krithika *et al*., 2022), and PLA (Bukar *et al*., 2025).

Karim *et al*. (2023) compared the usage of thermoplastic and thermoset materials in the fibre-reinforced polymer market, and the results are shown in Figure 2.

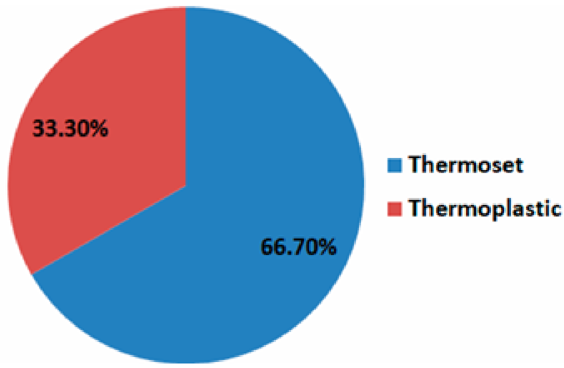

Figure 2: The distribution of the Fibre-reinforced polymer matrix (Karim *et al*., 2023).

3.2 Single Fibre Composites

Recent studies on natural fibre composites highlight the influence of fibre type, size, length, loading, and matrix on acoustic, thermal, and mechanical performance (Kalasee *et al*. (2025), Puyana-Romero *et al*., (2023), Bravo-Moncayo *et al*. (2024), James *et al*. (2025), and Bukar *et al*. (2025)

Acoustic properties: Artayani *et al*., (2024) found that chicken feather fibre composites achieved maximum sound absorption coefficients (SAC) of 0.87, 0.6, and 0.71 in starch, PVC, and no-matrix systems, respectively, due to differences in porosity. Kalasee *et al*. (2025) showed that 30 mm areca nutshell fibres with PVA binder enhanced low-frequency sound absorption, reaching SAC 0.90 above 1600 Hz. Puyana-Romero *et al*., (2023) reported that corn stem fibres improved SAC in plaster composites, with thicker samples (12 mm) performing better at 400–1600 Hz; ANN-based simulations successfully predicted SAC. The higher sound absorption ($\alpha \approx 0.63$) and airflow resistivity ($\sigma = 6750$ Pa·s/m^2) of smaller sugarcane bagasse fibres were explained because of their more homogeneous porous structure, higher specific surface area, and higher airflow resistivity by Haghighat *et al*. (2023). They improved the viscous and thermal dissipation of acoustic energy, and thus the sound absorption, especially at low frequencies.

Thermal properties: Anand *et al*. (2025) optimised coir fibre–reinforced PVC composites for thermal conductivity, achieving 0.801 W/mK at 2 wt% coir, 75 µm powder size, and potassium hydroxide treatment using CSA optimisation. On the other hand, Kandula *et al*. (2022) found that the decrease in thermal conductivity as the fibre volume fraction increases was attributed to the porous cellular structure of the natural fibres, which trapped more air in the composite. Air has very low thermal conductivity, and therefore, it prevents the heat transfer process and increases the thermal insulation ability of the composites. The results show that among the fibres studied, vakka fibre had the lowest thermal conductivity (0.179 W/m·K) due to its better porous microstructure and thermal resistance. The exceptional fire performance of the vakka fibre composite, as observed through its lower peak heat release rate and higher flame retardancy index, correlated with reduced heat transfer and development of a protective char layer that reduced the heat release rate and propagation of combustion. Similarly, Bravo-Moncayo *et al*. (2024) explained that the low thermal conductivity (0.0439–0.0564 W/m·K) of *Musa textilis, Furcraea andina, Cocos nucifera and Schoenoplectus californicus* fibres was due to their low density and high porosity, which resulted from a highly lignocellulosic structure, and the inclusion of entrapped air in their cellular network. These properties enabled high heat-transfer resistance and, therefore, thermal insulation properties comparable to those of conventional synthetic insulation materials. Based on this, the authors suggested that the natural fibres have considerable potential as a source of sustainable thermal insulation materials in building applications. The high thermal stability of the Kevlar-reinforced and 75% Kevlar/25% *Cocos nucifera* sheath (CNS) hybrid composites was attributed by Naveen et al. (2019) to the inherently high thermal stability of Kevlar, the aromatic polyamide structure, and the synergistic effect between Kevlar and the natural fibre. The high content of Kevlar led to a delay in thermal degradation, enhanced char formation, and better fibre–matrix bonding, which reduced polymer chain mobility in the composite and consequently its thermal decomposability. This means that 75% Kevlar/25% CNS hybrid composite had the best thermal behaviour of all the hybrid formulations. Meanwhile, Guna et al. (2025) considered that the low thermal conductivity of gypsum/flax-reinforced composites was due to three reasons: the low thermal conductivity of gypsum, the air-filled pores in the gypsum/flax-reinforced composite and the breakdown of continuous heat transfer paths in the composite. The gypsum used at a content of 6 wt. % resulted in a significant decrease in the thermal conductivity from 0.333 to 0.142 W/m·K. In addition, the better flame resistance was correlated with the release of chemically bound water from the gypsum during the heat, which absorbs heat, delays thermal degradation, and promotes the formation of a protective mineral barrier that reduces the transfer of heat and flame propagation.

Mechanical properties: in a study conducted by James *et al*. (2025) who produced guinea corn fibre–HDPE particle boards, shows that 40 wt% fibre composites met EN 312:2010 standards for general-purpose boards. The optimal tensile strength (28.52 MPa) and flexural strength (77.81 MPa) of Luffa cylindrica–PLA composites at fibre content of 30 wt.% and fibre length of 3 mm is attributed to the optimum combination of fibre content and fibre length that allowed the uniform dispersion of fibres, generation of optimum interfacing between fibres and the polymer matrix, and efficient stress transfer between the two components (Bukar *et al*. 2025). This linkage reduced the occurrence of fibre agglomeration and void formation and increased the load-bearing capacity of the composite. Furthermore, Vadivelvivek *et al*., (2023) explained that the addition of treated Borassus flabellifer sprout fibre to polyester composites led to their increased tensile, flexural, compressive, and impact strengths due to the removal of surface impurities and the increase in the surface roughness of fibres. The treatment allowed transfer of less stress within fibres and between the fibres and the polyester matrix and resulted in less fibre pull-out during loading. In addition, the hydrophilic properties of the fibres were considerably decreased after hemicellulose, lignin and other hydrophilic constituents were removed, thus increasing the dimensional stability of the composites and their water absorption characteristics.

Single fibre reinforced composites have shown great potential, but their ability to achieve three requirements (thermal, acoustic and mechanical) at a time is still limited. Because one natural fibre cannot have all the desirable properties for multifunctional uses, the hybridisation of different fibres is a topic of much research to obtain composites with desirable overall properties.

