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Modification in thermal and electrical characteristics of royal palm frond (*roystonea regia*) through blending with high-density polyethylene

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The objective of this research is to characterize royal palm fronds (RPFs) and fabricate biocomposites (BCs) by reinforcing the RPF powder with high-density polyethylene (HDPE). RPF was grinded into powder, and various analyses were conducted to determine their moisture content, lignin content, and water and alcohol-benzene solubility. HDPE was dissolved in xylene solvent and RPF powder was mixed with molted HDPE to fabricate polymer BCs. The fabricated polymer BCs underwent examination for their electrical conductivity and thermal stability using direct current (σDC) conductivity and thermogravimetric-differential thermal analysis-differential thermogravimetry (TG-DTA-DTG). The results showed that the electrical conductivity and thermal stability of the BCs were significantly lower compared to the original royal palm frond fibers.

Keywords: Biocomposites, Royal palm, Lignocellulosic biomass, HDPE.

INTRODUCTION

Agricultural waste has received growing attention over decades for sustainable development of society and industries. Worldwide production of biomass per year is estimated to be approximately 140 gigatons (Gt) [1]. Palm waste is a major portion of agriculture waste which accounts for millions of metric tons annually [2]. It consists of solid waste (empty fruit bunches, palm kernel shells, fibers, trunk residues) and liquid waste (palm oil mill effluent) [3]. It requires proper management to reduce environmental impact. Management practices include waste-to-energy conversion, composting, biomass utilization, sustainable production practices and wastewater treatment [4, 5]. Efficient management of palm waste reduces pollution, offers economic opportunities, and promotes sustainability in the palm oil industry [6].

Royal palm is a kind of ornamental palm tree, mostly planted at the roadsides [7]. Royal palm tree sheds fronds periodically as a waste material. These fronds can be utilized in various ways such as building material for roofs, buckets, furniture, utensils, and polymer composites [8-10]. Palm fronds, a common waste material produced by palm tree residues, often present challenges in terms of disposal due to the environmental pollution caused by burning them. However, there are several alternative methods available for managing palm fronds in a more sustainable manner. Composting is a popular option, where palm fronds are decomposed under controlled conditions to create nutrient-rich soil. This process not only eliminates waste but also produces organic fertilizer or soil amendments, benefiting plant growth and soil health [11, 12]. Another method is mulching, where shredded or chipped palm fronds are spread around plants to retain moisture, suppress weeds, and improve overall soil quality [13]. As the fronds gradually break down, they release valuable nutrients into the soil.

Modification of wood through reinforcing polymer materials has received growing attention since decades [14]. Lignocellulosic biomass represents a promising solution for sustainable development, capable of meeting the growing global demand. The fronds of the Royal palm (*Roystonea regia*) can be classified as lignocellulosic waste, which presents an opportunity for resource utilization. Royal palm fiber-based products have emerged as cost-effective and potent materials for the production of composites [15]. By harnessing the lignocellulosic properties of the waste from the Royal palm, it becomes feasible to convert this material into valuable resources, thereby contributing to sustainability and resource optimization. Royal palm-derived composites find applications in diverse fields such as construction materials, sound barriers, agriculture, eco-friendly materials, bioplastics, and biocomposites [16].

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Palm waste has advantages over other agrowaste derived from stubble, straw, bagasse, and low-grade wood. It is abundantly available, grows quickly, producing fronds multiple times a year, making it a more preferable renewable and sustainable resource for composite development [17]. Also, palm fronds possess strength and flexibility, enhancing composite performance. They are lightweight, reducing overall product weight for practical applications. Palm frond waste is often cost-effective due to its availability and lower cost compared to other materials [18].

