

Research Article

Mechanical and Water Absorption Properties of Jute/Palm Leaf Fiber-Reinforced Recycled Polypropylene Hybrid Composites

Rotich Gideon ^{1,2} and Desalegn Atalie ¹

¹Ethiopian Institute of Textile and Fashion Technology (EiTEX) Bahir Dar University, Bahir Dar 6000, Ethiopia

²Clothing and Textiles, South Eastern Kenya University, Kitui, Kenya

Correspondence should be addressed to Desalegn Atalie; desalegnatalie@yahoo.com

Received 10 April 2022; Accepted 28 April 2022; Published 9 May 2022

Academic Editor: Yasir Nawab

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Hybrid composites have proven endless benefits to the research communities in terms of environmental friendliness, mechanical properties, and development of new material. The present work explores the tensile, flexural, impact strengths, and water absorption properties of jute and palm leaf fiber-reinforced hybrid composites. Five types of hybrid composites were fabricated by varying jute and palm leaf fiber percentage of J100:P0, J25:P75, J50:P50, J25:P75, and J0:P100% with a constant weight ratio of polypropylene matrix. The findings showed that jute-palm leaf fiber-reinforced composite had positive effect on tensile, flexural, and impact strength. Experimental results showed that the J25:P75% (jute and palm leaf fiber) exhibited the highest tensile strength of 62.2 MPa and flexural strength of 82.26 MPa due to the optimal interfacial properties between the fibers and matrix. The impact strength of composites increased as the proportion of palm leaf fiber increased. Water absorption increased with jute fiber content, reaching a maximum of 1.26% at composite J100:P0, with lower water absorption at J0:P100% composite due to the higher moisture content of jute fiber.

1. Introduction

There is a growing interest in the development of natural fiber composites, alternate to the existing artificial fiber composites. In recent years, the application of hybrid natural fibers as reinforcement in composite structures has received attention due to their advantages of low cost, environmental friendliness, and favorable biocompatibility over synthetic fiber composite materials [1–6]. Natural fiber-reinforced polymer composites have received more attention as a result of environmental concerns. Natural fibers including coir, banana, jute, and sisal offer an appealing and environmentally friendly alternative to glass fibers for reinforcing polymer-based composites [7].

Natural fibers are replacing synthetic fibers in medium-strength applications due to benefits such as low cost, low density, abundant availability, environmental friendliness, nontoxicity, high flexibility, renewability, biodegradability, relative nonabrasiveness, high specific strength and stiffness, and ease of processing. Natural fibers offer several downsides

in addition to these benefits, such as high moisture absorption, limited heat stability, and low impact strength. The technique of hybridization can be utilized to improve the mechanical strength of a single natural fiber-reinforced polymer composite [8–10].

The bulk of composites made by researchers used synthetic fibers as reinforcement, such as armed, glass fibers, silica, and carbon fibers. They did, however, provide a possible environmental problem because these fibers can become a major problem after disposal [11]. A hybrid composite is made up of two or more types of fiber, with the benefits of one type of fiber complementing the shortcomings of the other [12, 13]. The use of natural fibers in a hybrid composite enables an environmentally sustainable product while still achieving the desired qualities in a balanced manner [14].

Numerous research works have been done natural fiber-based hybrid composites such as banana and palm leaf [15], palm leaf stalk fiber/jute fiber [16], banana/kenaf fiber [17], jute, pineapple leaf and glass fiber [17], banana, pineapple, and jute [18], jute/PP [19], and jute/glass fiber [20]. Gupta

and Srivastava reported that PVA (polyvinyl alcohol)/starch reinforced with date palm leaf (DPL) fiber-based hybrid composite can be used for packaging applications. The thermal stability of the composite with 30% fiber is better than that of a neat PVA. The hybrid composite's biodegradation rate was lowered by including DPL fiber into the composite [9]. Polypropylene is widely used as a composite matrix because of its excellent fatigue and abrasion resistance, low density, good surface hardness, greater softening point, good strength, light weight, and electrical and chemical resistance at high temperatures [21, 22].

Dhandapani and Megalingam reported that the tensile, flexural, and impact strength of sisal/palm fiber-reinforced hybrid composites increased as palm fiber content rose due to the tight link between the matrix and the fibers [23]. Jute and oil palm leaf are abundant, according to the researchers. According to a 2015 study, the palm oil sector in Malaysia generates 75.61 million tons of solid biomass waste per year, whereas the palm oil mill effluent (POME) waste created is 65.35 million tons per year [24]. Jute is an annual crop that takes 120 days to mature [8].

According to Jawaid et al., if properly constructed, hybrid composites derived from oil palm empty fruit bunches and jute could compete with synthetic composites. Automotive and aerospace have been mentioned as potential markets for oil palm-based hybrid composites in the future. Development of more appropriate, cost-effective manufacturing techniques, as well as composites with superior mechanical properties that use natural fibers as reinforcement, are ongoing problems. Nonetheless, advancements in this discipline have allowed natural fiber-based hybrid composites to be used in a variety of industries, including construction, automotive, and aerospace [25].