3.3 Hybrid Composites

A composite is made of two or more different types of reinforcement fibres that are contained in the same matrix. This is called hybridisation and gives the composite properties greater than any of the single fibre composites. It principally aims to achieve a balance between performance and cost, enhance specific properties and customise materials for targeted applications. Studies show that hybrid composites significantly improve performance: for example, banana–glass fibre composites increased sound absorption by 375.96% at a 25:75 ratio (Mondal & Hussain, 2023), while jute-based 3D hybrid composites achieved 44.9 dB noise reduction at 10,000 Hz (Nazari *et al*., 2024). The 44% enhancement in tensile strength and 63% enhancement in impact strength of balanite shell/Palmyra fibre/epoxy hybrid biocomposites were attributed to the synergistic effect of hybrid reinforcement, efficient stress transfer and improved interfacial adhesion between the fibres and the epoxy matrix (Charles *et al*., 2024). The mechanical properties were improved due to the hard balanite shell particles that increased stiffness and load-bearing capacity, and due to the Palmyra fibres, that enhanced toughness through fibre bridging, crack deflection and energy absorption mechanisms. Meanwhile, Aji *et al*., (2012) investigated the thermal stability of hybridised kenaf and pineapple fibre composites using thermogravimetric analysis, and the results revealed that adding natural fibres initially reduced thermal stability compared to pure plastics; hybridisation effectively minimised the rapid degradation seen in single-fibre materials. Aji *et al*. (2011) reported that hybridising kenaf and pineapple leaf fibres in an HDPE matrix improved the impact strength of the composite when appropriate fibre lengths and fibre loadings were employed. The enhancement was attributed to the synergistic interaction between the two fibres, improved stress transfer at the fibre–matrix interface, and increased energy absorption through fibre bridging and pull-out mechanisms during impact loading. Therefore, hybridisation, if properly and adequately done, could lead to a positive effect on the performance properties of the composites (thermal, acoustic and mechanical).

4. Processing and Fabrication Methods

The manufacturing process is essential in converting raw materials, fibres, and matrix into a high-performance composite component. The chosen fabrication method directly affects fundamental characteristics such as fibre orientation, fibre-matrix distribution, void content, and the final shape of the component. The selection of a method depends on factors such as part complexity, production volume, material type (thermoset vs. thermoplastic), and desired performance. For better understanding, a schematic classification of composite manufacturing process techniques was presented in Fig 3, into three main categories, and for each category, the manufacturing process identified is systematically described and compared in Table 1 with respect to the following: processing principle, advantage, limitation and typical engineering applications.

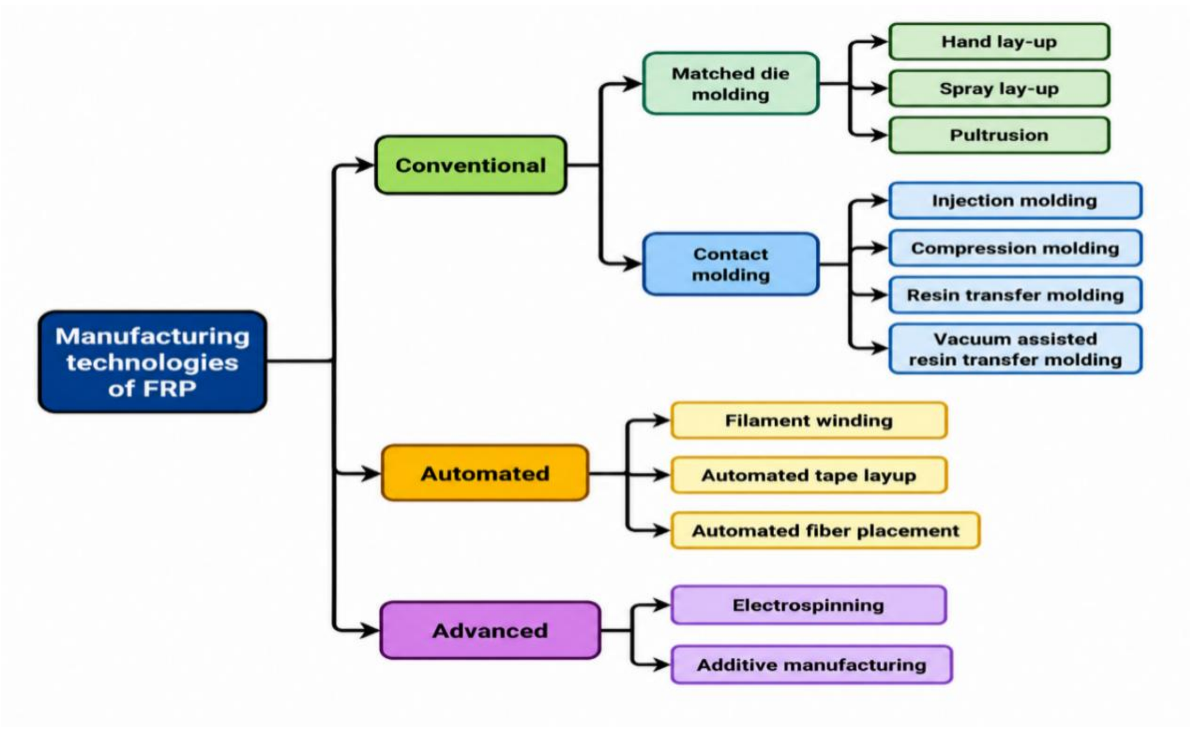

Figure 3: Classification of Fibre-reinforced Polymer manufacturing technologies (Rajak *et al*., 2019).

5. Characterisation and Performance Evaluation

A comprehensive evaluation of the physical, mechanical, thermal, and acoustic properties of bio-composites is essential to determine their suitability for specific engineering applications. Standardised testing provides the quantitative data needed to compare different material formulations, validate processing methods, and ensure that a component will perform reliably and safely in its intended environment. This section reviews the key performance metrics and testing standards cited in the literature for agro-waste biocomposites. Table 2 shows the properties of composites fabricated from agricultural waste fibres. It can be observed from Table 2 that the water absorption of Borassus flabellifer is very high at 47.25%, and this may be due to the high porosity, which is also 35.5%. However, these issues could be ameliorated with strategies such as fibre treatment and hybridisation, as seen in Aji *et al*. (2014).

