Kwaghe International
Journal of Sciences and Technology

ISSN: 1595-7977

Index: Harvard, Boston, Sydney University, Dimensions, Lens, ResearchGet Scilit, Semantic, Google Scholar, Base etc

https://doi.org/10.58578/KIJST.v3i3.11829

Thermal, Structural and Flammability Characteristics of Polypropylene Composites Reinforced with Untreated *Canarium schweinfurthii* Nut-Shell Particles

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Jul 4, 2026	Aug 1, 2026	Aug 13, 2026	Aug 18, 2026

Abstract

The increasing demand for sustainable materials has intensified interest in converting agricultural residues into functional fillers for polymer composites. This study investigated the thermal, structural, and flammability characteristics of polypropylene (PP) composites containing untreated *Canarium schweinfurthii* nut-shell (CFN) particles. The particles were processed to a size of 45 μm and incorporated into PP at loadings of 0, 10, 15, 20, 25, and 30 wt.% using solvent casting. The resulting composites were characterized through density measurement, flame-propagation testing, Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and X-ray diffraction (XRD). Composite density increased progressively with CFN loading. However, flame-propagation rates also increased at higher loadings, a response consistent with the combustible lignocellulosic composition of the particles and the generation of volatile degradation products. FTIR spectra displayed the characteristic functional groups of both PP and CFN, while the absence of new absorption bands indicated that filler–matrix interactions were

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predominantly physical. DSC revealed thermal events associated with moisture removal, PP crystallization, and degradation of the lignocellulosic constituents, demonstrating that CFN incorporation modified the matrix's thermal response. XRD analysis confirmed that the characteristic α-crystalline structure of PP was retained after particle incorporation, although the degree of crystallinity varied with filler loading. These findings demonstrate that untreated *C. schweinfurthii* nut-shell particles can function as sustainable biofillers in PP composites for nonstructural applications. The study further establishes how CFN loading influences composite density, thermal behavior, crystallinity, and flame propagation, although the increased flammability at higher loadings should be considered in subsequent material development.

Keywords: *Canarium schweinfurthii*; Crystallinity; Flame Propagation; Polypropylene Composites; Sustainable Biofillers

INTRODUCTION

Increasing concerns about environmental sustainability and the depletion of non-renewable resources have stimulated extensive research into the development of eco-friendly engineering materials. One approach receiving considerable attention is the incorporation of agricultural residues into polymer matrices to produce value-added composite materials. The use of lignocellulosic wastes as reinforcing agents in thermoplastics not only improves material utilization but also offers an environmentally responsible means of managing biomass residues that would otherwise constitute disposal challenges (Salazar-Cruz *et al.*, 2022). Among commercially available thermoplastics, polypropylene has remained highly attractive because of its low density, resistance to chemical attack, affordability, and ease of fabrication. Nevertheless, its relatively low rigidity and moderate resistance to elevated temperatures limit its performance in applications requiring enhanced structural capability. Reinforcement with natural fillers derived from agricultural by-products therefore represents a practical strategy for extending the applicability of polypropylene while promoting sustainable material development.

One agricultural residue that has received limited scientific attention is the shell of *Canarium schweinfurthii*. Large quantities of this lignocellulosic by-product are generated during the processing of the fruit, yet its potential for advanced material applications remains largely unexplored. The shell possesses a rigid structure and appreciable lignin content, characteristics that suggest its suitability as a reinforcing component in polymer

composites. When incorporated into a polypropylene matrix, these particles may influence the crystallization process by acting as nucleating entities, thereby modifying the internal structure and thermal response of the resulting composite. Understanding the nature of these interactions is essential for designing materials capable of maintaining desirable performance under thermal and mechanical loading conditions (Tran *et al.*, 2025). Despite the advantages associated with natural fillers, achieving effective interaction between lignocellulosic particles and polypropylene remains a significant challenge. The hydrophilic nature of plant-derived reinforcements contrasts sharply with the hydrophobic character of polypropylene, often resulting in weak interfacial bonding. This incompatibility can lead to inadequate stress transfer, particle agglomeration, and the formation of voids that adversely affect composite properties. To improve adhesion at the filler–matrix interface, maleic anhydride-grafted polypropylene is commonly introduced during composite processing. The reactive groups present in this compatibilizer facilitate interactions between the polymer chains and the hydroxyl-rich filler surface, thereby strengthening the interface and contributing to improved stability and mechanical efficiency of the composite system (Benchikh *et al.*, 2024; Soares *et al.*, 2023).

Evaluating the thermal characteristics of reinforced polypropylene systems is necessary for determining their potential in practical applications. Thermogravimetric analysis is widely employed to assess thermal stability and degradation behaviour by providing information on decomposition patterns and temperature resistance. In addition, scanning electron microscopy enables direct examination of the composite microstructure, offering insight into particle distribution, dispersion quality, and the degree of adhesion developed between the reinforcing phase and the surrounding matrix. Together, these techniques provide valuable evidence of the structural features responsible for the observed performance of the composites. Further understanding of filler-induced modifications can be obtained through complementary analytical methods. X-ray diffraction analysis is particularly useful for investigating the crystalline characteristics of polypropylene composites, allowing the identification of crystal structures and the assessment of changes in nucleation behaviour and crystal orientation resulting from the incorporation of *Canarium schweinfurthii* shell particles (Jordá-Reolid *et al.*, 2023). Likewise, Fourier-transform infrared spectroscopy provides information on the chemical environment of the composite by detecting functional groups and possible interactions occurring at the filler–matrix interface. This technique can therefore be employed to verify the effectiveness of

compatibilization approaches aimed at improving interfacial bonding and structural stability (Barhoumi *et al*., 2025).

