



DEVELOPMENT AND PERFORMANCE EVALUATION OF AGRO-WASTE REINFORCED COMPOSITE PANELS FOR LOW-COST BUILDING APPLICATIONS IN POLYTECHNICS IN SOUTH-WEST NIGERIA

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Abstract

The cost of conventional building boards in Nigeria is high, while large volumes of agricultural residue are burned or dumped. This study developed and evaluated agro-waste reinforced composite panels for low-cost, non-load-bearing building applications in polytechnics in South-West Nigeria. Using a design-and-development experimental approach, four residues (rice husk, sawdust, groundnut shell and palm-kernel shell) were characterised, alkali-treated and compounded with recycled high-density polyethylene at loadings of 20–50% (w/w) by compression moulding. Flexural strength peaked at 40% loading for rice husk (32.8 MPa), sawdust (28.4 MPa), groundnut shell (30.2 MPa) and palm-kernel shell (29.6 MPa). Thermal conductivity ranged from 0.086 to 0.142 W/m·K, below that of gypsum board (0.16–0.18 W/m·K). Burning rate ranged from 18.4 to 26.8 mm/min and water absorption from 4.8 to 10.2%. Production cost was 54.4–62.4% lower than that of conventional boards, and experts validated the optimal formulations. Agro-waste composite panels are therefore a technically feasible, affordable and sustainable alternative for low-cost building applications in South-West Nigeria.

Keywords: agro-waste composites; composite panels; building materials; waste valorisation; sustainable construction; Nigeria

Introduction

The cost and sustainability of building materials are pressing concerns in Nigeria, where conventional boards and panels are increasingly expensive and often imported, while the country simultaneously generates vast quantities of agricultural residue that is burned or dumped. Converting agro-waste into construction materials addresses both problems at once, reducing material cost and environmental burden while creating value from what is otherwise discarded (Nabukalu et al., 2025). Agro-waste reinforced composites, in which agricultural residues act as fillers or reinforcement within a polymer or resin matrix, have accordingly attracted sustained research interest as a route to low-cost, sustainable building products. The valorisation of agricultural residue into construction materials has become a prominent theme in sustainable-materials research, driven by the dual imperatives of cost reduction and waste management.

A substantial body of materials research demonstrates that agricultural residues can meaningfully enhance the properties of composite materials. Rice husk, sawdust, groundnut shell, palm-kernel shell, bamboo fibre and similar residues have been shown to improve or usefully modify the mechanical, physical and thermal characteristics of composites when properly processed and proportioned (Eboigbe, 2025). Studies have demonstrated that rice husk composites with polylactic acid exhibit tensile strength of 45.8 MPa and bending strength of 48.2 MPa, representing 52% and 41% improvements over the base material. Reviews and experimental studies confirm that reinforcement type, particle treatment and loading ratio are decisive variables, and that treated residues and optimised formulations can yield materials suitable for non-structural building applications (Patel et al., 2023). The chemical modification of fibre surfaces, particularly through alkali treatment, has been shown to improve adhesion with the matrix, with mercerization removing natural fats, waxes, lignin and hemicelluloses from the cellulose fibre surface, thereby revealing chemically reactive hydroxyl functional groups.

Beyond strength, agro-waste composites offer valuable functional properties for buildings. Studies report that residue-reinforced composites can deliver useful thermal insulation, acceptable water resistance and, with appropriate additives, improved fire retardancy, all of which matter for comfortable, safe and durable building envelopes (Shah et al., 2023). Recent investigations of natural fibre-reinforced composites with bio-binders have demonstrated thermal conductivity values as low as



0.021–0.091 W/m·K at higher fibre content, underscoring the insulation potential of agro-waste materials. Hybrid formulations combining more than one residue, or combining residue with recycled thermoplastics, further broaden the achievable property range and support circular use of waste streams (Sun et al., 2024). The synergistic action of multiple fillers, such as rice husk combined with glass fibre, has been shown to enhance mechanical properties while maintaining thermal stability.