As previously stated, natural fiber hybrid composites have the potential to balance the limitations of one filler with the requirements of the other. The mechanical and water absorption capabilities of jute/palm leaf fiber hybrid composites with recycled polypropylene matrix were evaluated and investigated in this study.

2. Materials and Methods

2.1. Materials. In this study, nonhybrid and hybrid jute and palm leaf fibers were employed as reinforcement, and recycled polypropylene (PP) was used as a matrix. Jute, palm leaf fibers, and PP waste were collected from G-Seven Trading and Industry—Addis Ababa and Bahir Dar City—Ethiopia, respectively. The physical, mechanical, chemical, and thermal properties of jute and palm leaf fiber are given in Table 1 and Figures 1 and 2.

2.2. Composite Preparation. The fibers were immersed in 5% NaOH solution for 4 hours at room temperature (21–28°C). The fibers were then rinsed multiple times with distilled water before being immersed in very diluted HCl to remove the NaOH that had adhered to the surface. Finally, the fibers were rinsed multiple times with distilled water before being dried in a 60°C oven for 2 hours. This alkali treatment removed natural and artificial impurities which improves

TABLE 1: Fiber properties.

No	Fiber properties	Jute fiber	Palm leaf fiber
1	Moisture content (%)	12.03	8.4
2	Tensile strength (MPa)	426	439
3	Elongation at break (%)	1.18	1.24
4	Cellulose content (%)	64.4	63
5	Hemicellulose content (%)	12	14
6	Lignin content (%)	11.8	2.2
7	Density (g/cc)	1.3	1.41

the fiber-matrix adhesion. It may also destroy the hydrogen bonding in cellulose hydroxyl groups of the fiber, thereby making them more reactive to the functional group of coupling agent, which in turn bonds to the polymer matrix.

The PP waste was crushed using gridding machine and changed to chips. The jute and palm leaf fibers were cut into 30 mm finally composite samples produced through melting, mixing, and molding process [26]. Jute and palm leaf fibers were added to the melted PP chips, mixed, and then transferred to the molding after uniform homogeneity to reduce fiber degradation due to heat. Compression molding is a closed-mold composite production method that employs matching metal molds and a 6 MPa external pressure. In this study, jute-palm leaf fiber hybrid composites were fabricated based on Table 2 weight percentage.

3. Characterization

3.1. Mechanical Properties of Fibers. The tensile strength and elongation of the jute and palm fibers were determined according to ES ISO 5079 standard using Tinius Olsen H1KS single-fiber strength tester as per the. The gauge length of the fibers was 50 mm, and a speed of 75 mm/min was maintained during the testing carried out at 20°C and 65 per cent relative humidity.

3.2. FTIR Analysis. PerkinElmer FTIR instrument was used for the analysis of PP, jute, and palm leaf fibers. The spectrum version of the instrument was 10.03.06. To fix the test specimen on the instrument, a 11 N pressure force was applied. Measurement was done in the wave number region between spectral range 400–4000 cm^{-1} with a resolution of 2 cm^{-1} . To fix the test specimen on the instrument, a 12 N pressure force was applied.

3.3. Differential Scanning Calorimetry (DSC). The PerkinElmer Differential Scanning Calorimeter (DSC4000 model) was used to determine the thermal properties of the PP, jute, and palm leaf fibers. The heating rate used was 10°C/min and the samples were tested within the range from 30 to 400°C. The samples were placed in aluminum crucible and its weight was approximately 5 mg.

3.4. Mechanical Properties of Composites. Nonhybrid and hybrid composite of tensile and flexural strength were evaluated by using Universal Tensile Machine (UTM model: WAW-600D) as per ASTM D 3039 and ASTM D7264 test

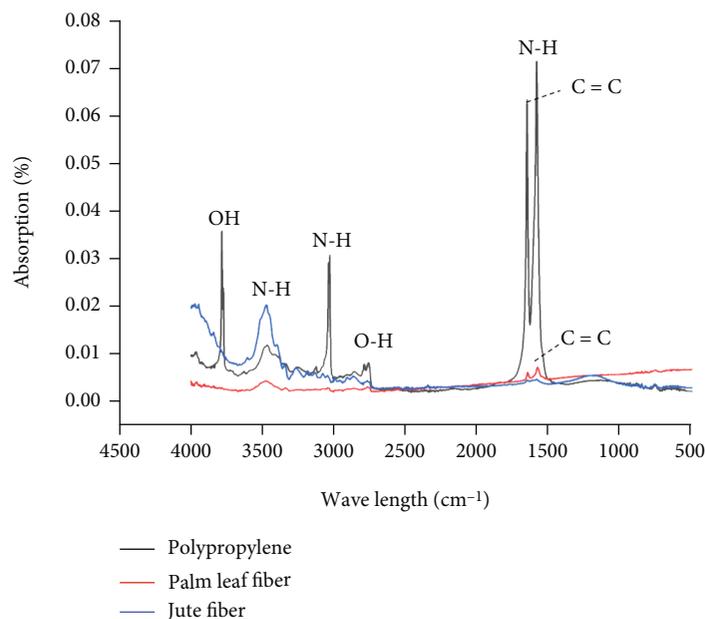


FIGURE 1: FTIR spectra of polypropylene, jute, and palm leaf fibers.