Apart from structural and thermal considerations, the processing behaviour of composite melts is equally important, particularly for manufacturing methods such as extrusion and injection moulding. Changes in the concentration of reinforcing particles can alter melt flow characteristics and viscosity, which directly influence processability and the quality of finished products. In addition, lignocellulosic fillers are generally susceptible to moisture uptake, and their incorporation may affect the water absorption behaviour of the composite. Such changes can influence dimensional stability and durability during long-term exposure to humid service environments. Consequently, understanding these hygrothermal responses is important for predicting the reliability of the material in practical use.

The dimensions and surface characteristics of the reinforcing particles also contribute significantly to the development of the composite microstructure. Variations in particle size distribution can affect nucleation efficiency, crystal growth behaviour, and the final morphology of the polypropylene matrix. Dynamic mechanical analysis further complements these investigations by providing information on the viscoelastic response of the material, including its stiffness, damping behaviour, and thermal transitions over a range of temperatures. Collectively, these evaluations facilitate the establishment of meaningful relationships between processing conditions, structure, and material performance in bio-based composite systems. Therefore, this study systematically investigates the thermal, structural, and morphological properties of polypropylene composites reinforced with *Canarium schweinfurthii* nut shell particles. Through the integration of multiple characterization techniques and the examination of the influence of filler loading, the study seeks to provide a comprehensive understanding of the mechanisms governing the behaviour of these composites. The findings are expected to advance the utilization of agricultural residues as functional reinforcements and contribute to the development of sustainable polymer composites possessing enhanced structural integrity and improved thermal performance for potential industrial applications.

MATERIALS AND METHODS

The materials used in this study were obtained from local sources within Nigeria to promote the utilization of indigenous resources in the development of sustainable polymer composites. *Canarium schweinfurthii* nut shells were collected from Barkin-Ladi Local Government Area of Plateau State, Nigeria. The shells were manually sorted to remove stones, damaged portions, and other extraneous materials before being thoroughly washed with distilled water to eliminate adhering dirt and impurities. The cleaned shells were air-dried under laboratory conditions prior to further processing. Commercial polypropylene (PP) pellets used as the polymer matrix were purchased from Jemita Market, Yola, Adamawa State, Nigeria. Analytical-grade xylene was employed as the solvent during composite preparation. Other reagents used during sample preparation included sodium hydroxide (NaOH), hydrochloric acid (HCl), and sodium chloride (NaCl). Distilled water produced in the Chemistry Laboratory of Modibbo Adama University (MAU), Yola, Nigeria, was used for cleaning and other preparatory procedures. The preliminary processing of the nut shells, including drying, grinding, and sieving, was carried out at the Chemistry Laboratory of Modibbo Adama University. Standard laboratory equipment such as an analytical balance, borosilicate glassware, funnels, spatulas, a laboratory grinder, a temperature-controlled heating system, and custom-fabricated aluminium moulds were employed during the fabrication of the composite samples.

Preparation of *Canarium schweinfurthii* Nut Shell Particles

The collected nut shells were first washed thoroughly with distilled water to remove adhering contaminants and then air-dried at ambient conditions. To ensure complete removal of moisture, the shells were further dried in an oven at 100 °C for 24 h. After drying, the samples were allowed to cool to room temperature and subsequently pulverized using a laboratory grinder. The resulting powder was sieved through a 45 μm mesh to obtain particles of relatively uniform size suitable for composite production. The sieved particles were stored in clean, airtight containers until required for subsequent processing (Atoshi *et al*., 2023)

Preparation of Polypropylene–*Canarium schweinfurthii* Shell Composites

Composite samples were prepared using the solvent casting technique. A fixed mass of 10 g of polypropylene pellets was used for all formulations. The polypropylene was introduced into a borosilicate beaker containing an appropriate quantity of xylene and

heated to approximately 150 °C until complete dissolution occurred, resulting in a homogeneous polymer solution. Predetermined quantities of *Canarium schweinfurthii* shell powder corresponding to filler loadings of 10, 15, 20, 25, and 30 wt.% were gradually added to the dissolved polypropylene while continuous stirring was maintained for approximately 5 min to facilitate uniform distribution of the particles within the polymer matrix. A control sample containing only polypropylene (0 wt.% filler) was also prepared under identical conditions. The composite formulations were calculated based on a constant polypropylene mass of 10 g and are presented in Table 1.

Table 1. Composite formulations used in the study.

Sample Code	Polypropylene (g)	Nut Shell Powder (g)	Filler Loading (wt.%)
PP	10.00	0.00	0
PP/CS10	10.00	1.11	10
PP/CS15	10.00	1.76	15
PP/CS20	10.00	2.50	20
PP/CS25	10.00	3.33	25
PP/CS30	10.00	4.29	30

After mixing, the resulting slurry was carefully poured into rectangular aluminium moulds measuring approximately 2 cm × 2 cm × 8 cm. The moulded specimens were allowed to stand under ambient laboratory conditions for approximately 40 h to facilitate solvent evaporation and sample stabilization. Thereafter, the specimens were conditioned in accordance with ASTM D618-99 prior to characterization.

Density Test

The density of the composites was determined following ASTM D792 standards. Each composite sample's mass was recorded using an analytical balance, and the volume was calculated from the dimensions of each sample (length × breadth × width), which were precisely measured with a digital vernier caliper. The density of the samples was then calculated as the mass-to-volume ratio (kg/m³) using the formula in Equation 1 (Ago *et al.,* 2024):

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \text{ kg/m}^3 \quad \ldots\ldots 1$$

This method provides an accurate measurement of the composite's density (Lawal, 2019)

Flammability Test (ASTM D635)

To find out how quickly different samples burn, the process starts by marking a 20 mm section on each specimen. Each specimen is then secured horizontally in a retort stand, ensuring that a 60 mm portion extends beyond the clamp. The free end of the sample is set on fire, and the time taken for the sample to ignite is noted as the ignition time (It). The specimen is allowed to burn until it reaches the 20 mm mark, and the distance burned (Dp) is then measured. The relative rates of burning can be calculated using the following expression in Equation 2 (Dass *et al.,* 2016:

$$\text{Relative rate of burning} = \frac{Dp}{It} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where D_p = Propagation distance measured in mm, P_t = Flame propagation time measured in seconds, I_t = Ignition time measured in seconds

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier-transform infrared spectroscopy was performed to identify the functional groups present in the composite materials and to investigate possible interactions between the filler and the polymer matrix. Spectral measurements were conducted within the wavenumber range of 4000–400 cm^{-1} using the attenuated total reflectance technique. The characteristic absorption bands associated with lignocellulosic constituents and polypropylene were identified and compared among the different formulations to evaluate changes resulting from filler incorporation.

