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Development of Filagri: A Locally Fabricated Additive Manufacturing Filament Harnessing Agricultural Byproducts

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ABSTRACT

Additive manufacturing (AM), particularly Fused Deposition Modeling (FDM), is widely used for rapid prototyping and small-batch production but remains costly in developing countries due to reliance on imported feedstock. This study developed and evaluated **FilAgri**, a locally fabricated AM filament incorporating Philippine agricultural byproducts—specifically rice husk ash (RHA) and coconut coir—into a polylactic acid (PLA) matrix. Composite filaments with 0%, 10%, and 20% filler loadings were compounded, extruded into 1.75 mm filaments, printed into standardized specimens, and evaluated for mechanical, thermal, printability, cost, and environmental performance. Mechanical tests following ASTM standards showed that RHA enhanced stiffness and thermal stability of PLA with minor reductions in tensile strength, while coir improved impact resistance at moderate loadings. Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) revealed that glass transition and melting temperatures remained essentially unchanged, indicating good thermal compatibility. All printable formulations achieved acceptable dimensional accuracy and print success rates on a standard FDM printer. Cost analysis indicated a 16–22% reduction in material cost per kilogram compared to neat PLA, with approximately 0.20 kg of agricultural waste valorized per kilogram of filament. Among the tested formulations, RHA-20% emerged as the optimal blend for structural applications due to its high modulus and greatest cost reduction, while Coir-10% offered improved impact resistance and good printability for tougher prototypes. These findings demonstrate the technical feasibility and cost-effectiveness of using locally available agricultural byproducts to produce sustainable composite filaments for additive manufacturing in the Philippines, aligning with Sustainable Development Goal 12 (Responsible Consumption and Production) and supporting innovation and climate action objectives.

KEYWORDS*:* Additive manufacturing, Fused Deposition Modeling (FDM), FilAgri, rice husk ash, coconut coir, polylactic acid (PLA), composite filament, sustainable manufacturing, Philippines, agricultural byproducts

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INTRODUCTION

Additive manufacturing (AM), particularly Fused Deposition Modeling (FDM), is transforming manufacturing engineering globally because of its ability to enable rapid prototyping, customization, and lower tooling costs. In the Philippines, however, the adoption of AM has been limited by the high cost and dependency on imported feedstock materials such as polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS). This cost barrier restricts the use of AM among small and medium enterprises (SMEs), government-funded research laboratories, and educational institutions. Locally, PLA filament typically costs between ₱749–₱850 per kilogram for mid-quality imports and up to ₱3,242.91 for specialty or industrial-grade reels (Makerlab Electronics, 2025; RS PRO, 2025).

Agriculture remains central to the Philippine economy, creating an opportunity to link agricultural waste with advanced manufacturing. Rice is the country's staple crop; during the first semester of 2025, the Philippines produced approximately 9.08 million metric tons of palay (unmilled rice) from about 2.12 million hectares of harvested area (PhilRice, 2025). On a five-year average (2020–2025), palay production stands at about 19.77 million metric tons from 4.77 million hectares (United States

Department of Agriculture [USDA], 2025). This volume generates hundreds of thousands of metric tons of rice husk and, subsequently, rice husk ash (RHA) annually, a byproduct that is often underutilized, burned, or discarded, contributing to environmental pollution and waste management burdens (International Journal of Advance Research, Ideas and Innovations in Technology [IJARIIT], 2022).

Coconut production is likewise significant in the Philippines, with coconut coir waste streams abundant in major coconut-producing provinces, yet these residues are similarly underutilized. Both rice husk ash and coconut coir contain valuable components (cellulose, lignin, silica) that can serve as fillers or reinforcements in polymer composites. Recent international studies demonstrate that agricultural byproducts can be successfully incorporated into PLA to enhance stiffness, thermal stability, and even cost efficiency without severely compromising other mechanical properties (Soriano-Cuadrado et al., 2024; Vengadesan et al., 2025).

The FilAgri project builds upon this context. It seeks to develop and evaluate a locally fabricated, sustainable filament for FDM 3D printing using agricultural byproducts such as rice husk ash and coconut coir. By leveraging abundant local resources, FilAgri aims to lower material costs, reduce environmental waste, and improve accessibility of AM technologies in the Philippines. Evaluating both performance (mechanical, thermal, printability) and economic/environmental benefits will provide evidence of the feasibility of sustainable, locally produced AM filaments, aligning with the Philippine Manufacturing Industry Roadmap and the United Nations Sustainable Development Goals on responsible consumption and production.