Biomass conversion technologies offer an innovative approach to managing palm fronds. Processes such as anaerobic digestion and gasification can convert the fronds into biogas, biofuels, or other forms of energy [19, 20]. This not only reduces waste but also generates renewable energy, contributing to a more sustainable energy mix. Additionally, palm fronds can be used as providing insulation and moisture absorption for livestock or animal shelters [21]. Palm fronds also have creative applications. They can be woven into baskets, mats, or used as material for crafting decorative items [22]. This approach promotes recycling and repurposing, reducing waste and adding aesthetic value to the fronds. While landfill disposal can be a last resort when no other options are available, it should be avoided due to its negative environmental impact.

EXPERIMENTAL

Material and method

In this research study, a novel approach was adopted to fabricate a polymer bio-composite by combining high-density polyethylene (HDPE) and RPF powder. Initially, both HDPE and RPF were ground into powder. Next, HDPE was dissolved in xylene solvent at a temperature of 90 °C while continuously stirring in isolated conditions. In the following step, RPF was added to the thick HDPE slurry with continuous stirring at a speed of 1000 rpm. The bio-composites (BCs) were prepared using HDPE and RPF in 10:90 wt %, respectively. A masterbatch was prepared by blending melted HDPE powder and RPF powder, which underwent compression pressure of 2000 psi and heating to a temperature of 200 °C at a rate of 1.25 °C per minute for a duration of 2 hours. During this process, the pressure gradually stabilized at around 1800 psi, indicating the completion of the compression. Efforts have been made to develop the BCs with uniform thickness and stable mechanical strength. The binding capability of HDPE with RPF powder was found appropriate in fabrication of bio-composite.

RESULTS AND DISCUSSION

Moisture content

The RPF was transformed into powder (Fig. 2). This RPF powder was utilized to determine its moisture content. 5gm of RPF powder was dried in an oven at 50°C. The weight of the RPF powder was measured at regular intervals, typically every hour, until a constant weight was achieved, indicating complete drying of RPF powder. % Moisture content = (5 – 4.53 / 5) × 100 = 9.41 %.

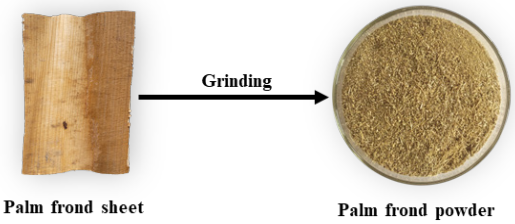

Fig. 1. Conversion of RPF sheets into powder

Water solubility analysis

ASTM D1106-56 was followed to determine the solubility of the RPF powder in distilled water as a solvent. Adding 2 g of the RPF powder to a beaker with 300 ml of distilled water at 23±2°C and stirring it thoroughly for 48 h the insoluble residue was filtered out with the help of filter paper and oven dried at 50°C for 4 h. The weight of insoluble residue found was 1.6 g.

% Water solubility = (Wt. of powder sample - Wt. of residue / Wt. of powder sample) × 100

% Water solubility = (2 – 1.6 / 2) × 100 = 20 %

Alcohol-benzene solubility

ASTM D1107-56 was followed for the alcohol and benzene solubility test of the RPF powder. 5 g of the previously dried RPF powder was packed in muslin cloth and placed in the Soxhlet and examined. This whole process of Soxhlet extraction method took 6 h, after that the residue was dried and weighed several times until its weight got constant, indicating that the residue is free from solvent. Total weight of the residue was found to be 4.48 g.

% Alcohol-benzene solubility = (Wt. of powder sample - Wt. of residue / Wt. of powder sample) × 100

% Alcohol-benzene solubility = (5 – 4.48 / 5) × 100 = 10.4 %.

Lignin content

ASTM D1106-96 is a standard test method for acid-insoluble lignin in wood and lignocellulosic materials like RPF powder. A representative palm frond sample was finely ground and transferred to a

500 mL Erlenmeyer flask. To the flask, 72 mL of 72 % sulfuric acid and 8 mL of 37 % hydrochloric acid were added and mixed thoroughly. The flask was heated on a 100°C water bath for 1 hour. After acid extraction, the flask was cooled, and the acid-insoluble residue was filtered using pre-weighed filter paper and vacuum filtration. The residue was washed with hot water until neutral, dried in a 50°C oven until a constant weight was achieved, and then weighed and recorded.