Differential Scanning Calorimetry (DSC)

The thermal properties of Nutshell/polypropylene composites were analyzed using differential scanning calorimetry (DSC) on a TA Instruments Model DSC-Q200. Approximately 5–7 mg of powdered DPF/PP composite sample was placed in an aluminum pan, with an empty aluminum pan serving as the reference. The DSC analysis was conducted in a nitrogen atmosphere, heating the sample from 50 to 195°C at a rate of 10°C/min.

X-ray Diffraction (XRD

X-ray diffraction analysis was employed to investigate the crystalline characteristics of the developed composites. Diffraction patterns were recorded using Cu-Kα radiation with a wavelength of 1.5406 Å over a 2θ scanning range of 5°–60° at a scanning rate of 2°

min^{-1}. The diffraction profiles were analysed to determine changes in crystallinity and crystal orientation associated with the addition of *Canarium schweinfurthii* shell particles. Variations in diffraction peak intensity and position were used to assess the influence of the filler on the structural organization of the polypropylene matrix.

RESULTS AND DISCUSSION

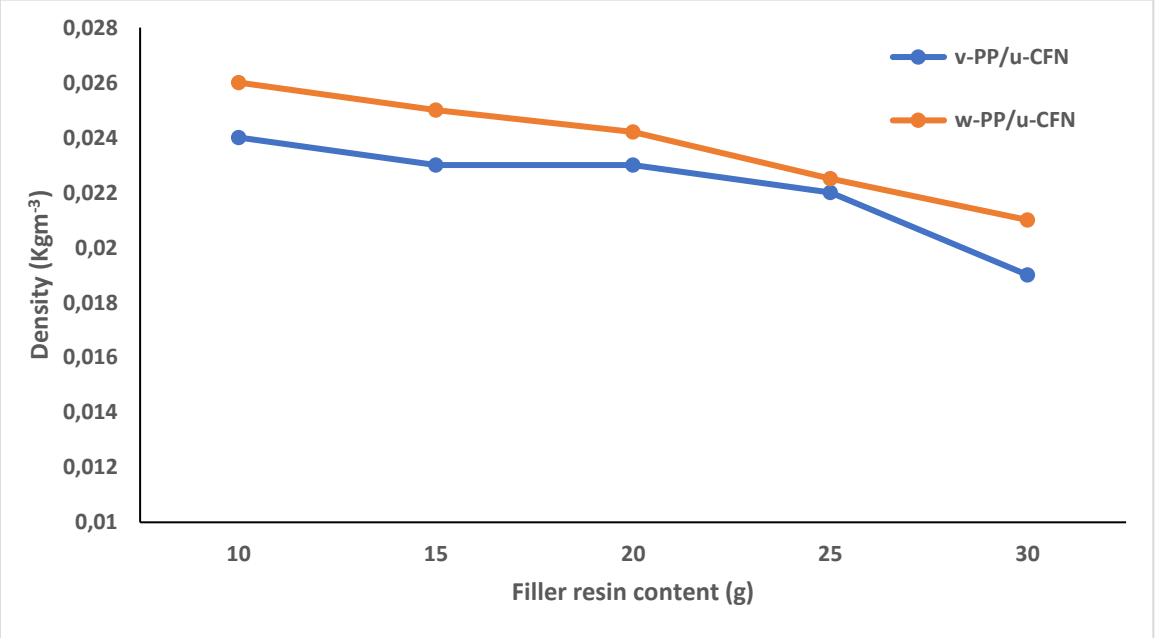


Figure 1: Effect of matrix content on density of untreated Canarium schweinfurthii fruit nut with unused and waste polypropylene-based composites at constant filler

Figure 1 presents the variation in density of polypropylene composites reinforced with untreated *Canarium schweinfurthii* fruit nut-shell (CFN) particles at filler loadings of 0, 10, 15, 20, 25, and 30 wt.%. The results indicate that the density of the composites increased progressively with increasing CFN content, suggesting that the incorporation of the lignocellulosic particles altered the packing characteristics and overall compactness of the polypropylene matrix. The observed increase in density can be attributed to the increasing proportion of the reinforcing phase within the composite structure. As the amount of CFN particles increased, a greater fraction of the available volume was occupied by the solid filler, leading to a corresponding increase in the mass per unit volume of the material. The presence of additional filler particles also restricted excessive shrinkage of the polymer phase during solidification, thereby contributing to a denser composite structure.

At lower filler loadings, the polypropylene matrix was able to adequately wet and surround the dispersed shell particles, resulting in relatively uniform structures with minimal disruption of the matrix continuity. However, as the filler concentration increased, the distance between neighbouring particles decreased, promoting closer particle packing within the composite. This improved packing efficiency may account for the gradual rise in density observed across the formulations. Although untreated lignocellulosic fillers generally exhibit limited compatibility with hydrophobic polypropylene, the increase in density suggests that the shell particles were sufficiently incorporated within the polymer matrix to enhance structural compactness. Nevertheless, the absence of chemical treatment may have contributed to the formation of localized interfacial defects, microvoids, and regions of particle agglomeration, particularly at higher filler loadings. Such imperfections are commonly reported in natural fibre-reinforced thermoplastic composites and arise from the weak interfacial interactions between the hydroxyl-rich filler surface and the non-polar polymer matrix (Kumar *et al.*, 2024). The occurrence of these interfacial voids may cause slight deviations from the theoretical density values expected for perfectly consolidated systems. Despite this limitation, the continuous increase in density observed in the present study indicates that the reinforcing effect of the *Canarium schweinfurthii* shell particles outweighed the influence of any defects introduced during processing. Similar observations have been reported for lignocellulosic particulate composites, where increasing filler loading enhances material compactness despite the absence of compatibilization (Ali, 2023).

