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Study of Multi-Waste Hybrid Epoxy Composites Using Chicken Feather, Banana Fiber and Egg Shells

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Abstract. The growing accumulation of poultry, agricultural, and food-processing waste has created an urgent need for sustainable pathways that convert such residues into useful engineering materials. This study examines the development of multi-waste hybrid epoxy composites reinforced with three commonly discarded bio-wastes: chicken feather fiber, banana plant fiber, and eggshell particulate. Chicken feather, a keratin-rich fiber byproduct of the poultry industry, offers low density, good thermal insulation, and hydrophobic behaviour; banana fiber, obtained from pseudo-stem or leaf sheath residue of banana cultivation, provides cellulose-based tensile reinforcement; and eggshell, a calcium-carbonate-rich particulate waste, functions as a rigid filler that improves stiffness and reduces water uptake. This paper reviews fabrication routes such as hand lay-up, compression moulding, and vacuum-assisted lay-up used to combine these three waste streams within an epoxy matrix, and compares their individual and combined effects on tensile, flexural, impact, hardness, water-absorption, and thermal properties. The economic and environmental value of converting these waste materials into automotive, packaging, construction, and consumer-good components is discussed, along with the processing challenges of fiber treatment, filler dispersion, and interfacial bonding. The review concludes that a ternary hybridisation strategy-combining a protein-based fiber, a cellulose-based fiber, and a mineral particulate-offers a promising balance of strength, stiffness, and sustainability that no single waste stream can achieve alone.

Keywords: Chicken feather fiber, Banana fiber, Eggshell particulate, Hybrid composite, Epoxy matrix, Agro-waste valorization, Sustainable materials

I. Introduction

The poultry, textile-fiber, and food-processing sectors generate enormous volumes of solid waste every year in the form of feathers, plant-fiber residue, and shell material. It is estimated that several billion tonnes of chicken feathers are discarded worldwide annually, most of which are landfilled, incinerated, or left to decompose, contributing to greenhouse gas emissions and disease risk [8]. Similarly, the banana crop leaves behind large quantities of pseudo-stem and leaf-sheath fiber once the fruit is harvested, and the food and bakery industry discards eggshell as a low-value byproduct despite its rich calcium carbonate content. Converting these three waste streams into reinforcement for polymer composites offers a way to simultaneously reduce disposal burden and create value-added engineering material. Epoxy resin is widely used as a composite matrix because of its high adhesive strength, low shrinkage, chemical resistance, and ease of processing at room temperature. When reinforced with natural fibers and particulate fillers, epoxy composites can approach the stiffness and strength of synthetic fiber composites while remaining lighter, cheaper, and more environmentally benign. Chicken feather fiber (CFF) is composed mainly of keratin protein and possesses a hollow, porous morphology that gives it a very low density, good acoustic and thermal insulation, and inherent hydrophobicity [1], [5], [6]. Banana fiber (BF) is a lignocellulosic fiber with comparatively high cellulose content, offering good tensile strength and stiffness once alkali-treated to remove waxes and lignin [10], [13]. Eggshell (ES) particulate is predominantly calcium carbonate with a small organic membrane fraction; when calcined and ground into fine powder it behaves as a rigid, low-cost mineral filler that can reduce water absorption and improve flexural modulus [9], [11], [12].

Individually, each of these waste-derived reinforcements has drawbacks: CFF composites tend to show comparatively low tensile strength because of the fiber's low intrinsic modulus; BF composites can suffer from high moisture absorption and fiber–matrix debonding; and ES-filled composites can become brittle at high filler loading. Hybridising the three materials in a single epoxy matrix is proposed as a way to offset these individual weaknesses — the feather fiber contributing light weight and insulation, the banana fiber contributing tensile reinforcement, and the eggshell particulate contributing stiffness and dimensional stability. This paper reviews the fabrication routes, property trends, comparative performance, value-creation opportunities, and outstanding challenges associated with such multi-waste hybrid epoxy composite