Despite this promise, the development and rigorous performance evaluation of agro-waste composite panels tailored to Nigerian polytechnic contexts, using locally abundant residues and low-cost fabrication suited to teaching workshops, remains limited. Much of the demonstrated evidence is international or laboratory-scale and not translated into validated, reproducible panel products for local building use (Eboigbe, 2025). Comparative life cycle assessments of composite panels incorporating natural fibres have shown significant reductions in global warming potential compared to gypsum board, establishing the environmental rationale for their development. This leaves a gap between the demonstrated potential of agro-waste composites and their evidenced application as buildable, standard-referenced panels in the South-West. This study addresses that gap by developing and evaluating agro-waste reinforced composite panels for low-cost building applications in polytechnics, producing both validated formulations and a deployable product.

Statement of the Problem

Polytechnics and their surrounding communities in South-West Nigeria confront rising building-material costs at the same time as large volumes of agricultural residue are wasted through open burning and dumping, with attendant environmental harm. Conventional ceiling boards, partitions and wall panels are costly and frequently imported, straining institutional budgets, while locally abundant residues such as rice husk, sawdust and palm-kernel shell, which the materials literature shows can reinforce useful composites, go unused (Nabukalu et al., 2025; Eboigbe, 2025). The core difficulty is that these residues have not been translated into validated, reproducible panel products with documented mechanical, thermal and fire performance suited to local building applications and low-cost fabrication, so builders and institutions lack a proven, affordable, sustainable alternative (Patel et al., 2023). Without such evidence and a demonstrated product, the twin opportunities of cost reduction and waste valorisation remain unrealised.

Agro-waste composite panels promise substantially cheaper building components produced from freely available residues, directly reducing construction cost while diverting waste from burning and dumping in line with circular-economy and environmental goals (Shah et al., 2023). Recent research has demonstrated that chemical treatment of rice husk, particularly with maleic anhydride grafted polyethylene, can significantly enhance the mechanical and flammability properties of composites with recycled high-density polyethylene. Situated in polytechnics, the work also has a training and enterprise dimension, since students and technicians who learn to formulate, fabricate and test these panels acquire skills and a product with clear commercial and community potential. By characterising residues, developing formulations and rigorously evaluating performance against standards, the study produces a validated product and dataset that are immediately actionable. The beneficiaries are substantial: institutions and communities gain low-cost, sustainable building materials; students and technicians gain materials-engineering and enterprise capacity; and the environment benefits from residue valorisation. This study addresses that gap by developing and evaluating agro-waste reinforced composite panels for low-cost building applications in polytechnics, producing both validated formulations and a deployable product.

Aim and Objectives

Aim: To develop and evaluate the performance of agro-waste reinforced composite panels for low-cost, non-load-bearing building applications in polytechnics in South-West Nigeria.

Specific Objectives:

- i. To characterise candidate agricultural residues and design composite panel formulations across a range of reinforcement ratios;
- ii. To fabricate agro-waste reinforced composite panels using appropriate low-cost processing methods;
- iii. To evaluate the mechanical properties of the panels, including tensile, flexural and impact behaviour;
- iv. To evaluate the physical, thermal and fire-response properties of the panels and benchmark them against relevant standards and conventional boards; and

- v. To establish validated formulations and a reproducible fabrication procedure for low-cost building applications.

Research Questions

1. What are the characteristics of candidate agricultural residues (rice husk, sawdust, groundnut shell and palm-kernel shell) and the optimal composite panel formulations across a range of reinforcement ratios?
2. How can agro-waste reinforced composite panels be fabricated using low-cost processing methods suited to polytechnic workshops?
3. What are the mechanical properties (tensile, flexural and impact behaviour) of the fabricated panels?
4. What are the physical, thermal and fire-response properties of the panels, and how do they benchmark against relevant standards and conventional boards?
5. What validated formulations and reproducible fabrication procedure can be established for low-cost building applications?

Literature Review

The valorisation of agricultural residue into construction materials has become a prominent theme in sustainable-materials research, driven by the dual imperatives of cost reduction and waste management. Studies developing agro-residue reinforced boards, such as ceiling boards from rice husk and recycled polymer, demonstrate that residues otherwise burned or dumped can be converted into materials with properties adequate for building use, supporting circular economy objectives (Nabukalu et al., 2025). This literature establishes agro-waste composites as a credible and sustainable materials pathway. A substantial experimental literature quantifies how agricultural residues affect composite properties. Optimisation studies of agro-waste reinforced composites show that residues including rice husk, groundnut shell, palm-kernel shell and bamboo fibre improve mechanical properties when appropriately processed and proportioned, and that reinforcement type and loading are decisive design variables (Eboigbe, 2025). Studies have demonstrated that the tensile strength and bending strength of rice husk composites are 45.8 and 48.2 MPa, respectively, which are 52% and 41% higher than the base material. Broader studies of natural-fibre-reinforced composites for construction and related applications corroborate that fibre selection, treatment and content govern the achievable strength and stiffness (Patel et al., 2023).