Table 1: Composites Fabrication Methods

Method	Process Description	Advantages	Disadvantages	Applications
Hand Lay-up	A manual process where layers of fibre mats are placed in an open mold and saturated with liquid resin by hand using brushes or rollers.	Low equipment cost, suitable for large and complex parts, and high design flexibility.	Labour-intensive, potential for quality variation (voids, inconsistent resin content), slow cycle times.	Boat hulls, wind turbine blades, architectural elements, large panels (Diniță *et al*., 2024; Iqbal *et al*., 2024a).
Compression Molding	Pre-mixed fibre and matrix compound (or pre-impregnated sheets) are placed in a heated mold cavity. The mold is closed, and pressure is applied to force the material to fill the cavity and cure.	High production rates for high-volume parts, excellent dimensional accuracy and surface finish, and low waste.	High initial tooling and equipment costs, limited to parts with moderate complexity.	Automotive body panels, furniture components, partition boards (Diniță *et al*., 2024; Iqbal *et al*., 2024a).
Injection Molding	Molten thermoplastic, often pre-compounded with short fibres, is injected under high pressure into a closed mold.	High precision and consistency for complex shapes, fast cycle times, and highly scalable for mass production.	Extremely high initial investment; potential for fibre length degradation; limits on part size due to mold and machine platen constraints.	Small, intricate automotive parts, consumer goods, and office equipment (Ichim *et al*., 2024; Iqbal *et al*., 2024a).
Extrusion	Molten thermoplastic mixed with fibres is forced through a die to create a continuous profile with a constant cross-section.	Continuous production process, low cost for high-volume profiles, good for wood-plastic composites.	Limited to parts with a uniform cross-section (e.g., pipes, decking, window frames).	Decking, fencing, window profiles, pipes (Diniță *et al*., 2024; Ichim *et al*., 2024).
Resin Transfer Molding (RTM)	Dry fibre preform is placed in a closed mold. Liquid resin is then injected under low pressure to impregnate the fibres, followed by curing.	High-quality surface finishes on both sides, good fibre-to-resin ratio, reduced volatile emissions, and can produce complex shapes.	Longer cycle times than compression or injection molding, complex tooling required.	Aerospace components, high-performance automotive parts, and large composite panels (Diniță *et al*., 2024; Iqbal *et al*., 2024b).
Pultrusion	A continuous process where fibres are pulled through a resin bath and then through a heated die, which shapes and cures the composite profile.	Excellent for creating constant cross-section profiles, high fibre alignment leading to remarkably high strength in the pull direction.	Limited to producing parts with a uniform shape (e.g., rods, beams, I-beams).	Structural beams, rods, window and door frames, and electrical components (Diniță *et al*., 2024; Iqbal *et al*., 2024b).

5.1 Mechanical Performance

Mechanical properties refer to the resistance of a material to the application of force, both in terms of deforming the material and failing. These are typically the most significant measures for semi-structural and structural applications. Based on the literature, it is generally accepted that the mechanical properties improve with increasing fibre content up to an optimum point, after which the properties will decrease due to poor wetting and fibre agglomeration (James *et al*., 2025). Flax fibres are found to have high flexural strength (≈62 MPa) and can be used for load-bearing applications (Lakshmaiya *et al*., 2025). The glass fibre reinforcement, however, significantly enhances the tensile strength of banana fibre composites, and multifunctional performance can be achieved (Krithika *et al*., 2022). The summary of the mechanical properties of different agro-waste composites as reported in the literature is shown in Table 3.

Table 2. Properties of Composites Fabricated from Agricultural Waste Fibres with citation (Kılınç & Korkmaz, 2024b; Nithyakalyani *et al*., 2016; Setyanto *et al*., 2024; Singh *et al*., 2021)

Property	Rice Husk	Sugarcane Bagasse	Borassus flabellifer
Physical properties			
Density (g/cm^3)	0.8-1.2	0.7-1.1	0.4-0.6
Water absorption (%)	10-15	12-18	47.25
Porosity (%)	5-10	6-12	35.5
Mechanical properties			
Tensile strength (MPa)	20-40	15-35	22-40
Flexural strength (MPa)	30-50	20-40	54
Impact strength (KJ/m^2)	5-10	4-8	11.6
Acoustic Properties			
Sound Absorption Coefficient	0.6-0.8	0.65-0.85	0.1-0.5
Noise Reduction Coefficient	0.4-0.6	0.5-0.7	0.1-0.3
Thermal Properties			
Thermal conductivity (W/mk)	0.2-0.4	0.18-0.3	0.03-0.04
Heat deflection Temperature (°C)	90-120	70-100	NA
Biological Properties			
Biodegradability (%)	70-90	75-90	
Bacterial resistance	Moderate	Moderate	
Fungal resistance	Moderate	Moderate	

Table 3: Mechanical Properties of Natural Fibre Biocomposite (Jabu *et al*., 2025; Kılınç & Korkmaz, 2024; Manickaraj *et al*., 2025; Singh *et al*., 2021).

Composite Reinforcement	Polymer Matrix	Tensile Strength (MPa)	Flexural Strength (MPa)	Young's Modulus (GPa)
Jute	Epoxy/Polyester/PP	300 – 700	85 – 112	20 – 50
Sugarcane Bagasse	Epoxy/PP	257.3 - 290.5	40 – 60	15 – 18
Wheat Straw	PMMA	58.19	N/A	N/A
Corn Stover	N/A	12 – 22	35 – 55	N/A
Borassus flabellifer	Epoxy	27.28	N/A	N/A
Bamboo	N/A	360.5 - 590.3	45 – 65	22.2 - 54.2

The mechanical properties of the composites from agricultural waste have been observed to be affected by the type of waste, the matrix material and the processing techniques (Kılınç & Korkmaz, 2024).

Ogah *et al.* (2022) studied biocomposites of hot-extruded recycled HDPE reinforced with rice husk, corn cob, walnut shell and wood floors. It was observed that the best performance of wood flour composites was in flexural modulus of 3.0 GPa, impact strength of 60 J/m and flexural strength of 27.4 MPa, which was better than rice husk, corncob, walnut shell composites and the control. The higher bulk densities of RHF, WSF and CCF resulted in agglomeration of the fillers and poor mechanical properties. However, the wood flour had a lower bulk density, which led to better dispersion and better performance of the composites.

Similarly, Velmurugan *et al.* (2023) studied the mechanical, morphological and moisture uptake of composite materials prepared from sugarcane bagasse fibre (SBF), rice husk (RH) and wood powder (WP) fillers using epoxy resin as matrix. The strength of SBF (single fibre) with epoxy composite matrix was 14 MPa to 18 MPa, and the weight was 230 g to 250 g. However, SBF combined with RH and WP showed better strength. The estimated strength was disclosed as 16 to 20 MPa, and the weight was 220 to 240 g.