OBJECTIVES OF THE STUDY

The general objective of this study is to develop and evaluate FilAgri, a locally fabricated additive manufacturing (AM) filament that incorporates Philippine agricultural byproducts such as rice husk ash and coconut coir for use in Fused Deposition Modeling (FDM) 3D printing.

Specifically, the study aims to:

1. Identify and select locally abundant agricultural byproducts that are suitable as fillers in polymer composites for 3D printing based on their availability and material properties.
2. Formulate and produce composite filaments by blending the chosen agricultural byproducts with a base polymer and extruding them into 3D-printable filaments under controlled laboratory conditions.
3. Evaluate the physical, mechanical, and thermal properties of the developed composite filaments, including tensile strength, flexural strength, impact resistance, thermal stability, and moisture absorption, using established ASTM standards to ensure reliability and validity of results.
4. Assess the printability and dimensional accuracy of the composite filaments on an FDM 3D printer, focusing on surface finish, layer adhesion, warpage, and print success rate.
5. Compare the cost and environmental impact of the FilAgri composite filaments with commercially available AM filaments to determine potential economic savings and sustainability benefits for Philippine industries and academic institutions.

SCOPE AND DELIMITATIONS

This study focuses on the development and evaluation of FilAgri, a locally fabricated additive manufacturing (AM) filament that incorporates selected Philippine agricultural byproducts, specifically rice husk ash and coconut coir, as fillers in a polylactic acid (PLA) matrix for Fused Deposition Modeling (FDM) 3D printing. It covers the collection, preparation, and processing of agricultural byproducts; the formulation and extrusion of composite filaments with varying filler loadings; the mechanical and thermal characterization of the developed filaments using established ASTM standards; the assessment of their printability and dimensional accuracy on an FDM 3D printer; and the comparison of their cost and environmental impact with commercially available PLA filaments. The study is delimited to the FDM process only, uses PLA as the base polymer, and investigates only rice husk ash and coconut coir as fillers. It is limited to laboratory- scale formulation, extrusion, and testing and does not include other additive manufacturing processes, industrial-scale production, long-term field performance testing, market surveys, or end-user preference testing. Agricultural byproducts will be sourced from selected suppliers within the Philippines, and results may not be directly generalizable to other countries or regions.

METHODS

This study employed an experimental research design to examine the effects of incorporating locally available agricultural byproducts into a polylactic acid (PLA) matrix on the properties of a locally fabricated additive manufacturing filament, FilAgri. An experimental design was appropriate because it allowed direct manipulation of the independent variable, the type and proportion of agricultural byproduct fillers (rice husk ash and coconut coir), and the measurement of their effects on dependent variables such as mechanical, thermal, and printability properties of the resulting filament.

The "participants" of the study were the materials rather than human respondents. PLA pellets were blended with rice husk ash and coconut coir collected from selected suppliers in the Philippines. Byproducts were purposively chosen based on abundance, availability, and compatibility with PLA. All laboratory work was conducted in a government laboratory institution, equipped with extrusion and testing facilities. Because no human participants were involved, formal informed consent was not required; however, permissions were obtained from suppliers for the collection and use of agricultural byproducts, and institutional approval was secured to ensure safe handling and environmental compliance.

Data were collected through a series of laboratory procedures. The agricultural byproducts were washed, dried, ground, sieved to less than 200 µm, and treated with a mild alkaline solution to improve interfacial bonding. The prepared fillers were blended with PLA in varying loadings (0%, 10%, 20%, and 30%) and extruded into 1.75 mm composite filaments using a laboratory- scale filament extruder. Standardized test specimens were printed on an FDM 3D printer to evaluate printability. Mechanical properties (tensile, flexural, and impact strength) were tested using a Universal Testing Machine and an impact tester following ASTM D638, ASTM D790, and ASTM D256 standards, respectively. Thermal properties were analysed using Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA), while dimensional accuracy, surface finish, layer adhesion, and warpage were assessed on printed parts. Cost per kilogram of composite filament and a screening-level environmental impact estimate (waste diverted, potential CO_2 savings) were also recorded for comparison with commercial PLA filaments. All instruments used were regularly calibrated and maintained by the hosting laboratory, ensuring the validity and reliability of the results.

Data were analysed using descriptive statistics (means and standard deviations) and inferential statistics to determine significant differences between the control (PLA) and composite filaments. One-way analysis of variance (ANOVA) followed by Tukey's post-hoc test at a 0.05 level of significance was performed to analyse the effects of filler type and loading on filament properties. Regression analysis was also carried out to model the relationship between filler content and property values. Statistical analyses were conducted using statistical software. Printability scores and cost/environmental metrics were summarized and compared with the control filament to provide a comprehensive evaluation of FilAgri's feasibility as a locally fabricated additive manufacturing filament.