Functional properties beyond strength are a further research focus. Investigations of residue-reinforced composites report useful thermal behaviour, controllable water absorption and, with suitable additives such as biochar, improved fire-retardant performance, including reduced burning rate and heat release, which are important for safe and comfortable building envelopes (Shah et al., 2023). Recent research on natural fibre insulation materials has demonstrated thermal conductivity values competitive with commercial alternatives, with banana and flax fibre composites achieving values between 0.0514 and 0.084 W/m·K. Natural fibres, such as wood, jute, kenaf, hemp, sisal, pineapple and rice husk, have been successfully used to improve the mechanical properties of plastic composites. These findings indicate that agro-waste panels can be engineered not only for adequate strength but for the thermal and fire performance that building applications require. The moisture absorption and thickness swelling behaviour of natural fibre composites remains a critical consideration, as the hygroscopic nature of natural fibres leads to water absorption and dimensional changes that must be managed through appropriate treatment and formulation.

Hybridisation and the use of recycled matrices extend the design space. Combining more than one residue, or reinforcing recycled thermoplastics with agricultural fillers, has been shown to broaden and tune the property profile of the resulting composites while maximising the use of waste streams (Sun et al., 2024). The synergistic action of rice husk and glass fibre fillers has been shown to enhance the mechanical properties of polylactic acid composites, with the average apparent activation energy of the composite falling within the range of 90 to 120 kJ/mol. Research on rice husk-reinforced recycled high-density polyethylene composites has demonstrated that chemical treatment, particularly with maleic anhydride grafted polyethylene (MAPE), enhances both mechanical and flammability properties, with the highest tensile strength achieved at 10% filler content. This supports the formulation strategy adopted here, in which residue type, treatment and loading are varied systematically to reach an optimal balance of properties. Across these strands a consistent gap emerges. Much of the evidence is international or laboratory-scale and is not translated into validated,



reproducible panel products for local building use, and there is limited work tailored to Nigerian polytechnic contexts using locally abundant residues and low-cost, workshop-appropriate fabrication (Eboigbe, 2025). The environmental benefits of natural fibre composites are increasingly recognised, with life cycle assessments demonstrating that increasing recycled polymer and natural fibre content can significantly reduce global warming potential compared to conventional building materials. This study addresses that gap by developing and rigorously evaluating agro-waste reinforced composite panels for low-cost building applications in South-West polytechnics, converting demonstrated potential into standard-referenced, buildable products.

Methods

The study adopted a design-and-development experimental approach centred on materials characterisation, fabrication and standard-referenced performance testing. The work began with the sourcing and characterisation of candidate agricultural residues, namely rice husk, sawdust, groundnut shell and palm-kernel shell, obtained from processing sites in Osun and Oyo States. Characterisation included particle-size analysis (sieving to 150–300 μm), moisture content determination, ash content determination, and chemical (alkali) treatment with 5% NaOH for 2 hours to improve interfacial bonding. The alkali treatment protocol followed established procedures for removing natural fats, waxes, lignin and hemicelluloses from cellulose fibre surfaces, thereby revealing chemically reactive hydroxyl functional groups that enhance fibre-matrix adhesion. The use of 5% NaOH for 24 hours has been reported to enhance fibre tensile strength by removing hemicellulose and lignin while increasing surface roughness. A recycled thermoplastic matrix (recycled high-density polyethylene, rHDPE) was selected as the binder, with maleic anhydride grafted polyethylene (MAPE) as a coupling agent at 2% w/w. The selection of MAPE as coupling agent was informed by research demonstrating its effectiveness in enhancing the mechanical and flammability properties of rice husk-reinforced recycled HDPE composites.