5.2 Acoustic Insulation Properties

Agro-waste composites are also good at sound absorption. This is due to the porous structure of agro-waste composites, which is an important characteristic for building interiors and automotive cabins to reduce noise pollution. The Sound Absorption Coefficient (SAC) is the ratio of sound energy absorbed by a material at a given frequency, and the Noise Reduction Coefficient (NRC) is the average of SAC values at mid-range frequencies. These are often measured in an impedance tube test following standard methods such as ISO 10534-2 or ASTM E1050 (ISO 10534-2, 2023; Mohammadi *et al*., 2024). Natural fibres have a porous, hollow and cellular microstructure which allows their sound absorption properties. This complex internal structure provides a twisting path for sound waves. During propagation through these micro-channels, energy is lost by viscous losses at the air-fibre interface and conversion to thermal energy, resulting in efficient sound absorption (Rahman *et al*., 2025b). Studies have revealed that density, frequency, thickness of the material, larger overall porosity, and the presence of an air gap behind the composite panel affect the acoustic performance (Mustafa *et al*., 2024; Parikh *et al*., 2025; Amuaku *et al*., 2023). The density of the material is very important for the absorption of sound. The material becomes less porous with the increase in density and decrease in the SAC. Generally, boards with lower density are better sound absorbers (Rao *et al*., 2025).

5.3 Physical Properties and Durability

Physical properties affect the long-term performance, durability of composites, and their suitability for specific applications. This section will focus on certain physical properties of agricultural-waste bio-composites, such as density, water absorption, and fibre size, and discuss how these properties affect their application potential.

a. Density

The low density of natural fibres enables the development of lightweight composites, which is advantageous for automotive and portable applications. Venkatesan *et al.* (2025) showed that paddy straw and coconut coir panels exhibited strong sound absorption at low frequencies (125–1000 Hz), achieving absorption coefficients of 0.59 and 0.52 at 1000 Hz, respectively, while wastepaper performed less effectively. Density had only a limited influence on improving absorption, and hybridisation was not explored. Similarly, Rao *et al.* (2025) reported that low-density agro-residue particle boards (300 kg/m^3) provided optimal sound absorption and lowest thermal conductivity, with coir-based boards showing superior acoustic performance and rice straw exhibiting the lowest thermal conductivity (0.098 W/m·K); increasing density reduced sound absorption but increased thermal conductivity, with no hybrid boards considered. Febriyanti *et al.* (2024) found that density influenced acoustic behaviour, as processed disposable face masks demonstrated notable sound absorption, with folded peach-coloured masks reaching a maximum coefficient of 0.70 at 400 Hz.

b. Water Absorption

Another critical problem in natural fibre composites is water absorption and thickness swelling, which causes dimensional instability, mechanical degradation and short service life in humid conditions (Ogah *et al*., 2022). A study by James *et al*., (2025) revealed that the moisture uptake of composites increases with the presence of fibre content and with the presence of short fibre compared to long fibre; the hydrophilic nature of natural fibre is the cause of this phenomenon. Similarly, Singh *et al*., (2023) reported that hemp/epoxy composite has more moisture uptake than long/epoxy fibre composite. The rise in water absorption from 1.81% to 4.17% as the corn husk fibre loading increased was attributed to the hydrophilic nature of the fibres which are referred to as lignocellulosic fibres and contain high hydroxyl groups that absorb moisture in the absorbent (Nkomo and Alugongo 2024). An increase in fibre loading also reduced the composite density, increased porosity, void content and number of fibres–matrix interfaces, leading to increased water ingress and retention inside the composite. To minimise these effects, surface treatments like alkali, acetylation and silane treatments have been commonly employed, which decrease the hydrophilicity of the fibres, increase fibre–matrix bonding and increase the long-term durability (Hosseini *et al*., 2023).

c. Fibre Size and Loading

The size of fibres (fineness) in natural fibre composites, usually in the form of diameter or linear density in micrometres, is one of the important parameters that affects the performance of natural fibre composites. Studies have revealed that small or short fibres generally improve the properties of composite materials: Haghighat et al. (2023) reported that smaller sugarcane bagasse fibres result in better sound absorption and airflow resistance; Singh et al. (2023) found that short hemp fibres showed better acoustical properties at low frequencies. Bukar *et al.* (2025) reported that shorter fibres of hemp (1 mm) showed better tensile modulus properties. The superior performance of shorter natural fibres is mostly due to better dispersion, strong bonding between fibres and matrix, no fibre agglomeration and voids, increased surface area between the fibre and the matrix, and better processability. The shorter fibres also result in higher airflow resistivity and more sound energy dissipation in acoustic applications as they form a more tortuous pore network. However, the optimum fibre length depends on the material and application, and if the critical fibre length for efficient stress transfer is not obtained, the reinforcement efficiency could be compromised if the fibres are too short.

5.4 Particle/ Fibre Boards

A board is a long, broad, and thin piece of any material; wood is similarly used in building or furniture manufacturing**.** Particleboards are divided into seven categories based on their characteristics. The SFS-EN 312 standard is used to define the characteristics of particle board classes across Europe. Particleboard classes are denoted by the letter 'P' followed by a number from 1 to 7. Table 4 shows a summary of the typical target property requirements for particleboard grades P1–P7 based on EN 312,

Table 4: Board grades and their minimum property requirement (Ramshankar *et al.,* 2021)

Property	P1	P2	P3	P4	P5	P6	P7
Density (kg/m³)	550–700	600–750	600–750	650–800	650–800	700–850	700–850
Water absorption (24 h, %)	<70	<60	<40	<35	<25	<20	<15
Thickness swelling (24 h, %)	Not specified	≤17	≤14	≤15	≤10	≤13	≤9
Tensile strength (MPa)	5–8	7–10	8–12	10–15	12–18	15–20	18–25
Flexural strength (MOR, MPa)	≥10.5	≥11	≥15	≥16	≥18	≥20	≥22
Flexural modulus (MOE, MPa)	≥1600	≥1800	≥2050	≥2300	≥2550	≥3150	≥3350
Internal bond (MPa)	≥0.28	≥0.40	≥0.45	≥0.35	≥0.45	≥0.40	≥0.50
Impact strength (kJ/m²)	2–3	3–4	3–5	4–6	5–7	6–8	7–10
Thermal conductivity (W/m·K)	0.10–0.18	0.10–0.18	0.10–0.17	0.10–0.17	0.10–0.16	0.10–0.15	0.10–0.15
Sound absorption coefficient (NRC)	0.10–0.20	0.15–0.30	0.20–0.35	0.20–0.40	0.25–0.45	0.30–0.50	0.35–0.60

Several studies have explored particle boards made from agricultural waste and natural fibres with various binders in Tamarin *et al.* (2023), Atoyebi *et al.* (2021), Rao *et al.* (2025) , and Ojewumi *et al.* (2023)).