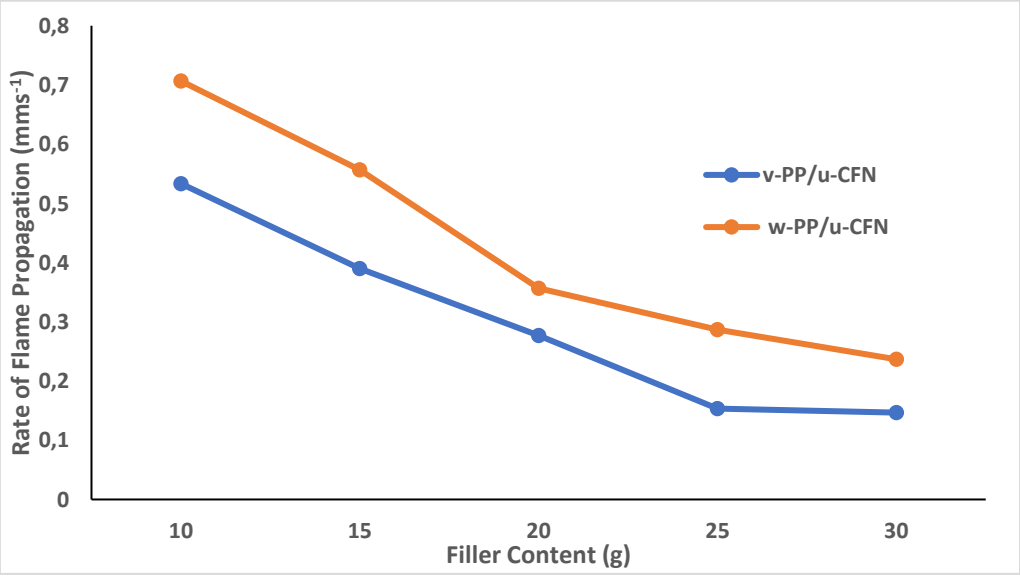


Figure 2: Effect of matrix content on rate of flame propagation of untreated *Canarium schweinfurthii* fruit nut (CFN) with unused and waste polypropylene-based composites at constant Polypropylene.

Figure 2 shows the effect of *Canarium schweinfurthii* fruit nut-shell (CFN) loading on the flame propagation behaviour of polypropylene composites containing untreated filler particles. The increase in flame spread observed at higher filler loadings suggests that the fire resistance of the composites decreased as the proportion of untreated CFN particles increased. At lower filler concentrations, the polypropylene matrix constituted the dominant phase and effectively enveloped the reinforcing particles. This continuous polymer network limited direct exposure of the lignocellulosic constituents to heat and oxygen, thereby slowing thermal degradation and retarding flame advancement across the specimen surface. However, as the CFN content increased from 10 to 30 wt.%, the amount of combustible biomass incorporated into the composite also increased. The higher concentration of lignocellulosic particles provided a greater supply of thermally degradable material, resulting in the generation of increased quantities of volatile decomposition products during combustion. These volatile compounds readily mixed with oxygen in the surrounding environment, thereby supporting flame growth and accelerating flame propagation through the composite.

The reduced effectiveness of the polymer phase at higher filler loadings may also have contributed to the observed behaviour. Increasing the amount of untreated shell particles decreased the continuity of the polypropylene matrix and reduced its ability to function as a protective barrier around the filler. Consequently, a larger proportion of the lignocellulosic reinforcement became susceptible to direct thermal attack, promoting earlier decomposition and facilitating the spread of the flame front. Similar observations have been reported for natural fibre-reinforced thermoplastic composites, where increasing filler content often results in diminished ignition resistance due to greater exposure of combustible plant constituents (Ao *et al.*, 2023). The thermal decomposition of these constituents releases flammable gases that sustain combustion and enhance flame spread within the composite structure (Muralidharan *et al.*, 2024). Poor interfacial adhesion can encourage the formation of microvoids and interfacial defects during processing. These discontinuities may act as channels that facilitate the diffusion of heat and oxygen into the interior of the material, thereby accelerating combustion. Increased filler loading can also intensify particle agglomeration, further contributing to non-uniform burning behaviour and higher flame propagation rates (Decsov *et al.*, 2023).

The phenomenon may also be associated with the candlewick effect commonly reported in natural fibre composites. Under thermal exposure, lignocellulosic particles can

promote the transport of molten degradation products and facilitate the continuous supply of combustible volatiles to the flame zone. This mechanism enhances flame sustainability and contributes to faster flame advancement as the concentration of the natural filler increases (Aloka *et al.*, 2024; Suruji, 2023). Increasing the proportion of untreated CFN particles increased the flame propagation rate, indicating reduced resistance to fire. While the incorporation of agricultural residues provides environmental and economic advantages, the results suggest that elevated filler concentrations may compromise flame retardancy. Therefore, optimizing filler loading or incorporating appropriate flame-retardant strategies may be necessary when these composites are intended for applications where fire safety is a critical requirement (Kanaginahal *et al.*, 2023).