II. Literature Review

Several independent studies have examined chicken feather fiber as a stand-alone epoxy reinforcement. Chadran et al., cited in Kareem et al. [1], fabricated open-mould CFF/epoxy composites at 2.5, 5, and 7.5 wt% loading and found that 2.5 wt% CFF gave the best combination of mechanical properties and thermal stability due to favourable interfacial adhesion; higher loadings reduced performance because of fiber agglomeration [1]. A related open-mould study using bio-based epoxy (SR-33 Greenpoxy) confirmed that 2.5 wt% CFF produced the highest tensile, flexural, impact, and hardness values along with improved crystallisationbehaviour [5]. Investigations that varied CFF form — barb versus rachis, mat versus chopped fiber — reported that feather barbs performed better in tension than the rachis, while the trend reversed for flexural strength [1]. Alkali (NaOH) treatment of CFF has repeatedly been shown to improve fiber–matrix adhesion and raise both tensile and flexural strength compared with untreated fiber [1], [8].

Hybridising chicken feather with other reinforcements has also been explored. Verma et al. combined 5 wt% CFF with varying crumb-rubber content and found the hybrid composite outperformed the single-fiber composite in tensile, flexural, and impact strength [7]. A study combining chicken feather with glass fiber reported that the hybrid reduced composite density by 30–40% relative to pure glass-fiber composite while achieving a storage modulus near 3.5 GPa and flexural strength in the 50–80 MPa range, demonstrating a genuine synergetic effect between a protein-based waste fiber and a synthetic fiber [1]. Taguchi-based optimisation of chicken-feather-fiber composites incorporating eggshell ash and kaolin filler achieved optimum tensile, flexural, and impact energies of 64.66 MPa, 74.84 MPa, and 1.37 J respectively, confirming that eggshell-derived filler can be co-optimised with feather fiber content and particle size [18]. Chicken feather fiber has also been hybridised with lignocellulosicCeibaPentandra bark fiber in a bioepoxy matrix, and with Sesbania grandiflora fiber, both of which reported stable thermal behaviour up to at least 300 °C and improved mechanical performance at intermediate fiber ratios [15], [19].

A separate body of research has focused on banana fiber and eggshell particulate as a binary hybrid system. Ganesan et al. reinforced epoxy with banana fiber and eggshell powder and reported that the eggshell filler markedly reduced water absorption and thickness swelling while keeping composite density in the 0.83–1.34 g/cm³ range, making the material suitable for automotive door panels and boat components [9]. A related study using NaOH-treated banana fiber (30 wt%) combined with calcined eggshell particulate at loadings from 0–20 wt% found that around 4 wt% eggshell filler gave the best thermal insulation and lowest water absorption, while roughly 20 wt% eggshell filler maximised flexural strength [10]. Ternary combinations extending beyond banana and eggshell have also been reported: a banana fiber–rice husk–eggshell hybrid epoxy composite showed that tensile strength increased with banana fiber content up to about 15 wt% before declining due to fiber agglomeration, and that all hybrid formulations outperformed the unreinforced epoxy control [11], [15-ref].

Eggshell filler has additionally been combined with other natural fibers such as jute and banana together, where 15 wt% eggshell gave the best tensile and flexural properties (tensile strength about 95 MPa, flexural strength about 117 MPa) while higher eggshell content reduced long-term water absorption to below 8% after 240 hours of immersion [12]. Nguyen et al. reviewed banana-fiber epoxy composites more broadly and noted that fiber loading, weave orientation, and alkali treatment strongly influence both mechanical strength and fire-retardant behaviour, with a 50:50 banana-fiber-to-resin ratio reported to withstand the highest loads among the combinations tested [13]. A closely related study directly relevant to the present ternary system evaluated a hybrid of banana fiber, glass fiber, and chicken feather with and without eggshell filler, reporting that the tensile and flexural strengths of the hybrid were both sensitive to the presence of eggshell filler, with the fully hybridised composite achieving the highest flexural strength among all combinations tested [17]. This directly supports the premise that combining a protein fiber (chicken feather), a cellulose fiber (banana), and a mineral filler (eggshell) can yield a more balanced property set than any two-component system.

Collectively, the literature indicates that (i) an optimum, comparatively low loading of chicken feather fiber (around 2.5–5 wt%) tends to maximise its individual contribution before agglomeration degrades performance; (ii) alkali treatment of both chicken feather and banana fiber consistently improves interfacial bonding and mechanical properties; (iii) eggshell particulate is most effective at moderate loadings (roughly 10–20 wt%) for improving stiffness and reducing water uptake, though excessive loading increases brittleness; and (iv) hybridising two or more of these waste streams generally outperforms any single-waste composite, motivating a systematic study of the full ternary chicken-feather/banana-fiber/eggshell system [1], [9]-[13], [17], [18].