Corn cob and sawdust boards were fabricated using a melted water sachet as a binder by Atoyebi *et al.* (2021), but the boards did not comply with the mechanical requirements (MOR, MOE) and were only suitable for non-structural applications. Tamrin *et al.* (2023) prepared rice husk–PVA board and found that the density and thickness swelling of the boards slightly increased after 6 weeks of indoor/outdoor exposure, while IB, MOR and MOE decreased with moisture absorption; the lack of alkali treatment caused the water resistance to be poor. Ojewumi *et al.* (2023) successfully created hybrid boards using cassava starch or urea formaldehyde as a binder for corn cob and sugarcane bagasse, where the type of binder and mixing ratio significantly influenced water absorption and swelling, with cassava starch being more environmentally friendly and reducing indoor pollution. Atoyebi *et al.* (2021) Conducted another work on coconut shell, husk, and palm kernel shell boards, which indicated that when the amount of the husk was increased, the water absorption also increased, while the mechanical properties were found to be poor due to the lack of any particle treatment. Similarly, Rao *et al.* (2025) investigated the effect of density on acoustic and thermal properties of Low-Density Particle Boards (LDPB) made from agro residues. The particle boards were manufactured from agro-residues (sugarcane bagasse, rice straw, wheat straw, and coir fibres) using melamine-urea-formaldehyde resin as a binder. The boards were produced at densities of 300, 400, and 500 kg/m³. The study involved a range of physical, mechanical, and acoustic tests: Modulus of Rupture (MOR), thickness swelling, water absorption, Sound Absorption Coefficient (SAC), Noise Reduction Coefficient (NRC), and thermal conductivity. The result showed coir-based boards exhibited superior sound absorption properties, particularly at higher frequencies, and showed the highest Modulus of Rupture (MOR) values. At lower densities (300 kg/m³), the boards demonstrated the best sound absorption and lowest thermal conductivity, with rice straw showing the lowest thermal conductivity (0.098 W/m-K). However, increasing the density of the boards resulted in reduced sound absorption but increased thermal conductivity. There was no mention of hybrid-based boards in the study.

6. Industrial Applications and Case Studies

The combination of desirable attributes in agro-waste biocomposites, including low density, improved mechanical strength, and good thermal and acoustic insulation, along with sustainability credentials, has facilitated their entry into multiple industrial sectors. These composites are proving to be viable alternatives to conventional materials, from reducing vehicle weight to creating eco-friendly building materials. This section highlights established and emerging applications supported by specific case studies.

1. Automotive Industry

The Ford Motor Company has been a trailblazer utilising agricultural waste, incorporating materials such as coconut shells, rubber from waste tyres, and wheat straw into components, including battery housing, structural guards, lightweight armrests, applique brackets, door cladding, and storage bins. (Jabu *et al*., 2025; Phiri *et al*., 2023). For natural fibre-reinforced polymer composites used in the automotive interior components (door panels, dashboards, seat backs, etc.), there is no single international standard that specifies minimum property requirements. Instead, automotive manufacturers establish their own specifications based on internationally recognised ASTM, ISO, SAE, and FMVSS test standards. Plate 1 shows some automobile parts fabricated from natural fibre composites. However, published literature and OEM specifications indicated the following minimum property requirements for natural fibre composites intended for automotive interior applications, as shown in Table 5.

Plate 1: Agricultural waste-based composite components utilised in automotive interiors (Patel *et al*., 2023)

Table 5: Minimum Property Requirements for Natural Fibre-Reinforced Composites for Automotive Interior Applications

Property	Minimum Requirement	References
1. **Tensile Strength**	25-50 MPa	Jabu *et al*., 2025
2. **Tensile Modulus**	2-5 GPa	Patel *et al*., 2023
3. **Flexural Strength**	50-100MPa	Phiri *et al*., 2023
4. **Flexural Modulus**	2.5-6 GPa	Kudva *et al.,* 2022
5. **Density**	$<1.30 g/cm^3$	Naik *et al.,* 2022
6. **Impact Strength**	$20-50 kJ/m^2$	Phiri *et al*., 2023
7. **Hardness**	60-80 Shore D	Jabu *et al*., 2025
8. **Water Absorption**	≤5%	Jabu *et al*., 2025
9. **Thermal conductivity**	0.03-0.20 W/m.K	Velmurugan *et al.,* 2023
10. **Sound Absorption**	≥0.30	Venkatesan *et al.,* 2025

2. Furniture and consumer goods

Application: Designers and manufacturers are increasingly exploring composites made from wheat straw, pineapple leaf fibres, and even mycelium (fungi's root structure) grown on agricultural waste. These materials are used to create lightweight, durable, and fire-resistant furniture with a strong environmental narrative. (Kılınç & Korkmaz, 2024). Plate 2 shows some furniture made from natural fibre composites.

3. Packaging

Application: Development of biodegradable and compostable food packaging, containers, films, and disposable cutlery. PLA-based composites reinforced with various agricultural fibres are being developed to provide the moisture and oxygen barrier properties required to maintain food freshness. Unlike conventional plastics, these materials are designed to decompose in industrial composting facilities, returning nutrients to the soil and closing the material loop (Kılınç & Korkmaz, 2024). Plate 3 shows packaging items made from natural fibre composites.

Plate 2: Fibreboard from Rice Straw for Furniture and Furniture Manufacturing (Singh *et al*., 2021).

Plate 3: The biodegradable materials in packaging applications (Kılınç & Korkmaz, 2024)

7. Research Gaps

The existing literature reveals a limited number of studies investigating the development of multifunctional agro-waste-based composites with tailored structural, thermal, and acoustic properties for applications in the automotive, furniture, and thermal insulation industries. Although several researchers have reported the development of hybrid biocomposites reinforced with different combinations of natural fibres, no documented study has been identified that explores the use of hybrid rice husk and Palmyra fruit fibre as reinforcement in a polypropylene matrix. Moreover, previous studies have mainly examined polymer matrices such as epoxy, polyvinyl acetate, polylactic acid, polyester and melamine urea-formaldehyde resins, whereas polypropylene, polyvinyl chloride or vinyl ester resins have been rarely or not reported for rice husk-Palmyra fruit fibre hybrid biocomposites. This represents a significant knowledge gap, since these polymers, especially polypropylene, have attractive properties such as low density, low cost, ease of processing, good chemical resistance and recyclability and can be promising matrices for the development of sustainable multifunctional biocomposites. To fill these gaps, our current research will focus on developing and characterising Hybrid rice husk–Palmyra fruit fibre reinforced polypropylene biocomposites prepared by melt blending and compression moulding. It will examine the modification of physical, mechanical, thermal, acoustical and morphological properties of the composites due to fibre treatment, fibre hybridisation, and optimises the composition of the fibre composites for achieving multifunctional properties.