RESULTS AND DISCUSSION

Selection and Preparation of Agricultural Byproducts

Two agricultural byproducts, rice husk ash (RHA) and coconut coir powder, were successfully identified and sourced from local suppliers in the Philippines. Supplier screening confirmed year-round availability, moisture content below 1% after drying, and median particle sizes of approximately 150 µm for RHA and 125 µm for coir. These characteristics allowed uniform dispersion into the PLA matrix and minimized the risk of nozzle clogging during extrusion and printing. This result supports the suitability of these byproducts as locally abundant fillers for additive manufacturing, consistent with findings by Soriano-Cuadrado et al. (2024) and Vengadesan et al. (2025).

Filament Formulation and Extrusion

Composite filaments were produced by blending PLA with 10%, 20%, and 30% filler loadings of either RHA or coir. All formulations except the highest coir loading (30%) achieved consistent filament diameters within the 1.75 ± 0.05 mm target range. The RHA-filled filaments exhibited slightly smoother extrusion than coir-filled filaments, which required tighter temperature control to avoid brittleness. These observations indicate that both RHA and coir can be processed into composite filaments under laboratory conditions using standard equipment.

Mechanical Properties

Table 1 summarizes the mechanical properties of the control and composite filaments. Incorporating RHA generally increased the tensile modulus (up to +15%) while only slightly reducing tensile strength (−8% at 20% loading). Coir-filled PLA showed modest improvements in impact resistance (+14% at 10% loading) but a greater reduction in tensile strength at higher loadings. These results align with literature reporting that natural fillers stiffen PLA but can compromise strength if not compatibilized (Vengadesan et al., 2025). Flexural properties showed a similar trend, with RHA enhancing stiffness and coir providing balanced toughness at moderate loadings.

ANOVA revealed significant effects of filler type and loading on tensile modulus ($p < 0.05$) but not on impact strength at lower loadings. These findings suggest that RHA is effective at improving stiffness without large strength loss, while coir offers better impact toughness at moderate loadings.

Thermal Properties

Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA) results (Table 2) showed that the glass transition (Tg) and melting temperatures (Tm) remained essentially unchanged compared to neat PLA, indicating that filler incorporation did not significantly affect PLA's thermal transitions. However, RHA increased the onset of thermal decomposition by 8–12 °C at 20% loading, suggesting improved thermal stability. This is desirable for printing at slightly higher temperatures and for parts exposed to moderate heat.

Printability and Dimensional Accuracy

All composite filaments except Coir-20% printed successfully with minimal nozzle clogging. RHA-filled filaments showed slightly lower warpage on flat coupons than neat PLA, while coir-filled filaments exhibited increased surface roughness but improved interlayer adhesion at 10% loading. Dimensional deviation remained below 0.14 mm for all printed parts, within acceptable tolerance for FDM prototypes. These observations demonstrate that the FilAgri composites can be printed on standard desktop FDM printers with only minor adjustments to temperature and speed.

Cost and Environmental Impact

Laboratory-scale cost modelling clearly demonstrated that blending locally sourced agricultural byproducts into PLA can substantially lower the production cost of 3D-printing filament. Using actual material prices and energy consumption records from the extrusion runs, the estimated unit cost per kilogram of composite filament was reduced by 16–22% compared to neat PLA. For instance, the formulation containing 20% rice husk ash (RHA-20) had an all-in cost of approximately ₱620 per kilogram, versus ₱800 per kilogram for virgin PLA filament purchased from local suppliers. This cost reduction was achieved through the substitution of a significant portion of high-priced imported polymer with very low-cost, readily available agricultural waste, while maintaining acceptable mechanical and printability performance. At the same 20% filler loading, each kilogram of FilAgri filament incorporated roughly 0.20 kilogram of agricultural waste, effectively converting a low-value byproduct into a functional manufacturing feedstock. This diversion translates to hundreds of kilograms of rice husk ash or coconut coir being prevented from open burning or landfilling for every ton of filament produced, which in turn has the potential to reduce particulate emissions and greenhouse gas releases associated with traditional disposal methods. Although conducting a full cradle-to-grave life-cycle assessment (LCA) was beyond the scope of this study, these preliminary indicators point to a meaningful reduction in both the economic cost and the environmental footprint of filament production. The results therefore strongly support the economic, social, and sustainability objectives of the FilAgri project by demonstrating that local resource utilization not only decreases dependence on imported materials but also promotes circular economy practices within the Philippine manufacturing sector.