III. Materials and Fabrication Methods

1. Waste Material Sourcing and Pre-treatment

Chicken feathers are collected from poultry-processing waste, washed to remove blood and dirt, dried, and either chopped into short fibers or separated into barb and rachis fractions. Banana fiber is extracted from the pseudo-stem or leaf sheath by mechanical decortication or retting, followed by washing and drying. Eggshells are collected from food-processing or bakery waste, washed, dried, and calcined at moderate temperature before being ground into fine particulate. All three reinforcements are commonly subjected to a 5% sodium hydroxide (NaOH) alkali treatment, which removes waxes, hemicellulose, and surface impurities, roughens the fiber surface, and improves mechanical interlocking with the epoxy matrix [1], [10], [11].

2. Composite Fabrication Techniques

The hand lay-up technique, sometimes combined with vacuum bagging, is the most widely used method for fabricating chicken-feather/banana/eggshell hybrid epoxy composites because it is low-cost and suited to short, discontinuous, or particulate reinforcement [1], [10]. Compression moulding is used where more uniform fiber distribution and lower void content are required, and has been applied successfully to chicken-feather hybrid systems [19]. In a typical ternary lay-up, a calculated weight fraction of treated banana fiber mat is placed in the mould, epoxy resin pre-mixed with eggshell particulate and chopped chicken feather fiber is poured over the mat, and the assembly is cured at room temperature or under mild heat before being cut into standard ASTM specimens for tensile, flexural, impact, and hardness testing.

IV. Comparative Analysis of Waste Reinforcements

Table 1 summarises the individual characteristics of the three waste-derived reinforcements discussed in the literature, and Table 2 compares the reported effect of each reinforcement on key composite properties when used in epoxy.

Table 1. Comparative Characteristics of the Three Waste Reinforcements

Parameter	Chicken Feather Fiber	Banana Fiber	Eggshell Particulate
Principal composition	Keratin protein (~91%)	Cellulose, hemicellulose, lignin	Calcium carbonate (~94%) + organic membrane
Physical form used	Chopped fiber / barb-rachis / mat	Chopped fiber / woven mat	Calcined, ground powder
Density	Very low	Low–moderate	Moderate (mineral filler)
Key contribution	Light weight, thermal & acoustic insulation, hydrophobicity	Tensile strength, stiffness	Rigidity, reduced water absorption
Optimum loading reported	≈2.5–5 wt%	≈15–30 wt%	≈10–20 wt%
Pre-treatment	Washing, NaOH treatment	Retting, NaOH treatment	Washing, calcination, grinding

Table 2. Reported Effect of Each Reinforcement on Composite Properties

Property	Chicken Feather Effect	Banana Fiber Effect	Eggshell Effect
Tensile strength	Moderate increase at low loading; declines beyond ~5 wt% [1]	Increases with fiber content up to ~15 wt% [11]	Improves up to moderate loading; excess causes agglomeration [9]
Flexural strength	Sensitive to fiber form (barb vs rachis) [1]	Improves with alkali treatment [13]	Maximised near ~20 wt% loading [10]
Impact strength	Improves in hybrid with crumb rubber [7]	Contributes toughness at moderate loading [11]	Can reduce toughness at high loading
Water absorption	Reduced due to hydrophobic feather [1]	Higher moisture uptake if untreated [13]	Markedly reduced, esp. at ≥15–20 wt% [9], [12]
Thermal behaviour	Good thermal/acoustic insulation [5]	Moderate thermal stability	Improves insulation at low loading (~4 wt%) [10]
Density	Lowers composite density [1]	Moderate reduction vs synthetic fiber	Slightly increases density

The comparison indicates that the three waste streams are largely complementary rather than competing: chicken feather fiber principally governs weight reduction and insulation, banana fiber principally governs tensile reinforcement, and eggshell particulate principally governs stiffness and moisture resistance. This complementary behaviour is the underlying rationale for combining all three in a single ternary hybrid composite, a strategy already shown to be effective in banana-fiber/glass-fiber/chicken-feather/eggshell systems [17] and in chicken-feather/eggshell-ash/kaolin systems [18].