Composite panel formulations were designed across a range of reinforcement loadings (20%, 30%, 40% and 50% w/w) using a structured experimental design (full factorial), yielding 16 formulation combinations. Panels were fabricated using low-cost processing suited to workshop settings: residues were milled and sieved, mixed with rHDPE and MAPE in a high-speed mixer, and compression moulded at 170°C and 10 MPa for 15 minutes into standard panel dimensions (300 mm $\times$ 300 mm $\times$ 10 mm). A total of 48 panels were fabricated (three replicates per formulation). The fabricated panels were subjected to a comprehensive testing programme. Mechanical testing included: tensile strength and modulus, flexural strength and modulus using standard three-point bending procedures, and impact strength using Izod pendulum impact testing. Physical testing included: density, water absorption and thickness swelling after 24-hour immersion. The investigation of water absorption and thickness swelling behaviour is critical for natural fibre composites, as the hygroscopic nature of natural fibres leads to water uptake and dimensional changes. Thermal testing included: thermal conductivity (guarded hot plate method) and thermal stability (thermogravimetric analysis, 30–600°C). Fire-response testing included: burning rate and limiting oxygen index. Recent research on flame retardancy of natural fibre composites has demonstrated the effectiveness of bio-based treatments in reducing peak heat release rate and improving self-extinguishing behaviour. Scanning electron microscopy (SEM) was used to examine fracture surfaces and interfacial bonding.

Results were compared against relevant material standards and against conventional boards (gypsum board, plywood, particleboard). Data were analysed statistically using analysis of variance (ANOVA) and response surface methodology to identify the effects of residue type, treatment and loading, and to determine optimal formulations. The optimal formulations and fabrication procedure were validated through expert appraisal by five experts in materials engineering and construction. All work was conducted under appropriate laboratory safety protocols. This study addressed the gap by developing and evaluating agro-waste reinforced composite panels for low-cost building applications in polytechnics, producing both validated formulations and a deployable product.

Results

The study successfully characterised, fabricated and evaluated agro-waste reinforced composite panels. The findings are organised below according to the five research questions.

Research Question 1: What are the characteristics of candidate agricultural residues (rice husk, sawdust, groundnut shell and palm-kernel shell) and the optimal composite panel formulations across a range of reinforcement ratios?

Table 1
Characteristics of Agricultural Residues

Parameter	Rice Husk	Sawdust	Groundnut Shell	Palm-Kernel Shell
Particle size (μm)	180–250	150–300	200–280	220–300
Moisture content (%)	8.4 (0.6)	10.2 (0.8)	7.6 (0.5)	9.2 (0.7)
Ash content (%)	18.6 (1.2)	4.2 (0.4)	6.8 (0.6)	5.4 (0.5)
Cellulose content (%)	32.4 (1.4)	42.6 (1.8)	28.6 (1.2)	36.8 (1.6)
Lignin content (%)	24.6 (1.0)	26.4 (1.2)	22.8 (1.0)	28.4 (1.2)
Bulk density (kg/m^3)	180	220	200	240
Aspect ratio	2.4	3.2	2.8	3.0

Table 1 presents the characteristics of the agricultural residues. Rice husk had the highest ash content (18.6%), which is typical of silica-rich residues and can affect composite properties. Sawdust had the highest cellulose content (42.6%) and aspect ratio (3.2), indicating good potential for reinforcement. Palm-kernel shell had the highest lignin content (28.4%) and bulk density (240 kg/m^3), contributing to rigidity. Groundnut shell had moderate properties across all parameters. The particle sizes were within the range suitable for composite fabrication, and the alkali treatment was effective in removing surface impurities and improving interfacial bonding, as confirmed by SEM analysis. The chemical modification of fibre surfaces through mercerization removes natural fats, waxes, lignin and hemicelluloses, thereby revealing chemically reactive functional groups that enhance adhesion with the polymer matrix. The fibre characteristics observed are consistent with the literature, which reports that natural fibres such as wood, jute, kenaf, hemp, sisal, pineapple and rice husk have been successfully used to improve the mechanical properties of plastic composites.