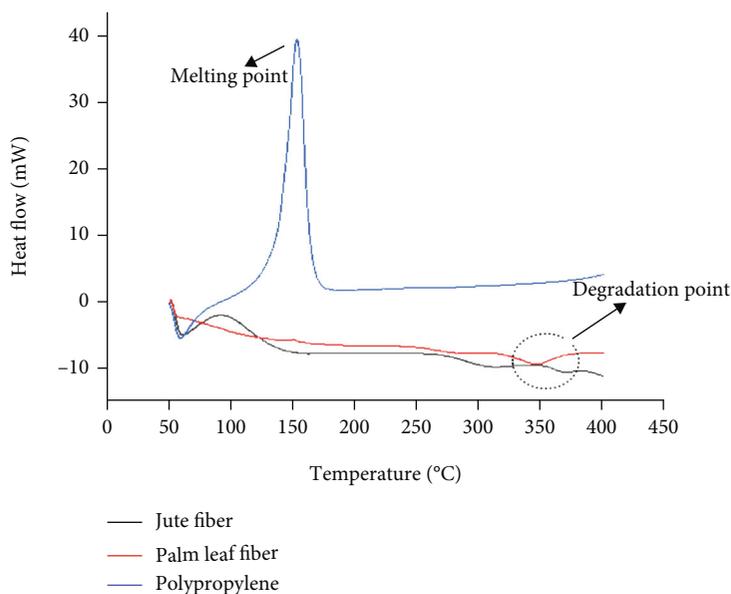


FIGURE 2: DSC analysis of PP, jute, and palm leaf fibers.

method, respectively. The impact test was then conducted according to ASTM D256 to study the energy absorbing characteristic of nonhybrid and hybrid jute and palm leaf fiber-reinforced composites using Charpy Impact tester model JBS-500B. Both the nonhybrid and hybrid jute and palm leaf fiber composites were subjected to the impact loading in the flatwise and edgewise orientations. Each of the mechanical tests was performed for five times, and the average findings were recorded.

3.5. *Water Absorption.* The water absorption of jute and palm leaf fiber-reinforced composites was measured as per ASTM D570. The composite samples were immersed in the water up to 15 days at room temperature. During the water

TABLE 2: Jute/palm leaf fiber-reinforced polymer composite.

Composites	Jute fiber content (%)	Palm leaf fiber content (%)	Total reinforcement (wt%)	Matrix (recycled PP) (wt%)
J100:P0	100	0	30	70
J75:P25	75	25	30	70
J50:P50	50	50	30	70
J25:P75	25	75	30	70
J0:P100	0	100	30	70

J: jute; P: palm leaf fiber; PP: polypropylene.

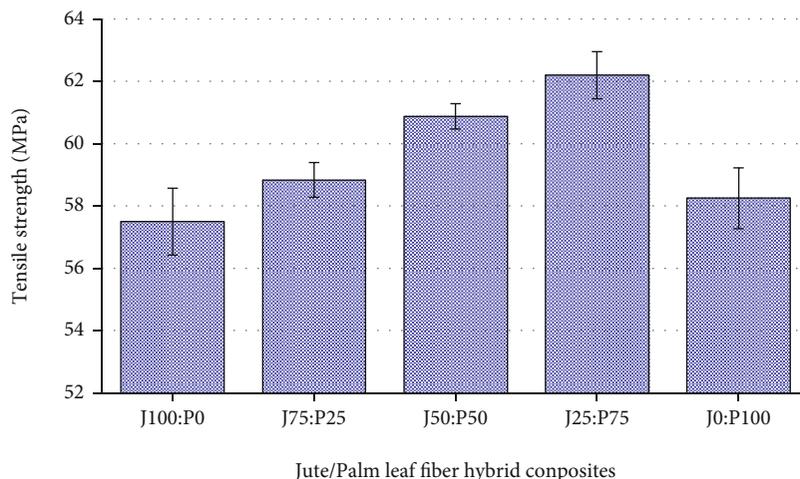


FIGURE 3: Tensile properties of jute/palm leaf fiber-reinforced hybrid composites.

TABLE 3: Analysis of variance (ANOVA) of composites.