V. Value Creation Opportunities

Multi-waste hybrid epoxy composites of this type have been proposed for several application areas. Automotive interior components such as door panels, dashboard trim, and roof liners benefit from the reduced weight and acoustic damping offered by chicken feather fiber together with the stiffness contributed by eggshell particulate [1], [9]. Marine and boat-building components can take advantage of the lower water absorption achieved through eggshell loading [9], [12]. Construction and building products, including low-load partition panels and insulation boards, can exploit the thermal-insulating character of chicken feather fiber together with the dimensional stability provided by eggshell filler [10]. Packaging, furniture panels, and general consumer goods represent lower-performance applications where all three waste streams can be used at relatively high combined loading to maximise waste utilisation and minimise material cost [9], [11]. Beyond the finished composite, this valorisation route also creates local economic opportunity in poultry-processing, banana-farming, and food-service regions by providing a market for what would otherwise be disposal-cost waste

VI. Mechanical and Functional Characterization Methods

Meaningful comparison across studies on chicken-feather/banana/eggshell hybrid composites depends on consistent testing procedures, since reported strength values are sensitive to specimen geometry, conditioning, and loading rate. This section summarises the standard test methods and characterization techniques used to evaluate the mechanical, microstructural, and thermal behaviour of these composites.

1. Mechanical Testing Standards

Tensile properties are almost universally evaluated per ASTM D638 on dog-bone specimens using a universal testing machine at a fixed crosshead speed, while flexural strength and modulus are obtained by three-point bending under ASTM D790. Izod or Charpy impact strength is measured under ASTM D256, and surface hardness is typically reported as Shore D per ASTM D2240, reflecting the relatively rigid character of the epoxy matrix.

Water absorption and thickness swelling are assessed by conditioning specimens in distilled water and periodically weighing them per ASTM D570, a test of particular importance for this ternary system given the moisture sensitivity of both chicken feather and banana fiber. Where dynamic mechanical behaviour is of interest, dynamic mechanical analysis (DMA) is used to obtain storage modulus, loss modulus, and glass transition temperature as a function of frequency and temperature.

2. Microstructural and Thermal Characterization

Scanning electron microscopy (SEM) of fracture surfaces is the primary tool for evaluating fiber–matrix adhesion, fiber pull-out, void content, and filler dispersion, and is routinely used to confirm whether alkali treatment has improved interfacial bonding. Fourier-transform infrared spectroscopy (FTIR) is used to verify the removal of waxes, hemicellulose, and surface impurities after NaOH treatment and to confirm the calcium-carbonate signature of processed eggshell particulate. Thermo-gravimetric analysis (TGA) quantifies the thermal decomposition profile and residual char content of each reinforcement and the resulting composite, which is particularly relevant for chicken feather fiber given its keratin-protein composition, while differential scanning calorimetry (DSC) is used to track curing behaviour and glass transition temperature of the epoxy matrix. Together, these microstructural and thermal methods complement the mechanical test data in Table 2 by explaining why particular loading ranges produce optimum performance.

VII. Economic and Environmental Analysis

Beyond mechanical performance, the case for multi-waste hybrid epoxy composites rests heavily on cost and environmental grounds. All three reinforcements are recovered from streams that currently carry a disposal cost rather than a market value, so their raw material cost is limited largely to collection, washing, and pre-treatment rather than cultivation or synthesis. This gives ternary hybrid composites a material-cost advantage over glass-fiber or carbon-fiber-reinforced epoxy, even after accounting for the added processing steps of alkali treatment, feather chopping, and eggshell calcination. Because eggshell particulate is a comparatively dense, low-cost mineral filler, replacing a portion of the more expensive banana fiber or virgin resin with eggshell can further reduce composite cost per unit volume without a proportional loss in stiffness.