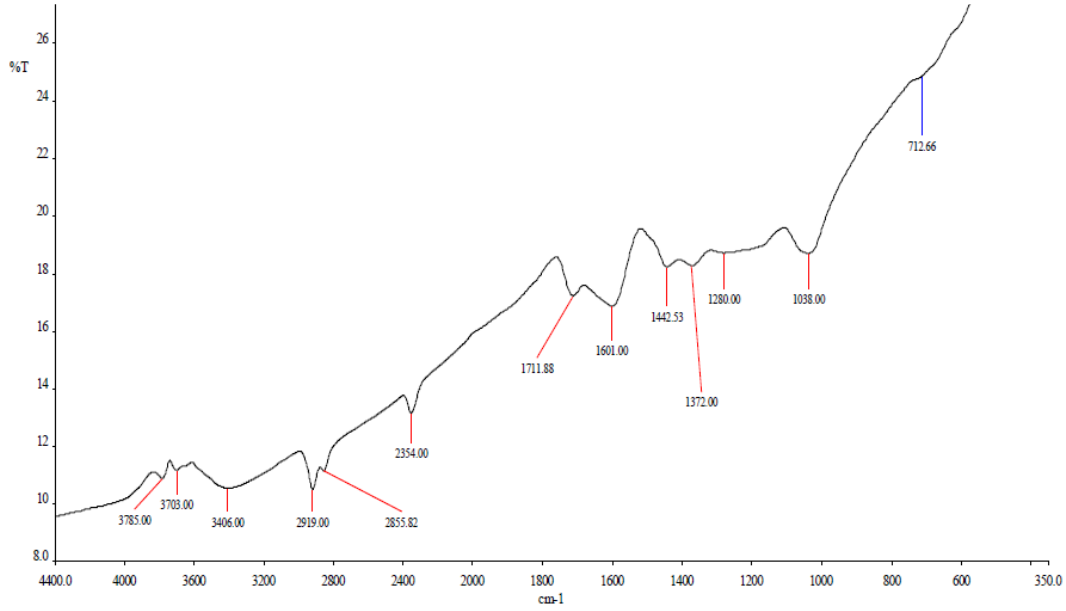


Figure 3: FTIR Spectrum for Untreated Canarium schweinfurthii nut/polypropylene composite

The Fourier transform infrared (FTIR) spectra of the polypropylene composites reinforced with untreated *Canarium schweinfurthii* nut-shell (CFN) particles at different filler loadings are presented in Figure 4. The absorption bands located around 2924 cm^{-1} and 2850 cm^{-1} are assigned to the asymmetric and symmetric stretching vibrations of aliphatic C–H bonds associated with the methylene and methyl groups of polypropylene. The persistence of these peaks across all formulations confirms that the fundamental chemical structure of the polypropylene matrix remained unchanged during composite fabrication. This observation suggests that the solvent casting process did not induce any significant

chemical degradation or modification of the polymer backbone. A broad absorption band observed within the region of 3400–3500 cm^{-1} is attributed to O–H stretching vibrations arising from hydroxyl groups present in cellulose, hemicellulose, and lignin, as well as moisture associated with the lignocellulosic filler. The presence of this band in the composite spectra confirms the incorporation of untreated CFN particles into the polypropylene matrix.

An absorption band appearing near 1730 cm^{-1} can be associated with C=O stretching vibrations originating from carbonyl-containing groups present in hemicellulose and other extractive components of the nut shell. The detection of this peak further confirms the presence of lignocellulosic constituents within the composite structure. Variations in the intensity of this band among the different formulations may be attributed to differences in filler concentration, with higher filler contents contributing a greater proportion of carbonyl-containing compounds to the overall spectrum. Additional peaks observed at approximately 1450 cm^{-1} and 1375 cm^{-1} correspond to CH_2 bending and CH_3 deformation vibrations characteristic of polypropylene. The retention of these absorption bands across all composite formulations indicates that the polymer matrix preserved its structural identity irrespective of the amount of CFN incorporated. Likewise, bands appearing in the fingerprint region below 1200 cm^{-1} are associated with a combination of C–O stretching, C–H rocking, and skeletal vibrations originating from both the polypropylene matrix and the lignocellulosic filler. The absence of additional peaks suggests that no new covalent bonds were formed between polypropylene and the untreated CFN particles during processing. Instead, the interaction between the two phases is likely dominated by physical adhesion and mechanical interlocking. Such behaviour is commonly reported in composites prepared from untreated natural fillers, where the hydrophilic filler surface exhibits limited chemical compatibility with hydrophobic thermoplastic matrices.