Properties	Source of variation	SS	df	MS	F	P value	F crit
Tensile strength (MPa)	Between groups	230.961	4	57.74025	91.51088	0.001	2.866081
	Within groups	12.61932	20	0.630966			
Flexural strength (MPa)	Between groups	1182.208	4	295.5521	1.69095	0.06	2.866081
	Within groups	85.54828	20	4.277414			
Impact strength (kJ/m ²)	Between groups	1129.639	4	282.4096	103.594	0.001	2.866081
	Within groups	54.5224	20	2.72612			
Water absorption (%)	Between groups	135.8208	4	33.9552	6.891503	0.001	2.578739
	Within groups	221.72	45	4.927111			

absorption test, the specimens were removed from the water and cleaned to eliminate any excess moisture on the composite surface, after which they were weighted using an analytical balance at a set time interval to acquire the mass until the saturation point was reached. The mass difference is required to determine moisture absorption percentage as demonstrated in Equation (1). After that, the moisture absorption percentage was then plotted against the square root of time [8].

$$\text{Moisture absorption (\%)} = \frac{Mt - M0}{M0} \times 100, \quad (1)$$

where $M0$ is the initial mass of the dry specimen and Mt is the mass of the immersed specimen after a certain period.

4. Results and Discussion

4.1. Fiber Properties

4.1.1. Physical and Chemical Properties. Table 1 shows moisture content, strength, elongation, cellulose, lignin, and density of jute and palm leaf fibers used for the study. Twenty tests were measured to get the mean value of mechanical properties.

4.1.2. FTIR Spectroscopy. Figure 1 shows the Fourier-transform infrared spectroscopy (FTIR) curve of the PP, jute, and treated palm leaf fibers. The spectra of the PP polymer display O-H absorption around 3782 cm^{-1} and N-H stretching at 3028 and 1584 cm^{-1} , respectively. Besides, C=C stretching of 1653 cm^{-1} was recorded for recycled PP polymer. Jute fiber has higher absorption than palm leaf fiber at $3000\text{-}4000 \text{ cm}^{-1}$ wavelength. However, both fibers have similar sinusoidal curve trend. Owing to this, N-H stretching was observed around 3465 cm^{-1} and O-H stretching of $3750\text{-}4000 \text{ cm}^{-1}$ and weak O-H stretching of 2756 cm^{-1} for jute and palm leaf fibers. Palm leaf fiber had weak C=C stretching of 1583 cm^{-1} to 1651 cm^{-1} wavelength.

4.1.3. DSC Analysis. The thermal properties of PP, jute, and palm leaf fibers using differential scanning calorimetry (DSC) have been analyzed in Figure 2. The degradation point of jute and palm leaf fibers was $340\text{-}380^\circ\text{C}$. This is the point at which a substance transforms or degrades into simpler chemical compounds. Environmentally benign and biodegradable, jute and palm leaf fibers have a degradation point. The highest degradation point is very important for manufacturing and using the technical textile products [27].

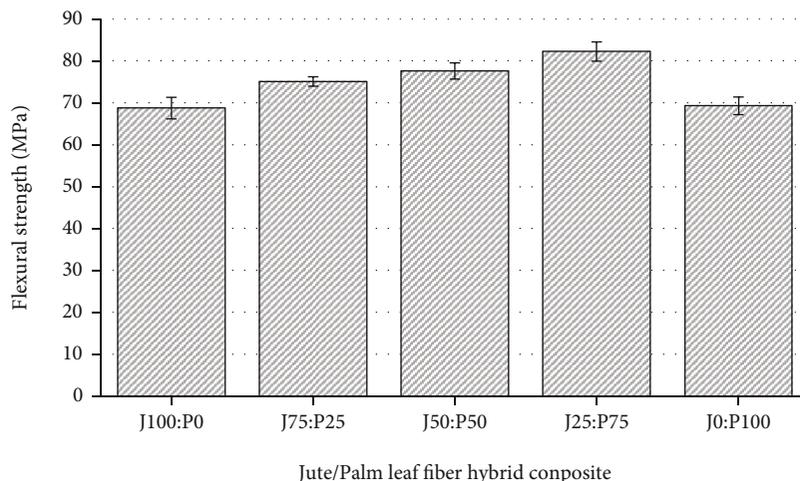


FIGURE 4: Flexural properties of jute/palm leaf-reinforced hybrid composites.

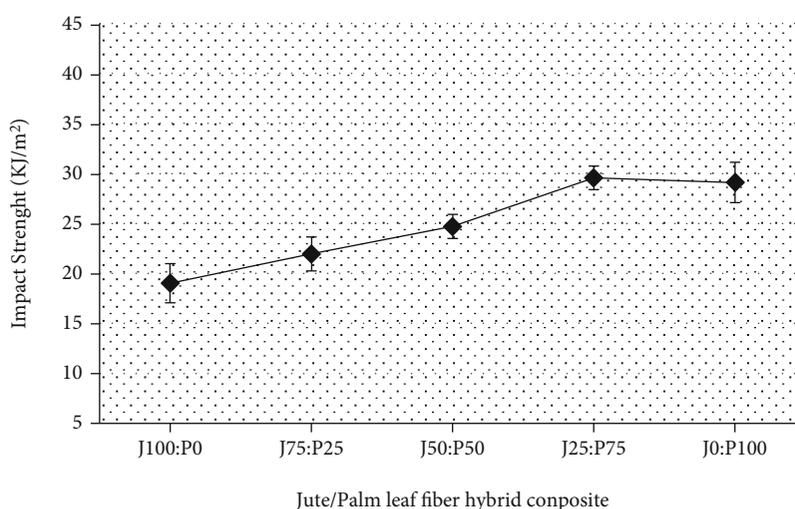


FIGURE 5: Impact properties of jute/palm leaf-reinforced hybrid composite.