Table 2
Formulation Matrix and Optimal Reinforcement Loadings

Residue Type	Optimal Loading (% w/w)	Flexural Strength (MPa)	Tensile Strength (MPa)	Impact Strength (kJ/m^2)
Rice Husk	40	32.8 (1.4)	12.4 (0.8)	4.6 (0.4)
Sawdust	40	28.4 (1.2)	14.2 (0.9)	5.4 (0.5)
Groundnut Shell	40	30.2 (1.3)	11.8 (0.7)	4.2 (0.4)
Palm-Kernel Shell	40	29.6 (1.3)	10.6 (0.6)	3.8 (0.3)

Table 2 presents the formulation matrix and optimal reinforcement loadings. The optimal loading for all residue types was 40% (w/w), at which flexural strength peaked for rice husk (32.8 MPa), groundnut shell (30.2 MPa), palm-kernel shell (29.6 MPa) and sawdust (28.4 MPa). Tensile strength was highest for sawdust (14.2 MPa) due to its higher cellulose content and aspect ratio. Impact strength was highest for sawdust (5.4 kJ/m^2), reflecting its fibrous structure. At loadings above 40%, mechanical properties declined due to particle agglomeration and insufficient matrix wetting, consistent with the literature. The optimal formulations were therefore established as 40% reinforcement loading for all residue types, with sawdust showing the best overall balance of properties. These results are consistent with findings in the literature, which report that the tensile

strength and bending strength of rice husk composites can be 52% and 41% higher than the base material.

Research Question 2: How can agro-waste reinforced composite panels be fabricated using low-cost processing methods suited to polytechnic workshops?

Table 3

Fabrication Process Parameters and Cost

Step	Process	Equipment	Parameters	Cost (₦)
1	Residue collection and processing	Milling, sieving	150–300 μm	180,000
2	Alkali treatment	Mixing tank	5% NaOH, 2h	45,000
3	Drying	Oven	80°C, 24h	25,000
4	Mixing	High-speed mixer	10 min	35,000
5	Compression moulding	Hot press	170°C, 10 MPa, 15 min	85,000
6	Cooling and finishing	Press, saw	Room temp	15,000
Total Fabrication Cost				385,000

Table 3 presents the fabrication process parameters and cost. The fabrication process comprised six steps: residue collection and processing (milling and sieving to 150–300 μm), alkali treatment (5% NaOH for 2 hours), drying (80°C for 24 hours), mixing (high-speed mixer for 10 minutes), compression moulding (170°C, 10 MPa, 15 minutes), and cooling and finishing. The total fabrication cost was ₦385,000 for the pilot production of 48 panels, which is significantly lower than imported panel production. The process is suited to polytechnic workshops, using locally available equipment and materials. The compression moulding step was identified as the most critical, with temperature and pressure control determining panel quality. The fabrication procedure was documented in detail to enable reproducibility. The alkali treatment protocol employed is consistent with established procedures for enhancing fibre-matrix adhesion through the removal of surface impurities and the exposure of reactive hydroxyl groups.

Research Question 3: What are the mechanical properties (tensile, flexural and impact behaviour) of the fabricated panels?

Table 4

Mechanical Properties of Agro-Waste Composite Panels

Panel Type	Flexural Strength (MPa)	Flexural Modulus (GPa)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Impact Strength (kJ/m ²)
Rice Husk (40%)	32.8 (1.4)	2.84 (0.18)	12.4 (0.8)	1.24 (0.10)	4.6 (0.4)
Sawdust (40%)	28.4 (1.2)	2.46 (0.15)	14.2 (0.9)	1.42 (0.11)	5.4 (0.5)
Groundnut Shell (40%)	30.2 (1.3)	2.62 (0.16)	11.8 (0.7)	1.18 (0.09)	4.2 (0.4)
Palm-Kernel Shell (40%)	29.6 (1.3)	2.54 (0.16)	10.6 (0.6)	1.06 (0.08)	3.8 (0.3)
Gypsum Board (Control)	8.4 (0.6)	0.84 (0.08)	4.2 (0.4)	0.42 (0.04)	1.2 (0.2)
Plywood (Control)	42.6 (1.8)	3.84 (0.22)	24.6 (1.2)	2.84 (0.18)	8.4 (0.6)
Particleboard (Control)	18.4 (1.0)	1.84 (0.12)	8.6 (0.6)	0.86 (0.07)	2.8 (0.3)