7.1 Future Trend

Biocomposites derived from agricultural waste provide a sustainable route for valorising agro-waste and reducing fossil-fuel dependence, but their full potential is limited by several challenges. These include the need for fibre surface treatments to improve matrix compatibility, limited moisture resistance and fire retardancy and the variability in natural fibre properties which affect product consistency. In addition, uniform fibre dispersion and optimisation of automated manufacturing processes remain critical to industrial scale-up. Specific research, hybridisation of agro-waste fibres to enhance multifunctional properties, and use of advanced computational modelling to fast-track design and optimisation of materials for construction and automotive applications would be necessary to future advances.

8. Conclusion

The literature reviewed in this study has indicated that hybrid biocomposites based on agricultural waste have great potential to be used as sustainable alternatives to conventional synthetic composites. This is because agro-waste fibres such as rice husk, sugarcane bagasse, and coconut coir are abundant, renewable, low-cost, and have favourable mechanical, thermal and acoustic properties. However, their extensive use is still limited with problems such as moisture absorption, variations in fibre properties, poor interfacial bonding between the fibre and matrix and difficulties in large-scale production. It is suggested that these problems can be overcome using appropriate fibre surface treatments, optimisation of processing parameters and by selective hybridisation of compatible natural fibres. More importantly, there is a remarkable research gap in the development of multifunctional hybrid biocomposites reinforced with rice husk and Palmyra fruit fibre, as evidenced by the literature, especially using polypropylene as the polymer matrix. Earlier studies have mainly dealt with thermosetting matrices such as epoxy, polyester, polylactic acid, polyvinyl acetate and melamine urea-formaldehyde, while polypropylene, which is characterised by low density, easy processing, recyclability and cost-effectiveness, has been ignored or received little attention. Thus, the development, optimisation and characterisation of hybrid rice husk–Palmyra fruit fibre reinforced polypropylene biocomposites constitute a timely and promising research direction to produce sustainable multifunctional materials for structural, thermal and acoustic engineering applications.

References

Aji, IS., Zainudin, ES., Moh, S., Khalina, A., & Zaman Khairul, D. 2014. Effect of Fibre/Matrix Modification on Tensile Properties and Water Absorption Behaviour of Hybridised Kenaf/PALF Reinforced HDPE Composite. *Research And Review Journal of Engineering and Technology*, *3*(3), 1–8.

Aji, IS., Zainudin, ES., Khalina, A., Sapuan, SM., & Khairul, MD. 2011. Studying the effect of fiber size and fiber loading on the mechanical properties of hybridized kenaf/PALF-reinforced HDPE composite. *Journal of Reinforced Plastics and Composites*, *30*(6), 546–553.

Aji, IS., Zainudin, ES., Khalina, A., Sapuan, SM., & Khairul, MD. 2012. Thermal property determination of hybridized kenaf/PALF reinforced HDPE composite by thermogravimetric analysis. *Journal of Thermal Analysis and Calorimetry*, *109*(2), 893–900.

Aminah, S., Malek, A., Amizah, W., & Jusoh, W. 2025. *Improvement of Sound Acoustic and Compressive Strength of Hybrid Polymer Composites (HPCs)*. *6*(1), 363–375

Amuaku, RK. Amanor, G., Adu-Gyamfi, F., Amoah Asante, E., Kweitsu, E., & Opare, S. 2023. Development and Evaluation of Agro-waste Composite for sound insulation. *Journal of the Ghana Institution of Engineering (JGhIE)*, *23*(4), 99–105.

Anand, S., Gopalan, V., & Pitchumani, SV. 2025. Optimization of Thermal Conductivity in Coir Fibre-Reinforced PVC Composites using Advanced Computational Techniques. *Scientific Reports*, *15*(1):1-21.

Artayani, M., Kusno, A., Mulyadi, R., & Jamala, N. 2024. A Study of The Sound Absorption Properties of Layered Composites on Chicken Feather Fibers. *Journal of Physics: Conference Series*, *2721*(1):1-7.

Atoyebi, OD., Aladegboye, OJ., & Fatoki, FO. 2021. Physico-Mechanical Properties of Particle Board made from Coconut Shell, Coconut Husk and Palm Kernel Shell. *IOP Conference Series: Materials Science and Engineering*, *1107*(1):1-10.

Atoyebi, OD., Orogbade, BO., Aladegboye, OJ., & Adebiyi, JA. 2021. Strength evaluation of agro waste particle board with melted pure water sachet as the binding agent. *IOP Conference Series: Materials Science and Engineering*, *1036*(1):1-11.

Bhuvaneswari, V., Devarajan, B., Arulmurugan, B., Mahendran, R., Rajkumar, S., Sharma, S., Mausam, K., Li, C., & Eldin, E. T. 2022. A Critical Review on Hygrothermal and Sound Absorption Behavior of Natural-Fiber-Reinforced Polymer Composites. *Polymers*, 14(21):1-25.

Bravo-Moncayo, L., Argotti-Gómez, M., Jara, O., Puyana-Romero, V., Ciaburro, G., & Guerrero, VH. 2024. Thermo-Acoustic Properties of Four Natural Fibers, Musa textilis, Furcraea andina, Cocos nucifera, and Schoenoplectus californicus, for Building Applications. *Buildings*, *14*(8): 1-25.

Bukar, M., Aji, I. S., Mshelia, ZA., & Hammajam, AA. 2025. Effects of Fibre Length and Fibre Loading on Tensile and Flexural Properties of Luffa Cylindrica Reinforced Polylactic Acid Composite. *AZOJETE*, *21*(1): 309–317.

Charles, D., Aji, IS., & Mshelia, ZA. 2024. Effect of Particle and Fibre Loading on Tensile, Flexural and Impact Properties of Hybridized Balanite Shell Particles and Palmyra Fibre Reinforced Epoxy Composite. *AZOJETE*, *20*(4): 891–902.

Diniță, A., Ripeanu, RG., Ilincă, CN., Cursaru, D., Matei, D., Naim, RI., Tănase, M., & Portoacă, AI. 2024. Advancements in Fiber-Reinforced Polymer Composites: A Comprehensive Analysis. In *Polymers, 16(1): 1-50.*

Edah, GO., Atiba, JO., & Fayomi, OSI. 2025. Advancements in Fibre-Reinforced Polymers: Properties, Applications (A mini review). *Next Materials*, *8: 1-13.*

Etemadinezhad, S., Samaei, SE., Taban, E., & Faridan, M. 2022. Experimental and Theoretical Investigation of the Acoustic Absorbers Fabricated from Natural Kenaf Fibres and Rice Husk. *Journal of Natural Fibers*, *19*(16), 15045–15057.