4.2. Jute/Palm Leaf Fiber Hybrid Composite Properties

4.2.1. Tensile Strength. Figure 3 shows tensile strength of jute/palm leaf fiber-reinforced hybrid composites and the tensile strength increased as palm leaf fiber increases. Due to this, better tensile strength of 62.2 MPa is found for the hybrid composite J25:P75. In contrast, composite reinforced with 100% jute fiber had lower tensile strength than others. Tensile strength of hybrid composite J25:P75 is 7.6%, 5.4%, 1.2%, and 1.9% as compared to those of composites J100:P0, J75:P25, J50:P50, and J0:P100, respectively. This is because of jute fiber having low tensile strength and elongation may break first and then the load is carried by the palm leaf fiber having high strength and elongation without the failure of matrix, inducing better stress transfer from matrix to fibers and thus resulting in increased mechanical properties of hybrid composite. Another reason is that high cellulose content of palm leaf fiber also contributes to increase the mechanical properties of composite. As evident in Table 3, the statistical analysis showed that tensile strength

of hybrid composite samples had significant difference with P value of 0.001 at $\alpha = 0.05$.

When compared to hybrid composites, nonhybrid palm leaf and jute fiber-reinforced composites had the lowest tensile strength. This is most likely due to the interfacial bond between the reinforcing fibers (jute and palm leaf) and the PP matrix, which is responsible for the composites' high strength. Because the stress is transferred from the matrix phase to the dispersion phase, the overall composite strength is increased. As seen in Table 1, the single fiber strength of jute and palm leaf fiber is comparable. However, tensile strength and elongation of composites were significant. This is because a lower amount of lignin in palm leaf fiber contributes to enhancing the mechanical properties of composites. Contrary, the reduction of tensile strength is due to the degree of compatibility at the level of the interfacial region between lignin and the matrix that is not desired [28]. Previous research has shown that the presence of lignin in a composite material lowers the material's bending mechanical properties [29, 30].

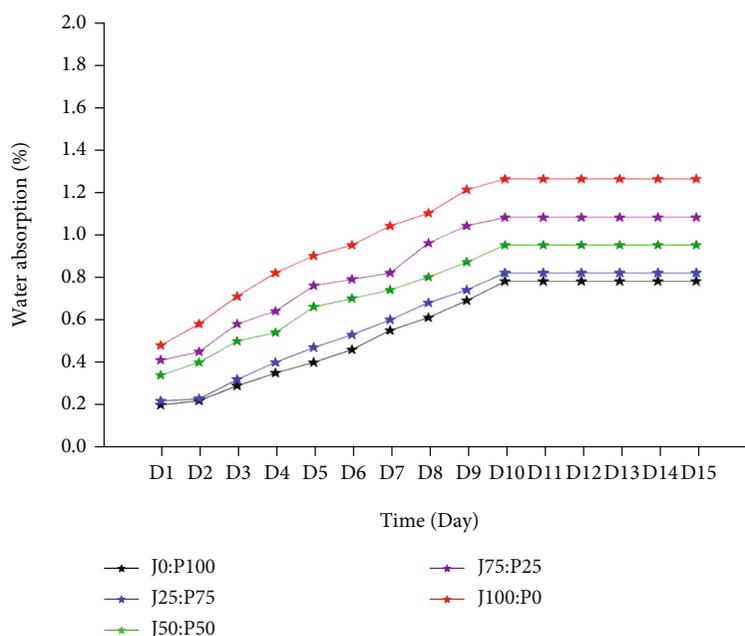


FIGURE 6: Water absorption jute/palm leaf fiber-reinforced hybrid composites.

TABLE 4: Comparison of mechanical properties of present hybrid composite with published work.

Reinforcement	Matrix	Fiber content	Tensile strength (Ma)	Flexural strength (MPa)	Impact strength (kJ/m ²)	Ref.
Banana/sisal	Epoxy	50/50	18.66	59.68	17.90	[32]
Banana/jute	Epoxy	50/50	18.96	59.84	18.23	[33]
Palm leaf stalk/jute	Polyester	50/50	64.30	145.66	27.01	[34]
Jute/sisal	Epoxy	50/50	102.08	361.90	30.10	[9]
Kenaf/palm leaf	PP	50/50	20.42	51.7	37.07	[8]
Palm leaf	PP		42	63	37.2	[35]
Jute	PP		28.4	35.1	65	[19]
Jute	PP		32	38	18	[36]
Jute/palm leaf	PP	50/50	60.88	77.62	24.7	Present work