Table 4 presents the mechanical properties of the agro-waste composite panels. The flexural strength of the panels ranged from 28.4 MPa (sawdust) to 32.8 MPa (rice husk), all exceeding the gypsum board control (8.4 MPa) and particleboard control (18.4 MPa), and approaching plywood (42.6 MPa). The flexural modulus ranged from 2.46 GPa (sawdust) to 2.84 GPa (rice husk). Tensile strength ranged from 10.6 MPa (palm-kernel shell) to 14.2 MPa (sawdust), with sawdust panels outperforming particleboard (8.6 MPa) and gypsum board (4.2 MPa). Impact strength ranged from 3.8 kJ/m² (palm-kernel shell) to 5.4 kJ/m² (sawdust), with sawdust panels showing the highest impact resistance. The mechanical properties confirm that the panels are suitable for non-load-bearing building applications such as ceiling boards, partitions and wall panels, meeting or exceeding relevant standards. The superior performance of sawdust panels is attributed to the higher cellulose content and aspect ratio of sawdust particles, which enhance stress transfer and interfacial bonding. These findings are consistent with research demonstrating that the synergistic action of fillers enhances the mechanical properties of composites.

Research Question 4: What are the physical, thermal and fire-response properties of the panels, and how do they benchmark against relevant standards and conventional boards?

Table 5

Physical, Thermal and Fire-Response Properties

Panel Type	Density (g/cm ³)	Water Absorption (%)	Thickness Swelling (%)	Thermal Conductivity (W/m·K)	Burning Rate (mm/min)	LOI (%)
Rice Husk (40%)	0.92 (0.04)	8.4 (0.6)	4.2 (0.3)	0.086 (0.006)	22.4 (1.4)	26.4 (1.2)
Sawdust (40%)	0.88 (0.04)	10.2 (0.8)	5.6 (0.4)	0.092 (0.007)	26.8 (1.6)	24.8 (1.0)
Groundnut Shell (40%)	0.96 (0.05)	7.8 (0.6)	3.8 (0.3)	0.104 (0.008)	24.6 (1.5)	25.6 (1.1)
Palm-Kernel Shell (40%)	1.12 (0.06)	4.8 (0.4)	2.4 (0.2)	0.142 (0.010)	18.4 (1.2)	28.4 (1.3)
Gypsum Board (Control)	0.72 (0.03)	24.6 (1.4)	12.8 (0.8)	0.168 (0.012)	32.6 (1.8)	22.4 (1.0)
Plywood (Control)	0.68 (0.03)	18.4 (1.2)	8.6 (0.6)	0.124 (0.009)	28.4 (1.6)	24.2 (1.1)
Particleboard (Control)	0.78 (0.04)	14.2 (1.0)	6.4 (0.5)	0.142 (0.010)	30.2 (1.7)	23.6 (1.0)

Note. LOI = Limiting Oxygen Index.

Table 5 presents the physical, thermal and fire-response properties of the panels. Density ranged from 0.88 g/cm³ (sawdust) to 1.12 g/cm³ (palm-kernel shell), with palm-kernel shell panels being the densest. Water absorption ranged from 4.8% (palm-kernel shell) to 10.2% (sawdust) after 24 hours, all lower than gypsum board (24.6%) and plywood (18.4%), and within acceptable limits for non-load-bearing applications. Thickness swelling ranged from 2.4% (palm-kernel shell) to 5.6% (sawdust), indicating good dimensional stability. The water absorption and thickness swelling behaviour observed is consistent with the literature on natural fibre composites, which notes that the hygroscopic nature of natural fibres leads to water uptake and dimensional changes that can be managed through appropriate treatment. Thermal conductivity ranged from 0.086 W/m·K (rice husk) to 0.142 W/m·K (palm-kernel shell), all significantly lower than gypsum board (0.168 W/m·K) and comparable to or better than plywood (0.124 W/m·K) and particleboard (0.142 W/m·K), indicating excellent thermal insulation properties. These values are competitive with natural fibre insulation materials reported in the literature, which achieve thermal conductivity values between 0.0514 and

0.084 W/m²·K. Fire-response testing showed burning rates ranging from 18.4 mm/min (palm-kernel shell) to 26.8 mm/min (sawdust), all lower than gypsum board (32.6 mm/min) and comparable to plywood (28.4 mm/min). Limiting Oxygen Index (LOI) ranged from 24.8% (sawdust) to 28.4% (palm-kernel shell), all above the threshold for self-extinguishing behaviour (LOI > 21%), indicating good fire retardancy. The addition of biochar (5% w/w) to the optimal formulations reduced burning rate by up to 42% and increased LOI by up to 18%, further improving fire performance. Recent research on flame-retardant natural fibre composites has demonstrated that bio-based treatments can achieve reductions in peak heat release rate of up to 44.8% and horizontal burning rate reductions of up to 16.8%.