Febriyanti, D., Arifa, SL., Aryani, SM., & Priliana, SCP. 2024. The Density Effect on Disposable Mask Waste as an Acoustic Absorber Material. *IOP Conference Series: Earth and Environmental Science*, *1404*(1): 1-9.

Gboe, NA., Ružickij, R., & Grubliauskas, R. 2024. Exploring the Sound Absorption Characteristics of Biodegradable Agricultural Wastes, Coconut Fiber, Groundnut Shell, and Sugarcane Fiber. *Environmental and Climate Technologies*, *28*(1): 940-951.

Guna, VCB., Chakraborty, S., & Guna, RA. 2025. Gypsum/flax reinforced composites with enhanced strength, thermal conductivity, sound absorption and flame resistance. *Emergent Materials*.1-12.

Haghighat, M., Samaei, SE., Amininasab, S., Faridan, M., Mehrzad, S., Sheikhmozafari, MJ., & Taban, E. 2023. The Impact of Fiber Size on the Sound Absorption Behavior of Composites Made from Sugarcane Bagasse Wastes Fibers. *Journal of Natural Fibers*, *20*(1): 1-16.

Hosseini, SB., Gaff, M., Li, H., & Hui, D. 2023. Effect of Fibre Treatment on Physical and Mechanical Properties of Natural Fibre-Reinforced Composites: A review. *Reviews on Advanced Materials Science*, *62*(1): 1-17.

Ichim, M., Muresan, EI., & Codau, E. 2024. Natural-Fiber-Reinforced Polymer Composites for Furniture Applications. In *Polymers, 16(22): 1-36.*

Iqbal, RM., Ahammad, R., Arifuzzaman, M., Islam, MS., & Islam, MM. (2024a). *Manufacturing and Properties of Jute Fiber Reinforced Epoxy Composites—A Comprehensive Review*.1-55.

ISO 10534-2. 2023. *Acoustics-Determination of Acoustic Properties in Impedance Tubes-Part 2: Two-microphone Technique for Normal Sound Absorption Coefficient and Normal Surface Impedance*.

Jabu, MA., Alugongo, A., & Nkomo, N. 2025. A Review of the Potential Applications of Composites from Agricultural Waste. In *International Journal of Engineering Trends and Technology*, 77(1):183–191

James, E., Aji, IS., & Dauda, M. 2025. Physical Properties of Guinea Corn Stalk Fibre Reinforced High-Density Polyethylene (HDPE) Composite for the Production of Particle Board. *AZOJETE*, *21*(1): 286–293.

Kalasee, W., Eakvanich, V., Rachsiriwatcharabul, N., Wattana, W., Dangwilailux, P., & Lakachaiworakun, P. 2025. Sound Absorption Properties of Natural Fiber Composite from Areca Nut Shells Fibers with Polyvinyl Alcohol. *Journal of the Korean Wood Science and Technology*, *53*(2): 105–118.

Kandula, R., Sanaka, SP., Ratna, RP., & Reddy, KH. 2022. Thermo-physical and Fire Properties of Natural Fiber Composites for Energy Saving Applications. *Journal of Natural Fibers*, *19*(15): 11845–11857.

Karim, AM., Abdullah, MZ., Deifalla, FA., Azab, M., & Wakar A. 2023. An Assessment of the Processing Parameters and Application of Fibre-Reinforced Polymer FRPs in the Petroleum and Natural Gas Industries: A Review. *Results in Engineering*, *18*, 1–20.

Kavun, Y., & Eken, M. 2024. Investigation of thermal, acoustic, mechanical, and radiation shielding performance of waste and natural fibers. *Applied Radiation and Isotopes*, *214*:1-13

Kılınç, I., & Korkmaz, M. 2024. *Agricultural Waste-Based Composite Materials: Recycling Processes, Technical Properties, and Industrial Applications*. *14*(2): 136-145.

Krithika, SMU., Mani, K., Thangavelu, SK., Bharathi, CM., Saravanan, K., & Prakash, C. 2022. Investigation of the Physical Properties and Acoustic Performance of Composites Developed from Natural Fibres. *AATCC Journal of Research*, *9*(4), 213–220.

Kudva, A., Mahesha, G., & Dayananda PK. 2022. Physical, Thermal, Mechanical, Sound Absorption and Vibration Damping Characteristics of Natural Fiber Reinforced Composites and Hybrid Fiber Reinforced Composites: A review. *Cogent Engineering,* 9:1-30.

Lakshmaiya, N., Udhayakumar, G., Sathiyamurthy, S., Nadh, VS., Maranan, R., & Mammo, WD. 2025. Multi-functional Natural Fibre Composites using Flaxseed and Cotton: Tailoring Acoustic, Mechanical, and Thermal Properties for Eco-friendly Applications. *Discover Applied Sciences*, *7*(8): 1-19.

Lekshmi, MS., Vishnudas, S., & Anil, KR. 2023. Experimental investigation on acoustic performance of coir fiber and rice husk acoustic panels. *Applied Acoustics*, *204*: 1-12.

Manickaraj, K., Thirumalaisamy, R., Palanisamy, S., Ayrilmis, N., Massoud, EES., Palaniappan, M., & Sankar, SL. 2025. Value-added utilization of agricultural wastes in biocomposite production: Characteristics and applications. In *Annals of the New York Academy of Sciences*, 1549(1): 72–91.

Mohammadi, M., Taban, E., Tan, W. H., Che Din, N. Bin, Putra, A., & Berardi, U. 2024. Recent Progress in Natural Fibre Reinforced Composites as Sound Absorber Material. *Journal of Building Engineering*, *84*: 1-30.

Mondal, MS., & Hussain, SZ. 2023. Banana-Glass Fiber Composite for Acoustic Insulation and Prediction of Its Properties by Fuzzy Logic System. *Journal of Natural Fibers*, *20*(2):1-18.

Mustafa, E., Mohamed, HK., Hashima, WA., & Abd El-Aziz, MY. 2024. Acoustic and thermal performance of home furnishings made of blended cotton-jute fabrics. *Journal of Industrial Textiles*, *54*: 1-29.

Naik, V., Kumar, M., & Kaup, V. 2022. A Review on Natural Fiber Composite Material in Automotive Applications. *Engineered Science,* 18:1-10.

Nazari, S., Ivanova, T. A., Mishra, RK., Müller, M., Akhbari, M., & Hashjin, ZE. 2024. Effect of Natural Fiber and Biomass on Acoustic Performance of 3D Hybrid Fabric-Reinforced Composite Panels. *Materials*, *17*(23): 1-19.