4.2.2. Flexural Strength. Flexural strength of hybrid composite had shown increasing trend from sample J100:P0, J75:P25, J50:P50, and J25:P75, respectively. Like tensile strength, the maximum flexural strength of 82.26 MPa was found at J25:P75 hybrid composite. Contrary, the least flexural strength of 68.75 MPa was recorded at composite sample reinforced with 100% jute fiber (J100:P0). As it can be seen in Figure 4, the flexural strength of hybrid composite J25:P75 is found 82.26 MPa which is 83.6%, 91.3%, 94.4%, and 98.9% more as compared to those of composites J100:P0, J75:P25, J50:P50, and J0:P100, respectively. Previous reports stated that weight percentage of palm leaf fiber shows dislocation of tightly packed fiber and matrix stickiness [23]. Nonhybrid palm leaf and jute fiber-reinforced composites demonstrated the lowest flexural strength, respectively, with compared to hybrid composites. This is because jute/palm leaf fibers with PP matrix have better interfacial characteristics.

As illustrated in Table 3, the statistical analysis showed that hybrid composites are insignificant different in flexural strength at P value of 0.06 when $\alpha = 0.05$.

4.2.3. Impact Strength. Figure 5 shows the impact strength of jute and palm leaf fiber-reinforced hybrid composite. Like tensile and flexural strength, impact strength increased as palm leaf fiber content increases. Composite reinforced with pure palm leaf fiber had the highest impact strength of 38.2 kJ/m² which is 49.8%, 57.4%, 64.7%, and 77.4% better than those of composites J100:P0, J75:P25, J50:P50, and J25:P75, respectively. On the other hand, composite sample J100:P0 had lower impact strength of 19.02 kJ/m², followed by J75:P25, J50:P50, and J25:P75, respectively. Interfacial adhesion of jute/palm leaf fiber with combination of PP matrix may result in greater dispersion of components into matrices, resulting in increased impact resistance of composites, as described above.

The ANOVA result showed that the developed hybrid composite had significant difference in impact strength at F calculated (F) value of 103.594, F critical value of 2.866081, and P value of 0.001. As mentioned above, when the P value is ≤ 0.05 , this means the composite properties are completely different and if P value is > 0.05 inverse. In addition to this, when F critical $< F$ calculated (F), it interpreted as the results are significantly difference.

4.2.4. Water Absorption. Figure 6 shows water absorption of hybrid jute/palm leaf fiber-reinforced composite. The percentage water absorption of composites had increased as the immersion time increases and palm leaf fiber content increases. Owing to this, composite samples J100:P0, J75:P25, J50:50, J25:P75, and J0:P100 are found 0.78%, 0.82%, 0.95%, 1.08%, and 1.26%, respectively, at 10 days. The composite J100:P0 had higher water absorption due to moisture content of fibers. As given in Table 3, the jute and palm leaf fiber moisture content was 12.03% and 8.4%, respectively, and it had significant effect on water absorption of composite. In the view of the moisture uptake, hybridization of different fibers is considered to be beneficial to the moisture sensitivity of the composites. It can be seen that the incorporation of palm leaf fiber in the hybrid composites was able to improve the resistance against moisture due to the lower moisture content of palm leaf fiber [8].

According to previous studies, including hydrophobic fibers into the jute composite increases moisture resistance and reduces water absorption into the composite [31].

4.2.5. Comparison of Jute/Palm Leaf-Reinforced Composites with Other Hybrid Composites. Table 4 shows the comparison of mechanical properties of the present jute/palm leaf fiber-reinforced hybrid composite with different earlier published works. The tensile strength of the present hybrid composite is found to be higher by 60%, 50%, and 40% as compared to those of composites banana/sisal/epoxy, jute/banana/epoxy, and kenaf/palm leaf/PP, respectively. Flexural strength of present hybrid composite is observed to be higher by 33.4%, 23.1%, and 23% as compared to those of composites kenaf/palm leaf/PP, banana/sisal/epoxy, and banana/jute/epoxy, respectively. Impact strength of present hybrid composite is 27.5% and 26.2% more than those of hybrid composites banana/sisal/epoxy and banana/jute/epoxy, respectively.

5. Conclusion

Natural fiber hybridization in composites ensures both an environmentally friendly result and a balanced pursuit of required properties. The aim of this research work is that nonhybrid and hybrid composites were fabricated by varying jute and palm leaf fiber percentage of J100:P0, J25:P75, J50:P50, J25:P75, and J0:P100% with a constant weight ratio of polypropylene matrix. The findings revealed that the relative fiber ratio had a significant effect on composite mechanical characteristics. The favorable hybrid effect was achieved by incorporating palm leaf fiber into hybrid composites. When the percentage palm leaf fiber content was

raised, the mechanical characteristics of composites improved. This phenomenon could be explained by palm leaf fiber's inherent higher strength, which results in higher mechanical strength. As a result, the incorporation of palm leaf fiber in composites improved mechanical properties and water resistance due to its high fiber strength and low moisture content compared to jute fiber. When compared to pure palm leaf and jute composite, this novel family of hybrid composite materials has unique features. Generally, tensile strength of the present hybrid composite is found to be 60%, 50%, and 40% greater than that of banana/sisal/epoxy, jute/banana/epoxy, and kenaf/palm leaf/PP, respectively. When compared to composites kenaf/palm leaf/PP, banana/sisal/epoxy, and banana/jute/epoxy, the present hybrid composite has 33.4%, 23.1%, and 23% better flexural strength. The study concludes that the jute/palm leaf/PP hybrid composite had high tensile strength, whereas the J75:P25 composite with 50% PP matrix has improved tensile, flexural, impact, and moisture resistance. As a result, the produced lightweight and low-cost hybrid composites would be a good fit for medium-load applications such as building partition boards, automobiles, doorframes, train interior panels, and bags.