Differential Scanning Calorimetry (DSC) Analysis

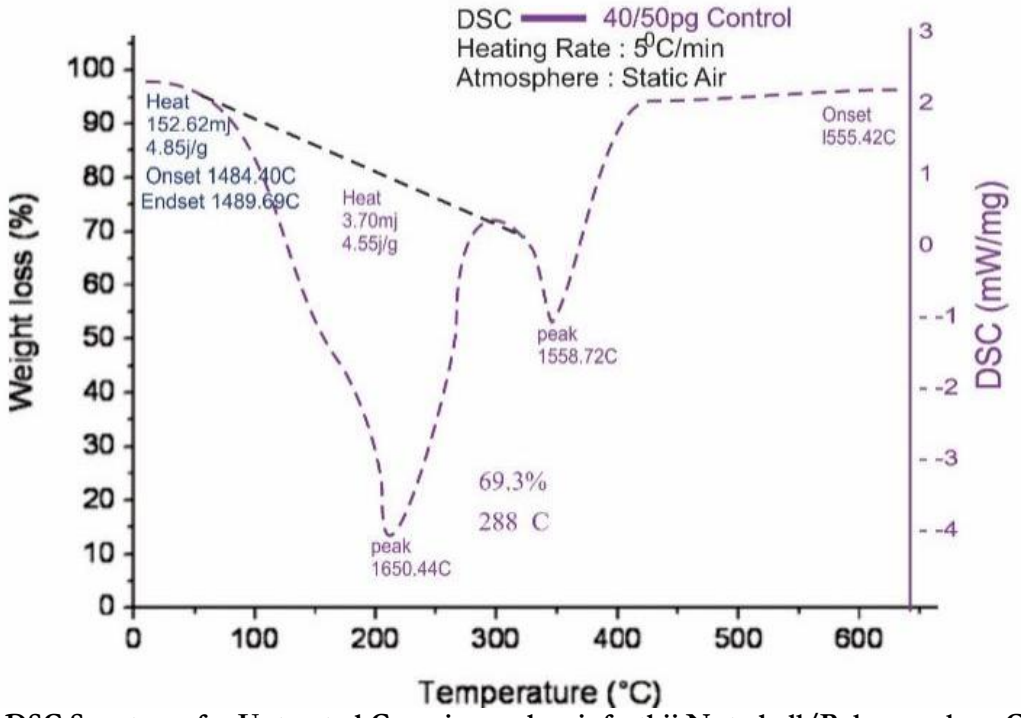


Figure 4: DSC Spectrum for Untreated Canarium schweinfurthii Nut-shell/Polypropylene Composite

The Differential Scanning Calorimetry (DSC) thermogram of the untreated *Canarium schweinfurthii* nut-shell (CFN) reinforced polypropylene composite provides valuable information regarding the thermal transitions and heat-induced structural changes occurring within the material. The DSC curve revealed an initial thermal event occurring between approximately 148.40 °C and 148.69 °C. This transition may be attributed to the evaporation of physically absorbed moisture and the release of low-molecular-weight volatile compounds associated with the lignocellulosic filler. Natural fillers are known to retain small amounts of moisture due to the presence of hydroxyl-containing components such as cellulose and hemicellulose. The removal of these volatile constituents during heating contributes to the stabilization of the composite prior to the onset of major thermal transformations.

At elevated temperatures, the thermogram indicated a major degradation event centred around 288 °C, accompanied by an estimated mass loss of approximately 69.3%. This substantial reduction in mass is attributed primarily to the decomposition of the lignocellulosic components of the CFN particles, particularly hemicellulose, cellulose, and portions of lignin. Hemicellulose generally undergoes thermal degradation at relatively

lower temperatures, followed by cellulose decomposition, while lignin degrades over a broader temperature interval. The release of volatile degradation products generated from these constituents contributes significantly to the observed mass loss during heating (Masuelli, 2021). Following the principal degradation stage, a residual char fraction remained, indicating that some portions of the composite possessed sufficient thermal resistance to withstand complete decomposition. The formation of this carbonaceous residue is often associated with the gradual degradation of lignin and the generation of thermally stable structures during pyrolysis. Such char residues may provide a degree of protection by acting as a physical barrier that limits heat penetration and slows the diffusion of oxygen into the underlying material during continued thermal exposure (Bichang'a *et al*., 2024).

The degradation behaviour observed in the present study also reflects the intrinsic characteristics of untreated lignocellulosic fillers. Because the CFN particles retained their native chemical composition, including extractives and hydroxyl-rich constituents, the composites may exhibit lower thermal stability than systems containing chemically modified fillers. The presence of these thermally sensitive components can facilitate earlier degradation and contribute to the evolution of combustible volatiles during heating (Kumar *et al*., 2024). Nevertheless, the DSC results demonstrate that untreated *Canarium schweinfurthii* particles remain capable of influencing the thermal behaviour of polypropylene composites through their effect on crystallization and degradation mechanisms. The nucleating action of the shell particles, together with the formation of residual char during decomposition, contributes to the overall thermal response of the material. These findings highlight the important role of filler incorporation in modifying the thermal characteristics of polypropylene-based composites and provide useful insight into their suitability for applications involving moderate thermal exposure (Rao *et al*., 2024).

X-ray Diffraction (XRD) Analysis

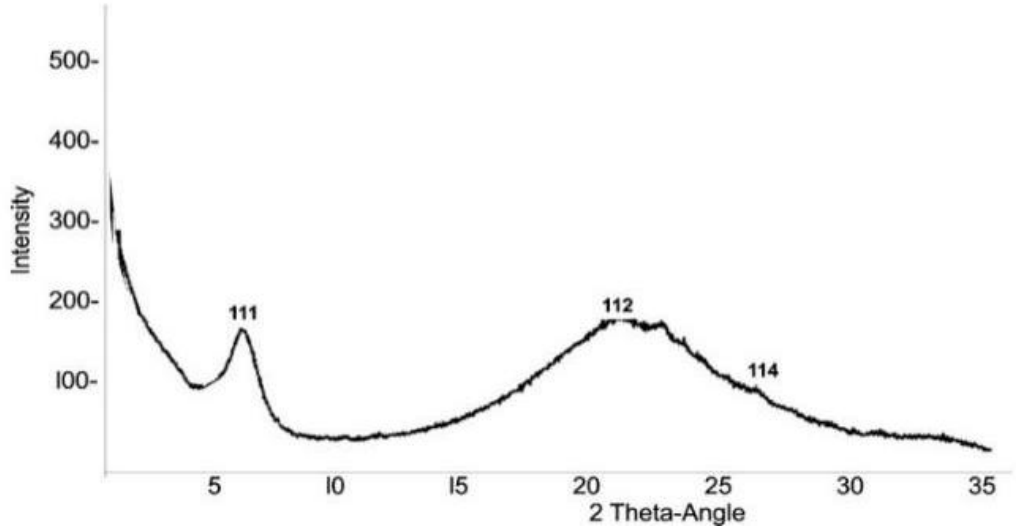


Figure 5: XRD Spectrum for untreated *Canarium schweinfurthii* Nut

The X-ray diffraction (XRD) patterns of the polypropylene composites reinforced with untreated *Canarium schweinfurthii* (CFN) nut-shell particles are presented in Figure 5. The diffraction profiles provide insight into the crystalline characteristics of the developed composites and the influence of filler incorporation on the structural organization of the polypropylene matrix. Although the composites contained different CFN loadings, the principal diffraction peaks remained at approximately the same 2θ positions, indicating that the incorporation of untreated nut-shell particles did not alter the fundamental crystalline structure of polypropylene. Characteristic diffraction peaks were observed around 2θ values of approximately 14°–15°, 17°–18°, 20°–21°, and 25°–26°, corresponding to the typical α-crystalline phase of polypropylene. The persistence of these reflections across all formulations confirms that the solvent casting process and the addition of untreated CFN particles did not induce the formation of new crystalline phases within the polymer matrix. Rather, the reinforcement influenced the degree of structural ordering within the existing polypropylene crystalline framework.