From an environmental standpoint, diverting chicken feathers, banana pseudo-stem residue, and eggshells from landfill or open burning reduces methane and particulate emissions associated with their decomposition or incineration, while also avoiding the energy- and emissions-intensive extraction routes required for glass or carbon fiber. A full life-cycle assessment (LCA) of the waste-to-composite value chain would need to weigh the energy inputs of washing, drying, calcination, and alkali treatment against these avoided disposal emissions, and no such comprehensive LCA has yet been reported for the specific ternary chicken-feather/banana-fiber/eggshell system; this remains an open item for future work. Nonetheless, the qualitative direction of the evidence — waste-stream diversion, reduced reliance on synthetic fiber production, and lower embodied energy relative to glass-fiber composites — supports the sustainability rationale outlined in the Introduction and reinforces the value-creation opportunities discussed in Section V.

Qualitatively, the ternary waste hybrid compares favourably with conventional reinforcement on several of these dimensions. Its reinforcement is sourced from disposal-cost poultry, agricultural, and food-processing waste rather than mined silica or energy-intensive synthetic fiber drawing, and its typical density (roughly 0.83-1.34 g/cm cubed, per Ganesan et al. [9]) is markedly lower than glass-fiber epoxy (around 1.8-2.0 g/cm cubed), translating directly into lighter finished components. At end-of-life, the natural-fiber and mineral-filler fraction is partly bio-based, though the epoxy matrix itself remains non-biodegradable in all three systems, so end-of-life advantages are partial rather than complete. Set against a neat, unreinforced epoxy baseline, the ternary hybrid trades a small density penalty for substantially improved stiffness, reduced water uptake, and a productive use for otherwise wasted material, reinforcing the case made in Section V.

Challenges and Future Scope

A number of processing and performance challenges remain. Because chicken feather fiber, banana fiber, and eggshell particulate differ substantially in density, surface chemistry, and particle/fiber geometry, achieving uniform dispersion of all three within a single epoxy matrix is difficult, and settling or agglomeration during curing can create localised weak zones [1], [9]. Determining the optimum combined loading of all three reinforcements is more complex than optimising any one material alone, since the beneficial loading range for one reinforcement (e.g., low CFF content) can differ from that of another (e.g., higher eggshell content), requiring multi-factor optimisation techniques such as Taguchi design or response-surface methodology, as already applied to related chicken-feather hybrid systems [18].

Moisture sensitivity of the untreated cellulose fiber, variability in feather and eggshell waste quality depending on source, and the added processing steps of washing, calcining, and alkali treatment all add cost and complexity relative to using a single reinforcement. Long-term durability, biodegradability at end-of-life, and fire performance of the ternary hybrid also require further investigation [13]. Future work should focus on establishing standardised treatment protocols for all three waste streams, systematically mapping the ternary composition space (chicken feather : banana fiber : eggshell ratio) using statistical design of experiments, and evaluating the resulting composites against ASTM standards for the specific target application. Integration with Industry 4.0 tools such as automated sorting of poultry and agricultural waste, and life-cycle assessment of the full waste-to-composite value chain, would further strengthen the case for industrial-scale adoption.

VIII. Conclusion

This review has examined the fabrication and comparative performance of hybrid epoxy composites reinforced with three widely available waste streams: chicken feather fiber, banana fiber, and eggshell particulate. Evidence from the literature shows that each waste material contributes a distinct property advantage — chicken feather fiber for light weight and insulation, banana fiber for tensile reinforcement, and eggshell particulate for stiffness and moisture resistance — and that combining them in a ternary hybrid composite can produce a more balanced overall property profile than any single-waste or binary-waste system. Reported applications span automotive interiors, marine components, construction panels, and general consumer products. Key challenges remain around achieving uniform dispersion of three dissimilar reinforcements, optimising the combined loading ratio, and standardising pre-treatment protocols, but the reviewed studies collectively indicate that multi-waste hybrid epoxy composites represent a promising and under-explored route for converting poultry, agricultural, and food-processing waste into value-added engineering material.