Data Availability

All data experiments can be found in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The project was supported by the Ethiopian Institute of Textile and Fashion Technology (EiTEX), Bahir Dar University.

References

- [1] M. Alhijazi, Q. Zeeshan, B. Safaei, M. Asmael, and Z. Qin, "Recent developments in palm fibers composites : a review," *Journal of Polymers and the Environment*, vol. 28, no. 12, pp. 3029–3054, 2020.
- [2] M. H. Ameer, K. Shaker, M. Ashraf et al., "Interdependence of moisture, mechanical properties, and hydrophobic treatment of jute fibre-reinforced composite materials," *The Journal of the Textile Institute*, vol. 108, no. 10, pp. 1768–1776, 2017.
- [3] K. Shaker and Y. Nawab, *Lignocellulosic fibers: sustainable biomaterials for green composites*, Springer Nature, 2022.
- [4] K. Shaker, M. Umair, S. Shahid et al., "Cellulosic fillers extracted from *Argyrea speciosa* waste: a potential reinforcement for composites to enhance properties," *Journal of Natural Fibers*, pp. 1–13, 2020.
- [5] K. Shaker, R. M. W. U. Khan, M. Jabbar et al., "Extraction and characterization of novel fibers from *Vernonia elaeagnifolia* as a potential textile fiber," *Industrial Crops and Products*, vol. 152, article 112518, 2020.
- [6] S. Tigabe, D. Atalie, and R. K. Gideon, "Physical properties characterization of polyvinyl acetate composite reinforced