Differences in peak intensity and peak broadening were observed as the filler loading increased. At relatively low filler concentrations, the diffraction peaks appeared more pronounced, suggesting that the presence of CFN particles may have provided heterogeneous nucleation sites that facilitated the organization of polypropylene chains into ordered crystalline regions. The structural behaviour observed in the present study is consistent with reports on other natural filler-reinforced thermoplastic composites, where

untreated lignocellulosic particles influence the degree of crystallinity without changing the fundamental crystalline phase of the polymer matrix (Kumar *et al.*, 2024; Melyna & Afridana, 2023; Lee *et al.*, 2021; Mani *et al.*, 2024). Variations in crystallinity arising from filler incorporation have been linked to changes in stiffness, dimensional stability, and thermal behaviour of the resulting composites.

CONCLUSION

This study investigated the influence of untreated *Canarium schweinfurthii* nut-shell (CFN) particles on the thermal, structural, and morphological characteristics of polypropylene composites prepared through the solvent casting technique. The results demonstrated that the incorporation of CFN particles significantly affected the behaviour of the polypropylene matrix, confirming the potential of this underutilized agricultural residue as a sustainable reinforcing material. The density of the composites increased progressively with increasing filler loading, indicating improved material compactness and a greater contribution of the lignocellulosic phase to the overall structure of the composites. Conversely, the flame propagation rate increased as the CFN content increased, suggesting that higher filler concentrations reduced the fire resistance of the composites due to the combustible nature of the lignocellulosic constituents and the increased generation of volatile degradation products during thermal exposure. FTIR analysis confirmed the successful incorporation of untreated CFN particles into the polypropylene matrix without altering the intrinsic chemical structure of the polymer. The DSC results revealed distinct thermal transitions associated with the removal of absorbed moisture, crystallization processes within the polypropylene matrix, and the degradation of the lignocellulosic constituents of the nut shell. XRD analysis showed that the characteristic α-crystalline structure of polypropylene was retained after filler incorporation. Although the presence of untreated CFN particles modified the degree of crystallinity through nucleating and chain-restricting effects, no new crystalline phases were generated.

The study demonstrates that untreated *Canarium schweinfurthii* nut-shell particles can be effectively utilized as reinforcement in polypropylene composites, offering a promising route for the valorization of agricultural waste into value-added engineering materials. While increasing filler content improved composite densification, it also influenced flammability and interfacial interactions, emphasizing the importance of optimizing filler

loading to achieve a desirable balance between physical, thermal, and structural properties. The outcomes of this work contribute to the growing body of knowledge on sustainable polymer composites and highlight the potential of *Canarium schweinfurthii* nut-shell particles as environmentally friendly reinforcements for non-structural and semi-structural applications. Future studies should focus on the incorporation of compatibilizers or environmentally benign surface modification techniques to enhance filler–matrix adhesion, improve moisture resistance, and further optimize the overall performance of these bio-based composite systems.

REFERENCES

Ago, A. M., Johnson, G., Yakubu, J., Bifam, M., Dass, P. M., & Martha, J. (2024). Optimization and the influence of additives on the interfacial bonding between cocoa fruit shell powder and polypropylene-based composites. *African Journal of Biochemistry and Molecular Biology Research, 1*(1), 258–269. https://doi.org/10.58578/ajbmbr.v1i1.3474

Aloka, N. A. K., Jayasinghe, R., Priyadarshana, G., & Nilmini, A. H. L. R. (2024). Influence of fibre loading on the physico-mechanical properties of water hyacinth (*Eichhornia crassipes*) fibre-reinforced polyethylene composites. *Asian Journal of Chemistry, 36*(8), 1772. https://doi.org/10.14233/ajchem.2024.31699

Ali, R. (2023). *Impact of wood particles (reed)/polypropylene composites on the physical and structural properties* [Preprint]. *Research Square*. https://doi.org/10.21203/rs.3.rs-3508708/v1

Ao, X., Vázquez-López, A., Mocerino, D., González, C., & Wang, D. (2023). Flame retardancy and fire mechanical properties for natural fiber/polymer composites: A review. *Composites Part B: Engineering, 268*, Article 111069. https://doi.org/10.1016/j.compositesb.2023.111069

Atoshi, M. A., Joshua, Y., Gani, J., & Reuben, P. (2023). Rating of some physical properties of polyethylene/Iroko wood dust composite. *Bima Journal of Science and Technology Gombe, 7*(2), 113–122.