% Lignin = (Wt. of powder sample - Wt. of residue / Wt. of powder) × 100

% Lignin = (1 – 0.45/1) × 100 = 55 %.

Electrical conductivity

I-V characteristics for BCs derived from RPF and HDPE powder were determined with increasing voltage from 5 to 30 V [23]. RPF has rendered gradual rise in current ranging from 0.0439 to 0.17 A whereas BCs showed a rise in current from 0.028 to 0.138 A. The fabricated biocomposite exhibits lower electrical conductance compared to the RPF (Fig. 2).

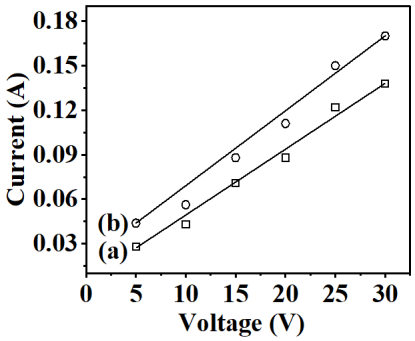

Fig. 2. I-V characteristics of (a) BCs, (b) RPF.

Thermal stability

Thermal stability of the materials and BCs was ascertained through DTG-TG-DTA [24-26]. The relative thermal stability of HDPE (Fig. 3a), RPF powder (Fig. 3b), and BCs (Fig. 3c) was investigated through their respective TG-DTA-DTG. TG demonstrates the weight loss rendered by the material with reference to temperature at a constant heating rate. Decomposition of material in TG is expressed as TG onset. Prior to TG onset, weight loss associated with material was attributed to moisture content. TG endset is the temperature at which the thermal decomposition of material is concluded. Beyond TG endset the residual weight associated with the sample is termed as char yield. Multiple steps in TG demonstrate the various stages of the decomposition process which is revealed through DTA. DTG demonstrates a rate of degradation of materials. Wide DTA peaks demonstrate the amorphous behavior of HDPE, RPF powder and BCs. Fig. 3a showing simultaneous TG-DTA-DTG of HDPE reveals TG onset at 400°C leaving 98.0 % weight residue. Prior to TG onset, 0.1 % weight loss by HDPE at 99.9°C corresponds to moisture content associated with HDPE. DTG reveals the single step degradation of HDPE with weight loss at a rate of 3.527 mg/min at 473°C. Major peaks correspond to degradation temperature (weight residue %) at 100 (99.9) and 400 (98.0), and have shown endset at 95°C leaving 1.1 % weight residue.

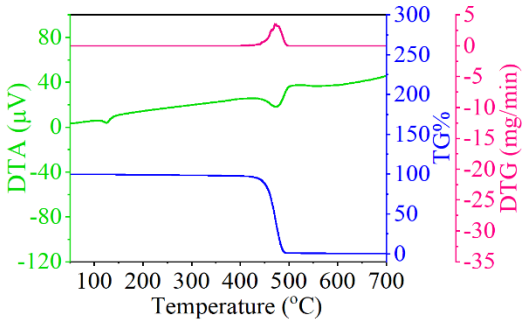

Fig. 3 (a). TG-DTA-DTG of HDPE.

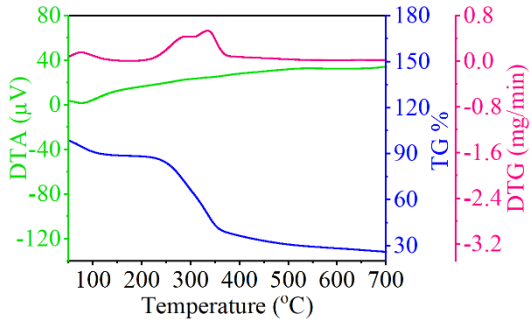

Fig. 3 (b). TG-DTA-DTG of RPF.