- with jute fibers filled with rice husk and sawdust," *Journal of Natural Fibers*, pp. 1–12, 2021.
- [7] T. Muruganrama, J. Mahalingam, S. Dharmalingam, and S. Natarajan, "Investigation of static and dynamic mechanical properties of short palmyra palm leaf stalk fiber (PPLSF) reinforced polymer composites," *Journal of Natural Fibers*, pp. 1–17, 2020.
 - [8] N. L. Feng and N. Razali, "Mechanical properties and water absorption of kenaf/pineapple leaf fiber-reinforced polypropylene hybrid composites," *Polymer Composites*, vol. 41, no. 4, pp. 1255–1264, 2019.
 - [9] M. K. Gupta and R. K. Srivastava, "Mechanical, thermal and water absorption properties of hybrid sisal/jute fiber reinforced polymer composite," *Indian Journal of Engineering and Materilas Sciences*, vol. 23, pp. 231–238, 2016.
 - [10] L. Yan, N. Chouw, and K. Jayaraman, "Flax fibre and its composites—a review," *Composites Part B: Engineering*, vol. 56, pp. 296–317, 2014.
 - [11] M. Venkatasudhahar, P. Kishorekumar, and N. Dilip Raja, "Influence of stacking sequence and fiber treatment on mechanical properties of carbon- jute-banana reinforced epoxy hybrid composites," *International Journal of Polymer Analysis and Characterization*, vol. 25, no. 4, pp. 238–251, 2020.
 - [12] T. P. Sathishkumar, J. Naveen, and S. Satheshkumar, "Hybrid fiber reinforced polymer composites – a review," *Journal of Reinforced Plastic Composite*, vol. 33, no. 5, pp. 454–471, 2014.
 - [13] Tm, V. R. Maddela, and Babu, "Hybrid composites and their behavior," *Intrnational Journal of Modern Trends Science Technology*, vol. 3, no. 11, pp. 50–56, 2017.
 - [14] J. Tusnim, N. S. Jenifar, and M. Hasan, "Effect of chemical treatment of jute fiber on thermo- mechanical properties of jute and sheep wool fiber reinforced hybrid polypropylene composites," *Journal of Thermoplastic Composite Materials*, 2020.
 - [15] M. Saad, I. S. Agwa, and B. A. Abdelsalam, "Improving the brittle behavior of high strength concrete using banana and palm leaf sheath fibers," *Mechanics of Advanced Materials and Structures*, vol. 29, pp. 1–10, 2022.
 - [16] D. Shanmugam and M. Thiruchitrabalam, "Static and dynamic mechanical properties of alkali treated unidirectional continuous palmyra palm leaf stalk fiber/jute fiber reinforced hybrid polyester composites," *Materials and Design*, vol. 50, pp. 533–542, 2013.
 - [17] A. Alavudeen, N. Rajini, S. Karthikeyan, M. Thiruchitrabalam, and N. Venkateshwaran, "Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: effect of woven fabric and random orientation," *Journal of Materials & Design*, vol. 66, pp. 246–257, 2015.
 - [18] K. Muthukumar, R. V. Sabariraj, S. Dinesh Kumar, and T. Sathish, "Materials today: proceedings investigation of thermal conductivity and thermal resistance analysis on different combination of natural fiber composites of banana, pineapple and jute," *Materials Today: Proceedings*, vol. 21, pp. 976–980, 2020.
 - [19] X. Y. Liu and G. C. Dai, "Surface modification and micromechanical properties of jute fiber mat reinforced polypropylene composites," *Express Polymer Letters*, vol. 1, no. 5, pp. 299–307, 2007.
 - [20] M. Y. Khalid and M. A. Nasir, "Mechanical characterization of glass and jute fiber-based hybrid composites fabricated through compression molding technique," *International Journal of Material Forming*, vol. 14, no. 5, pp. 1085–1095, 2021.
 - [21] T. Quazi, H. Shubhra, and A. K. M. M. M. Alam, "Echanical properties of polypropylene composites: mater, a review," *Journal of Thermoplastic Composite*, vol. 26, no. 3, pp. 62–391, 2013.
 - [22] S. Siddika, F. Mansura, M. Hasan, and A. Hassan, "Effect of reinforcement and chemical treatment of fiber on the properties of jute-coir fiber reinforced hybrid polypropylene composites," *Fibers*, vol. 15, no. 5, pp. 1023–1028, 2014.
 - [23] N. Dhandapani and A. Megalingam, "Mechanical and sound absorption behavior of sisal and palm fiber reinforced hybrid composites," *Journal of Natural Fibers*, pp. 1–14, 2021.
 - [24] S. D. Oseghale, A. F. Mohamed, and A. O. Chikere, "Status evaluation of palm oil waste management sustainability in Malaysia," *OIDA International Journal of Sustainable Development*, vol. 10, no. 12, pp. 41–48, 2017.
 - [25] M. Jawaid, H. A. Khalil, A. Hassan, R. Dungani, and A. Hadiyane, "Composites : part B effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites," *Composites Part B Engineering*, vol. 45, no. 1, pp. 619–624, 2013.
 - [26] N. Gebremedhin and G. K. Rotich, "Manufacturing of bathroom wall tile composites from recycled low-density polyethylene reinforced with pineapple leaf fiber," *International Journal of Polymer Science*, vol. 2020, Article ID 2732571, 2020.
 - [27] D. Atalie and R. K. Gideon, "Extraction and characterization of Ethiopian palm leaf fibers research journal of textile and apparel article information," *Research Journal of Textile and Apparel*, vol. 22, 2018.
 - [28] S.-Y. Zhang, B.-H. Fei, Y. Yu, H.-T. Cheng, and C.-G. Wang, "Effect of the amount of lignin on tensile properties of single wood fibers," *Forest Science and Practice*, vol. 15, no. 1, pp. 56–60, 2013.
 - [29] P. V. Joseph, K. Joseph, and S. Thomas, "Effect of processing variables on the mechanical properties of sisal-fiber-reinforced polypropylene composites," *Composites Science and Technology*, vol. 59, no. 11, pp. 1625–1640, 1999.
 - [30] T. Marisa, H. Ounis, A. Benchabane, and L. Sedira, "Effect of lignin on the mechanical properties of a composite material based on date palm leaflets and expanded polystyrene wastes," *TECNICA ITALIANA-Italian Journal of Engineering Science*, vol. 63, no. 2-4, pp. 393–396, 2019.
 - [31] F.-r. C. Salt-fog and S. Environment, "Dynamic mechanical behavior analysis of flax/jute," *Polymers*, vol. 12, p. 716, 2020.
 - [32] N. Venkateshwaran, A. ElayaPerumal, A. Alavudeen, and M. Thiruchitrabalam, "Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites," *Materials & Design*, vol. 32, no. 7, pp. 4017–4021, 2011.
 - [33] M. Boopalan, M. Niranjanaa, and M. J. Umopathy, "Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites," *Composites Part B: Engineering*, vol. 51, pp. 54–57, 2013.
 - [34] B. Gedif and D. Atalie, "Recycling of 100% Cotton Fabric Waste to Produce Unsaturated Polyester-Based Composite for False Ceiling Board Application," *International Journal of Polymer Science*, vol. 2022, 2022.
 - [35] S. S. Suradi, R. M. Yunus, and M. D. H. Beg, "Oil palm bio-fiber-reinforced polypropylene composites: effects of alkali fiber treatment and coupling agents," *Journal of Composite Materials*, vol. 45, no. 18, pp. 1853–1861, 2011.
 - [36] M. N. Khan, J. K. Roy, N. Akter, H. U. Zaman, T. Islam, and R. A. Khan, "Production and properties of short jute and short e-glass fiber reinforced polypropylene-based composites," *Open Journal of Composite Materials*, vol. 2, 2012.