Barhoumi, N., Attia-Essaies, S., Samet, A., Ghanem, A., Khlifi, K., & Majid, F. (2025). Eco-friendly polypropylene composite reinforced with natural fillers: Mechanical properties and wear resistance. *MATEC Web of Conferences, 414*, Article 03003. https://doi.org/10.1051/matecconf/202541403003

Benchikh, L., Aouissi, T., Aitferhat, Y., Chorfi, H., Abacha, I., Kebaili, M., Guessoum, M., Merzouki, A., Grohens, Y., Carraro, M., & Djellali, S. (2024). Effect of different compatibilization routes on the mechanical, thermal, and rheological properties of polypropylene/cellulose nanocrystal nanocomposites. *Polymer Bulletin, 81*(12), 11007. https://doi.org/10.1007/s00289-024-05225-w

Bichang'a, D. O., Oladele, I. O., Alabi, O. O., Aramide, F. O., Oluseye, O., Borisade, S. G., Githinji, D. N., & Ojemaye, M. O. (2024). *Coconut shell agro-waste-derived cellulosic powder as a potential reinforcement for sustainable polymeric composite applications* [Preprint]. *Research Square*. https://doi.org/10.21203/rs.3.rs-4374947/v1

Dass, P. M., Mathias, B., Andrew, A., & Atoshi, M. A. (2016). Water absorption, flammability, hardness, and morphology tests on composites prepared from high-density polyethylene films/Doka wood dust particles. *British Journal of Applied Science & Technology, 17*(5), 1–10.

Decsov, K. E., Ötvös, B., Thanh, T. T. N., & Bocz, K. (2023). The effect of cellulose fibre length on the efficiency of an intumescent flame-retardant system in poly(lactic acid). *Fire, 6*(3), Article 97. https://doi.org/10.3390/fire6030097

Jordá-Reolid, M., Moreno, V., García, A. M., Covas, J. A., Gómez-Caturla, J., Martínez, J. I., & Quiles-Carrillo, L. (2023). Incorporation of argan shell flour in a biobased polypropylene matrix for the development of highly environmentally friendly composites by injection molding. *Polymers, 15*(12), Article 2743. https://doi.org/10.3390/polym15122743

Kanaginahal, G. M., Tambrallimath, V., Murthy, M., Mahale, R. S., Patil, A., Pawar, S. Y., & Kakkamari, P. (2023). Flammability studies of natural fiber-reinforced polymer composites fabricated by additive manufacturing technology: A review. *Journal of the Institution of Engineers (India): Series D, 105*(2), 1291. https://doi.org/10.1007/s40033-023-00509-3

Kumar, S. M. V., Jeyakumar, R., & Sakthivelmurugan, E. (2024). Evaluation of physico-mechanical, water absorption, and thermal properties of *Alstonia macrophylla* fiber-reinforced polypropylene composites. *Cellulose Chemistry and Technology, 58*, 547. https://doi.org/10.35812/cellulosechemtechnol.2024.58.51

Kumar, S. S., Shyamala, P., Pati, P. R., Mishra, D. K., Sharma, V. S., Tank, G., & Kanan, M. (2025). Investigation and machine-learning-based prediction of mechanical properties in hybrid natural fiber composites. *Scientific Reports, 15*(1). https://doi.org/10.1038/s41598-025-18944-5

Lee, C. H., Abdan, K., & Lee, S. H. (2021). Importance of interfacial adhesion conditions in the characterization of plant-fiber-reinforced polymer composites: A review. *Polymers, 13*(3), Article 438. https://doi.org/10.3390/polym13030438

Mani, S. K., Selvaraj, S., Sivanantham, G., Sahayaraj, A. F., Iyyadurai, J., & Mani, M. (2024). Advancements in chemical modifications using NaOH to explore the chemical, mechanical, and thermal properties of natural fiber polymer composites. *International Polymer Processing, 39*(4), 406. https://doi.org/10.1515/ipp-2024-0002

Masuelli, M. (2021). Fiber-reinforced plastics. In *IntechOpen eBooks*. IntechOpen. https://doi.org/10.5772/intechopen.95632

Melyna, E., & Afridana, A. P. (2023). The effect of coffee husk waste addition with alkalization treatment on the mechanical properties of polypropylene composites. *Equilibrium, 7*(1), 14. https://doi.org/10.20961/equilibrium.v7i1.68556

Muralidharan, N. D., Subramanian, J., Rajamanickam, S. K., Krishnasamy, P., Thiagamani, S. M. K., & Khan, A. (2024). Flame-retardant characteristics of natural fiber-reinforced polymer composites: A thematic review. *Polymer Composites, 45*(14), 12530. https://doi.org/10.1002/pc.28699

Rao, H. J., Melnikov, A., Fakhr, E. A., Pulikkalparambil, H., & Spitas, C. (2024). *Isolation and alkali treatment of novel natural fiber from Chinese burr stalk for sustainable polymer composites and versatile applications* [Preprint]. *Research Square*. https://doi.org/10.21203/rs.3.rs-5317079/v1

Salazar-Cruz, B. A., Chávez-Cinco, M. Y., Morales-Cepeda, A. B., Ramos-Galván, C. E., & Rivera-Armenta, J. L. (2022). Evaluation of thermal properties of composites prepared from chemically treated pistachio shell particles and polypropylene. *Molecules, 27*(2), Article 426. https://doi.org/10.3390/molecules27020426

Soares, C., Moura, E. A. B., Arenhardt, V., Deliza, E. E. V., & Filho, F. de S. P. (2023). Biotechnology management in the Amazon and the production of polypropylene/Brazil nut shell fiber biocomposites. *Revista de Gestão e Secretariado, 14*(7), 10734. https://doi.org/10.7769/gesec.v14i7.2424

Suruji, N. F. A. (2023). Physical and mechanical properties of bamboo fibers filled with calcium carbonate powder-reinforced epoxy composites for roofing applications. *International Journal for Research in Applied Science and Engineering Technology, 11*(11), 1254. https://doi.org/10.22214/ijraset.2023.56551

Tran, T. M. N., Prabhakar, M., Lee, D., & Song, J. (2025). Enhanced mechanical and thermal properties of green PP composites reinforced with bio-hybrid fibers and agro-waste fillers. *Advanced Composites and Hybrid Materials, 8*(2). https://doi.org/10.1007/s42114-025-01277-2