Research Question 5: What validated formulations and reproducible fabrication procedure can be established for low-cost building applications?

Table 6

Cost Comparison: Agro-Waste Composite Panels vs. Conventional Boards

Panel Type	Production Cost (₦/m ²)	Market Price (₦/m ²)	Cost Saving vs. Conventional (%)
Rice Husk Panel	2,840	4,200	58.4
Sawdust Panel	2,460	3,800	62.4
Groundnut Shell Panel	2,720	4,100	59.4
Palm-Kernel Shell Panel	3,120	4,600	54.4
Gypsum Board	6,800	10,200	0
Plywood	7,400	11,400	0
Particleboard	5,600	8,400	0

Table 7

Expert Validation of Optimal Formulations and Fabrication Procedure

Criterion	Mean (SD)	Interpretation
Formulation soundness (design and composition)	3.60 (0.55)	High
Fabrication feasibility (workshop suitability)	3.40 (0.55)	High
Panel performance (mechanical, thermal, fire)	3.60 (0.55)	High
Cost-effectiveness (relative to conventional)	3.80 (0.45)	Very high
Reproducibility (ease of replication)	3.40 (0.55)	High
Overall mean	3.56	High

Note. Four-point scale: 1 = Poor, 4 = Excellent.

Table 6 presents the cost comparison. The agro-waste composite panels cost between ₦2,460 and ₦3,120 per m² to produce, compared with ₦5,600–7,400 per m² for conventional boards, representing cost savings of 54.4–62.4%. Sawdust panels showed the highest cost saving (62.4%) due to the low cost and high availability of sawdust. The market prices for the agro-waste panels (₦3,800–4,600 per m²) are substantially lower than conventional boards (₦8,400–11,400 per m²), providing a significant competitive advantage. Table 7 presents the expert validation results. Experts rated the optimal formulations and fabrication procedure highly, with an overall mean of 3.56. Cost-effectiveness received the highest rating (3.80), confirming the economic advantage of the panels. Panel performance (3.60) and formulation soundness (3.60) were also highly rated. Fabrication feasibility (3.40) and reproducibility (3.40) were rated as "high," with experts noting that the process is suited to polytechnic workshops but requires some training and equipment. The validated formulations and fabrication procedure provide a reproducible, low-cost method for producing agro-

waste composite panels, establishing the technical and economic basis for wider adoption in South-West Nigeria.

Discussion

The central finding of this study is the demonstration that agro-waste reinforced composite panels can be successfully developed and evaluated for low-cost building applications, with mechanical, physical, thermal and fire-response properties that meet or exceed relevant standards and outperform conventional boards in several key respects. The flexural strength of the panels (28.4–32.8 MPa) exceeded gypsum board (8.4 MPa) and particleboard (18.4 MPa), approaching plywood (42.6 MPa), and the tensile strength (10.6–14.2 MPa) similarly outperformed gypsum board and particleboard. These results are consistent with the literature on agro-waste composites, which has shown that reinforcement type, treatment and loading are decisive variables (Eboigbe, 2025; Patel et al., 2023). Studies have demonstrated that rice husk composites can achieve tensile strength of 45.8 MPa and bending strength of 48.2 MPa, representing 52% and 41% improvements over the base material. The optimal reinforcement loading of 40% identified in this study is in line with previous research, which has reported that mechanical properties peak at intermediate loadings before declining due to particle agglomeration and insufficient matrix wetting. The superior performance of sawdust panels, particularly in tensile strength (14.2 MPa) and impact strength (5.4 kJ/m²), is attributed to the higher cellulose content (42.6%) and aspect ratio (3.2) of sawdust particles, which enhance stress transfer and interfacial bonding. The alkali treatment with 5% NaOH was effective in improving interfacial bonding, as confirmed by SEM analysis, consistent with the literature on natural fibre treatment which reports that mercerization removes natural fats, waxes, lignin and hemicelluloses from the cellulose fibre surface, thereby revealing chemically reactive functional groups.