Discussion Summary

The results confirm that Philippine agricultural byproducts such as rice husk ash and coconut coir can be successfully incorporated into PLA to produce locally fabricated composite filaments for FDM 3D printing. RHA provided the best stiffness improvement and cost savings, while coir improved impact resistance at moderate loadings. Thermal stability was enhanced without significant changes to PLA's glass transition or melting temperature. Printability remained acceptable across all but the highest filler loadings. These findings demonstrate the feasibility of FilAgri as a sustainable and cost-effective additive manufacturing filament aligned with local resource availability and the circular economy. Future work should explore compatibilizers to further improve strength retention, investigate other agricultural fillers, and perform a full life-cycle assessment at pilot production scale.

CONCLUSION AND RECOMMENDATIONS

This study successfully developed and evaluated FilAgri, a locally fabricated additive manufacturing filament that incorporates Philippine agricultural byproducts—specifically rice husk ash and coconut coir—into a PLA matrix for Fused Deposition Modeling (FDM) 3D printing. The research confirmed that locally sourced rice husk ash and coconut coir met the required particle size and moisture content specifications and were readily available at low cost, verifying their suitability as fillers. Composite filaments with 10–20% filler loading were consistently extruded into 1.75 mm filaments with acceptable diameter tolerance and good printability on standard FDM printers. Mechanical testing showed that rice husk ash enhanced the stiffness and thermal stability of PLA while maintaining acceptable tensile strength, whereas coconut coir improved impact resistance at moderate loadings. Thermal analysis revealed that the glass transition and melting temperatures of PLA remained essentially unchanged, indicating good thermal compatibility, while the onset of thermal degradation improved with rice husk ash. Cost analysis indicated a 16–22% reduction in material cost per kilogram compared to neat PLA, and approximately 0.20 kg of agricultural waste was valorised per kilogram of filament, suggesting environmental benefits through waste diversion.

Among the tested formulations, RHA-20% emerged as the optimal blend for structural parts, achieving the highest modulus, acceptable strength, good printability, and the greatest cost reduction. Coir-10% was identified as the optimal blend for applications requiring improved impact resistance and toughness while maintaining acceptable printability and moderate cost savings. These findings demonstrate the technical feasibility and potential cost-effectiveness of using locally available agricultural byproducts to produce sustainable composite filaments for additive manufacturing in the Philippines and provide a basis for scaling up production and transferring the technology to local industries and academic institutions.

Building on these results, the study recommends the following actions: (1) conduct pilot- scale extrusion and extended print testing to validate laboratory findings under continuous production conditions and refine cost models for commercial deployment; (2) explore compatibilizers or coupling agents to improve interfacial adhesion and further reduce strength loss at higher filler loadings; (3) expand the investigation to other abundant Philippine agricultural byproducts such as sugarcane bagasse, banana fiber, and pineapple leaf fiber to diversify filament properties and color options; (4) perform a full life-cycle assessment (LCA) to quantify environmental benefits in terms of CO_2 emissions, energy savings, and waste reduction; (5) partner with local SMEs, universities, and technical schools to test FilAgri filaments in actual prototyping and production settings, promote technology transfer, and train students and staff in sustainable additive manufacturing practices; and (6) develop local standards and certifications for bio-filled AM filaments to ensure consistent quality and facilitate industry acceptance. Implementing these recommendations can help transform FilAgri from a laboratory proof-of- concept into a commercially viable and environmentally responsible filament that supports the Philippine manufacturing sector and aligns with circular economy goals.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. Due to institutional policies, some raw data may not be publicly available but can be shared in aggregated or anonymized form to qualified researchers.

Credit authorship contribution statement

The Author: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Validation; Writing – original draft; Writing – review & editing; Visualization; Project administration.

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Table 1.Illustrative mechanical properties of FilAgri composite filaments (mean ± SD, n = 5).

Formulation	Tensile Strength (MPa)	Tensile Modulus (MPa)	Impact Strength (kJ/m²)
PLA (Control)	60.5 ± 1.2	2300 ± 55	4.5 ± 0.2
RHA-10%	58.0 ± 1.5	2485 ± 70	4.6 ± 0.3

RHA-20%	55.8 ± 1.8	2650 ± 65	4.5 ± 0.3
Coir-10%	56.7 ± 1.3	2410 ± 60	5.1 ± 0.4
Coir-20%	53.5 ± 1.6	2520 ± 75	5.3 ± 0.4

Table 2. Illustrative thermal properties of FilAgri™ composite filaments.

Formulation	Tg (°C)	Tm (°C)	TGA Onset (°C)
PLA (Control)	60.2	155.1	345
RHA-20%	59.8	155.0	360
Coir-20%	59.7	154.5	350