References

1. M. Kareem et al., "Morphological and Mechanical Analysis of Epoxy–Chicken Feather Fiber Composites With COMSOL-Assisted Simulation," Material Design & Processing Communication, 2025, doi: 10.1155/mdp2/5587820.
2. D. et al., "Mechanical characteristics of chicken feather teak wood dust epoxy filled composite," MATEC/Materials Science and Engineering conference series, 2018.
3. "Investigation on mechanical properties of chicken feather fibers reinforced polymeric composites," Materials Today: Proceedings, ScienceDirect, 2020, doi: 10.1016/j.matpr.2020.10.xxx.
4. "Development of chicken feather fiber filled epoxy protective coating for metals," Materials Today: Proceedings, ScienceDirect, 2020, doi: 10.1016/j.matpr.2020.05.xxx.
5. "Mechanical properties of composites with chicken feather and glass fibers," ResearchGate/Journal article, 2016.
6. A. Verma, P. Negi, and V. K. Singh, "Experimental investigation of chicken feather fiber and crumb rubber reformed epoxy resin hybrid composite: mechanical and microstructural characterization," Journal of Mechanical Behavior of Materials, vol. 27, nos. 3–4, 2018, doi: 10.1515/jmbm-2018-0014.
7. "Mechanical Behavior of Chicken Fiber Augmented Epoxy Composites," JETIR, available: jetir.org/papers/JETIRDW06174.pdf.
8. S. K. Paramasivam, M. Marimuthu, A. Sakthivel, J. Rajasekar, S. Palanisamy, K. Mausam, A. Alagarsamy, Q. Ma, and S. A. Al-Farraj, "Mechanical and thermal behavior analysis of chicken feather/Sesbania grandiflora fibers-based hybrid epoxy composites," BioResources, vol. 20, no. 4, pp. 8591–8610, 2025.
9. V. Ganesan, J. S. Chohan, G. S. Subburaj, H. Panneerselvam, K. Y. Nagabhushanam, M. K. Venkatesan, and D. Jebasingh, "Experimental Analysis of Mechanical Properties of Banana Fibre/Eggshell Powder-Reinforced Hybrid Epoxy Composite," Engineering Proceedings, MDPI, 2024.
10. "Mechanical, Moisture Absorption and Thermal Stability of Banana Fiber/Egg Shell Powder-Based Epoxy Composites," Engineering Proceedings, 2024, doi: 10.3390/engproc2024061011.
11. A. A. Adediran, O. L. Ogundipe, T. A. Adekanye, I. C. Okolie, B. E. Ihimekpen, O. A. Aogo, B. T. Ogunsemi, and P. P. Ikubanni, "Mechanical properties of hybrid banana fibre, rice husk, and eggshell reinforced epoxy composite," Research on Engineering Structures and Materials, vol. 11, no. 5, pp. 2193–2209, 2025.
12. "Eggshell bio-filler integration in jute/banana fiber-reinforced epoxy hybrid composites: Fabrication and characterization," Journal of Applied Polymer Science, Wiley, 2024, doi: 10.1002/app.56155.
13. T. A. Nguyen et al., "Banana Fiber-Reinforced Epoxy Composites: Mechanical Properties and Fire Retardancy," International Journal of Chemical Engineering, 2021, doi: 10.1155/2021/1973644.

14. "Banana stem and chicken eggshells as a filler of polyester composites for particleboard application," Discover Materials, Springer, 2025, doi: 10.1007/s43939-025-00297-5.
15. S. MavinkereRangappa, J. Parameswaranpillai, S. Siengchin, M. Jawaid, and T. Ozbakkaloglu, "Bioepoxy based hybrid composites from nano-fillers of chicken feather and lignocellulose CeibaPentandra," Scientific Reports, vol. 12, no. 397, 2022, doi: 10.1038/s41598-021-04386-2.
16. "Eggshell bio-derived hydroxyapatite particle-wool/polyester staple fibers hybrid reinforced epoxy bio-composites for biomedical services," ScienceDirect, 2024.
17. "Evaluation of the impact of the eggshell filler on banana fibre, glass fibre and chicken feather hybrid composite," Chemical Engineering Research Bulletin, available: banglajol.info/index.php/CERB.
18. "Chicken feather hybrid reinforced epoxy composites with eggshell ash and kaolin filler: Taguchi optimization of tensile, flexural and impact properties," International Journal of Advanced Manufacturing Technology, 2023, doi: 10.1007/s00170-023-11108-7.
19. I. O. Oladele, B. A. Makinde-Isola, A. A. Adediran, M. O. Oladejo, A. F. Owa, and T. M. A. Olayanju, "Mechanical and wear behaviour of pulverised poultry eggshell/sisal fiber hybrid reinforced epoxy composites," (as cited in ref. [18]).