Fig. 3b represents simultaneous TG- DTA- DTG of RPFP which reveals TG onset at 223.0°C leaving 87.49 % weight residue. Prior to TG onset 8.7 % weight loss attributes to residual moisture associated with RPF powder at 99.9°C without appearance of any rate of dehydration. RPF powder has shown major peaks corresponding to degradation temperature (weight residue %) at 289 (75.4) and 338.5 (53.3) with the degradation rate of 0.440 and 0.532 mg/min, respectively. The endset corresponds to 363.2°C leaving 40.1 % weight residue. It is also showing a minor peak at 75°C with the rate of 0.159 mg/min.

Fig. 3c represents simultaneous TG- DTA- DTG of BCs, revealing TG onset at 241.0°C leaving 88.1 % weight residue. Prior to TG onset 6.4 % weight loss by BCs at 99.9°C attributed to residual moisture with BCs. DTG reveals the expulsion of moisture from BCs at the rate of 0.102 mg/min at 99.9°C. BCs shows major peaks corresponding to degradation temperature (weight residue %) at 278 (75.4) and

329.5 (53.3) with the degradation rate of 0.372 and 0.596 mg/min, respectively. The endset corresponds to 347.2°C leaving 49.5 % weight residue.

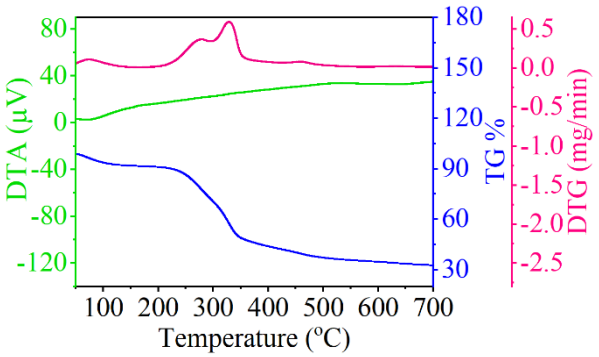

Fig. 3(c). TG-DTA-DTG of RPF.

The research findings indicate that the moisture content of RPF powder was determined to be 9.41 %. Furthermore, the percent water solubility of RPF powder was found to be 20 % and the percent alcohol-benzene solubility was found to be 10.4 %, indicating the solubility of RPF powder in different solvents. The lignin content of the RPF powder was found to be 55 %, suggesting a significant presence of lignin in the sample.

The resulting polymers BCs were subjected to examinations for electrical conductivity, and thermal stability using direct current (σDC) conductivity, and thermogravimetric-differential thermal analysis-differential thermogravimetry (TG-DTA-DTG), respectively. The findings revealed a decrease in electrical conductivity and an increase in thermal stability in the BCs compared to the original royal palm frond fibers.

CONCLUSION

In conclusion, the research findings provide valuable insights into the characteristics of RPF powder and its resulting polymer BCs. The moisture content of the RPF powder was determined to be 9.41 %, indicating a relatively low moisture content. The solubility tests showed that the RPF powder had a water solubility of 20 % and alcohol-benzene solubility of 10.4 %, suggesting its solubility in different solvents. The presence of lignin in the RPF powder was significant, with a content of 55 %.

Moreover, the examination of the resulting polymer BCs revealed interesting observations. The electrical conductivity of the BCs was found to decrease compared to the original royal palm frond fibers. This indicates that the transformation process from RPF powder to BCs resulted in a decrease in electrical conductivity. On the other hand, the thermal stability of the BCs increased, suggesting improved resistance to high temperatures. These findings suggest that the transformation process alters the properties of the fibers, making them more suitable for applications requiring enhanced thermal stability.

Overall, this research provides important information about the composition and characteristics of RPF powder and its resulting polymer BCs. It contributes to our understanding of the potential applications of RPF powder and the effects of the transformation process on its properties. Further studies can build upon these findings to explore the practical implications and potential uses of RPF powder and BCs in various fields.

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