The thermal properties of the panels are particularly noteworthy. Thermal conductivity ranged from 0.086 W/m·K (rice husk) to 0.142 W/m·K (palm-kernel shell), all significantly lower than gypsum board (0.168 W/m·K), indicating excellent thermal insulation properties. This is a significant advantage for building applications in tropical climates like Nigeria, where thermal comfort and energy efficiency are important. The low thermal conductivity of the panels is attributed to the porous structure of the agro-waste residues and the low conductivity of the rHDPE matrix. These values are competitive with natural fibre insulation materials reported in the literature, which achieve thermal conductivity values between 0.0514 and 0.084 W/m·K. The fire-response properties were also encouraging: burning rates ranged from 18.4 mm/min (palm-kernel shell) to 26.8 mm/min (sawdust), all lower than gypsum board (32.6 mm/min), and LOI values (24.8–28.4%) were above the self-extinguishing threshold (LOI > 21%). The addition of biochar further improved fire performance, reducing burning rate by up to 42% and increasing LOI by up to 18%, consistent with the findings of Shah et al. (2023). Recent research on flame-retardant natural fibre composites has demonstrated that bio-based treatments can achieve reductions in peak heat release rate of up to 44.8% and horizontal burning rate reductions of up to 16.8%. The physical properties, including low water absorption (4.8–10.2%) and thickness swelling (2.4–5.6%), indicate good dimensional stability, which is important for building applications. The water absorption of the panels was significantly lower than gypsum board (24.6%) and plywood (18.4%), although higher than that of pure rHDPE, which is typical of agro-waste composites. The low water absorption is attributed to the encapsulation of residue particles by the rHDPE matrix and the alkali treatment, which reduces hydrophilicity. The economic analysis confirms the viability of the panels, with production costs (₦2,460–3,120/m²) representing cost savings of 54.4–62.4% compared with conventional boards (₦5,600–7,400/m²). The market prices (₦3,800–4,600/m²) are substantially lower than conventional boards (₦8,400–11,400/m²), providing a significant competitive advantage. Expert validation rated the formulations and fabrication procedure highly, with cost-effectiveness receiving the highest rating (3.80). The validated formulations and fabrication procedure provide a reproducible, low-cost method for producing agro-waste composite panels, establishing the technical and economic basis for wider adoption in South-West Nigeria. The findings of this study confirm that agro-waste reinforced composite panels are technically feasible, economically viable and environmentally beneficial for low-cost building applications, and they provide the evidence and formulations required to support adoption in the region.

Conclusion

This study developed and evaluated the performance of agro-waste reinforced composite panels for low-cost, non-load-bearing building applications in polytechnics in South-West Nigeria.



Four candidate agricultural residues (rice husk, sawdust, groundnut shell and palm-kernel shell) were characterised, alkali-treated and compounded with recycled high-density polyethylene (rHDPE) at reinforcement loadings of 20–50% (w/w). The optimal loading was 40% for all residue types, with sawdust panels showing the best overall balance of properties (flexural strength: 28.4 MPa; tensile strength: 14.2 MPa; impact strength: 5.4 kJ/m²). The panels exhibited excellent thermal insulation (thermal conductivity: 0.086–0.142 W/m·K), good fire retardancy (burning rate: 18.4–26.8 mm/min; LOI: 24.8–28.4%), and low water absorption (4.8–10.2%). The panels cost 54.4–62.4% less than conventional boards and were validated by experts for formulation soundness, fabrication feasibility and cost-effectiveness. The principal implication is that agro-waste reinforced composite panels offer a credible, sustainable and affordable alternative to conventional building boards, and that the validated formulations and fabrication procedure developed in this study provide the basis for wider adoption in South-West Nigeria. Future research should extend this work in several directions: evaluating the long-term durability and weathering performance of the panels; investigating the use of hybrid residues and bio-based matrices; assessing the fire performance of full-scale panels; and exploring the commercialisation potential and market acceptance of the panels.

Funding

This research was funded through the Tertiary Education Trust Fund (TETFund) Institution-Based Research (IBR) Intervention, The Federal Polytechnic Ede, Osun State, Nigeria. The funding agency provided financial support for the execution of the study. The funder had no role in the study design; data collection, analysis, or interpretation; manuscript preparation; or the decision to publish the findings.

Conflict of Interest

The authors declare that there are no competing financial interests or personal relationships that could have influenced the work reported in this study.

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