Nithyakalyani, P., Dhandapani, N., & Murugan, AM. 2016. *Experimental Investigation of Propertiesand Sound Absorption Test on Reinforced Composite Material of Raw Palmyra Fiber*, 4(6): 1664-1670.

Nkomo, NZ., & Alugongo, AA. 2024. Development and Characterization of Mechanical and Acoustic Properties of a Corn Husk/Fly Ash Hybrid Composite Board. *International Journal of Engineering Trends and Technology*, *72*(9): 384–389.

Ogah, AO., Ezeani, OE., Nwobi, SC., & Ikelle, II. 2022. Physical and Mechanical Properties of Agro-Waste Filled Recycled High-Density Polyethylene Biocomposites. *South Asian Research Journal of Engineering and Technology*, *4*(4): 55–62.

Ojewumi, ME., Ojewumi, EO., Ibrahim, OO., Oyinlola, OR., Oladapo, FO., & Jolayemi, KJ. 2023. Production of Particleboard from Agricultural Waste - A Sustainable Approach to Waste Management. *Journal of Sustainable Materials Processing and Management*, *3*(2): 72-90.

Parikh, HH., Rana, H., Raj, A., & Joseph Gbadeyan, O. 2025. Acoustic Performance of Coir Fibre-Reinforced Starch-Based Bio Composites. *Composites and Advanced Materials*, *34*: 1–11.

Patel, RV., Yadav, A., & Winczek, J. 2023. Physical, Mechanical, and Thermal Properties of Natural Fiber-Reinforced Epoxy Composites for Construction and Automotive Applications. *Applied Sciences, 13: 1-28.*

Phiri, R., Mavinkere Rangappa, S., Siengchin, S., Oladijo, OP., & Dhakal, HN. 2023. Development of Sustainable Biopolymer-Based Composites for Lightweight Applications from Agricultural Waste Biomass: A Review. *Advanced Industrial and Engineering Polymer Research*, *6*(4): 436–450.

Puyana-Romero, V., Jaramillo Cevallos, WA., & Ciaburro, G. 2023. Simulation of Acoustic Properties of Plaster Matrix Composite Material Reinforced with Corn Stem Fibers. *Fibers*, *11*(3): 1-21.

Rahman, MA., Ndiaye, M., Weclawski, B., & Farrell, P. 2025a. Palmyra Palm Shell (Borassus flabellifer) Properties Part 2: Insights into its Thermal and Mechanical Properties. *Engineering Reports*, *7*(3):1-16.

Rahman, MA., Ndiaye, M., Weclawski, B., & Farrell, P. 2025b. Palmyra Palm Shell (Borassus flabellifer) Properties Part 3: Insights into its Morphological, Chemical, and Thermal Properties After Alkali Treatment. *Engineering Reports*, 7(4): 1-13.

Rajak, DK., Pagar, DD., Kumar, R., & Pruncu, CI. 2019. Recent progress of reinforcement materials: A comprehensive overview of composite materials. *Journal of Materials Research and Technology*, *8*(6): 6354–6374.

Ramshankar, P., Sukumar, B., Kumar, SK., Karan, V., & Karthick, C. 2021. Experimental Investigation on Sound Absorption Property of a Panel Board Using Maize Stem. *Journal of Physics: Conference Series*, *2070*(1): 1-9.

Rao, CMK., Sheshagiri, BM., Ramamoorthy, velayutham R., Amvan, M., Nandanwar, A., Vijayakumar, P., Avudaiappan, S., & Guindos, P. 2025. Effect of Density on Acoustic and Thermal Properties of Low-Density Particle Boards Made from Agro Residue: Towards Sustainable Material Solutions. *BioResources*, *20*(1): 601–624.

Samaei, SE., Berardi, U., Asilian Mahabadi, H., Soltani, P., & Taban, E. 2023. Optimisation and Modelling of the Sound Absorption Behaviour of Polyurethane Composite Foams Reinforced with Kenaf Fibre. *Applied Acoustics*, *202*:1-12.

Samaei, SE., Mahabadi, HA., Mousavi, SM., Khavanin, A., Faridan, M., & Taban, E. 2022. The Influence of Alkaline Treatment on Acoustical, Morphological, Tensile and Thermal Properties of Kenaf Natural Fibres. *Journal of Industrial Textiles*, *51*(5): 8601-8625.

Setyanto, RH., Herdiman, L., Susmartini, S., & Rohman, T. 2024. Acoustic sound absorbing material and mechanical properties made from rice husk ash and bagasse reinforced glutinous glue. *AIP Conference Proceedings*, *2838*(1):

Singh, G., Gupta, MK., Chaurasiya, S., Sharma, VS., & Pimenov, DY. 2021. Rice straw burning: a review on its global prevalence and the sustainable alternatives for its effective mitigation. *Environmental Science and Pollution Research*, *28*(25): 32125–32155.

Singh, JK., Rout, AK., & Kumari, K. 2021. A Review on Borassus Flabellifer Lignocellulose Fibre Reinforced Polymer Composites. *Carbohydrate Polymers*, 262:1-13.

Singh, R., Nayak, S., Hegde, S., & Padmaraj, NH. 2023. Influence of Fibre Length and Moisture Content on Sound and Vibration Characteristics of Hemp/Epoxy Composite. *Journal of Applied Engineering Science*, *21*(3): 957–962. 2

Tamrin, FP., Rahmad HP., Jonesman, S., & Edison S. 2023. Properties changes of rice husk-particleboard during indoor and outdoor exposure. *World Journal of Advanced Research and Reviews*, *20*(3): 1334–1340.

Vadivelvivek, V., Natarajan, N., Nijandhan, K., & Boopathi, C. 2023. Investigation of Mechanical Performance of Borassus Flabellifer Sprout Fibre Reinforced Polymer Composites. *Cellulose Chemistry and Technology, 57*(6): 637–644.

Valipour, F., Taban, E., Samaei, SE., Pourtaghi, G., & Konjin, ZN. 2022. Improvement of Natural Fibres' Properties and Evaluation of its Applicability as Eco-friendly Materials in Noise Pollution Control. *Journal of Environmental Health Science and Engineering*, *20*(2): 647–656.

Velmurugan, G., Karunakaran, P., Sampath, PS., & Varahamoorthi, R. 2023. Experimental Study of Sugarcane Bagasse Fiber with Rice Husk and Wood Powder Polymer Matrix Composite. *Journal of Natural Fibers*, *20*(2): 1-19.

Venkatesan, B., Kannan, V., Priya, RP., & Shenbagam, KN. 2025. Utilizing Agricultural Waste Materials for the Development of Sustainable Sound Absorption Materials. *Nature Environment and Pollution Technology*, *24*: 285–394.