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ORIGINAL ARTICLE

Extraction and characterization of *Dypsis lutescens* peduncle fiber: agro-waste to probable reinforcement in biocomposites—a sustainable approach

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Abstract

To include sustainability into their products, composite industries use natural resources as raw materials. This study explores the isolation and characterization of novel *Dypsis lutescens* peduncle fiber (DLPF) extracted from the peduncle of *Dypsis lutescens* an agro-waste. The thermo-mechanical and chemical characteristics of DLPF were comparable to other eco-friendly fibers utilized as firming material in polymer composites. Towards favoring the composite industry in deciding the use of DLPF as firming material in polymer composite cellulose composition (51.11 wt%), least wax (0.31 wt%), minimum density (1.35 g/cm^3), greater crystallinity index (49%), tensile strength (122–198 MPa), and Young's modulus (2.3–5.8 GPa) were assessed. The thermogravimetric (TGA-DTG) and differential scanning calorimetry (DSC) analysis revealed the thermal stability (224 °C), endothermic, and exothermic characteristics of DLPF with increase in temperature correspondingly. The prevalence of key operational clusters in the DLPF was recognized through Fourier transform infrared spectroscopy (FTIR) spectrum. The exterior texture of DLPF was captured through scanning electron microscope (SEM) to understand the interference characteristics of the DLPF with matrix when utilized as firming material in polymer composites. The assessed mechanical features, thermal characteristics, and chemical nature of DLPF give scope that it can be employed as a firming material in polymer composites employed in lesser weight structures.

Keywords Waste management · Sustainability · Eco-friendly fiber · Biodegradable material · Cellulosic fiber

1 Introduction

The environmental policies at national and international levels direct industries to adapt sustainable practices in both products and processes. This awareness is due to environmental threats and natural disasters faced by the people in recent days [1]. Moreover, the list of endangered species gets longer in recent decades. Hence, composite industries have

Highlights

- Biowaste *Dypsis lutescens* peduncle fiber (DLPF) characterized for probable reinforcement.
- Low wax (0.31 wt%) and density (1.35 g/cm^3) of DLPF ensure good bonding features.
- Thermal studies (TGA and DSC) confirm thermal stability of DLPF till 224 °C.
- Specific properties of DLPF suit as reinforcement for bio-composite applications.

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plunged on identifying several ways to incorporate sustainable practices in their products and processes [2, 3]. The initial effort is to replace the artificial synthetic material such as glass, kelvar, and aramid utilized as firming material in polymer composites. These strengthened materials are the main burden withstanding members in polymer composites [4]. Hence, its physical, mechanical, and thermal characteristics are more important from functional aspects. The processing of synthetic fibers consumes more energy, and hence it is costlier which influences the economic aspects of synthetic material–strengthened polymer composites [5]. Another important factor to be considered is the health risk of developing cancer and other abnormalities to people exposed to processing environment of synthetic fibers for a longer period [6]. The synthetic fibers are non-degradable, and its waste management further possesses environmental and health hazards. The above factors forced composite industries to explore natural sources as an alternate for synthetic materials.

The natural fibers are preferred as the best alternative for synthetic fibers to be employed as firming material in polymer composites owing to its plenty of availability, natural existence, minimal density, and ease of handling with very less energy consumption [7, 8]. Natural fibers can be sourced from plants, minerals, and animals. The identification and utilization of natural fibers from agro-waste would be more economical to composite industry as well as helps in managing the environment concerns that arise out of the agro-wastes [9]. This also addresses the threat of deforestation if the natural fibers are harvested in bulk as raw material for composite industries. Numerous products made of eco-friendly fiber–strengthened polymer composites have already been penetrated the market such as seats for automobiles, interior shelves, and doors for buildings, automobile dashboards, and other interior support structures in automobiles and buildings [10, 11]. The fibers from flora which are reinforced in polymer composites are an important parameter to be considered in the design process.

There are few hurdles that need to be given special attention to widen the possibility of using fibers from flora to be utilized as firming material in polymer composite industries. The basic hurdle is non-uniformity in the aspect ratio of natural fibers extracted from plants. This non-uniformity in shape and size of the natural fiber makes the design of floral fiber-reinforced polymer composites more complex to target specific applications. Another primary issue to be considered is that the characteristics of natural fibers extracted from plants differ based on the plant to plant, geographical locality where the plant survives, part of the plant, and maturity of the plant or plant part from which the floral fiber is mined [12, 13]. Hence, a complete characterization of the natural fiber is required before being employed as firming material in polymer composites. Even though the floral fibers were available in plenty, its harvesting for uninterrupted supply to industries needs to be channelized. This needs to be ensured without affecting the sustainability of environment. For this purpose, to retain the sustainability of the environment, researchers and engineers are focusing on the possibility of extracting fibers from agro-waste [14, 15]. The use of agro-waste as natural fiber sources not only retains the sustainability of environment but also helps in managing the agro-waste more economically without harming the environment.

The hydrophilic behavior of natural fibers segregated from plants affects the bonding strength between the matrix and the fibers when reinforced in polymer composites [16]. This can be controlled to certain extent by subjecting the segregated natural fibers to surface modifications before reinforcing in polymer composites. The inherent influential parameters that the mechanical and physical characteristics of floral fibers depend on are cell size, chemical composition, cell arrangement, fiber extraction process, and angle of microfibrils [17]. The interrogations on the natural fibers segregated from *Citrullus lanatus*, a climber plant, possessed 53.7 wt% cellulose with an acceptable density value of 1227 kg/m^3 which is adequate to be reinforced in polymer composites [18]. The hydrophilic behavior of *Citrullus lanatus* fiber is reflected by the crystallinity index value of 33.33% which requires surface modification before being reinforced in polymer composites. The natural fibers segregated from *Calamus manan* with 42 wt% cellulose possessed a tensile load–bearing capacity of 273.28 ± 52.88 MPa recognized by single fiber tensile test [19]. The *Calamus manan* natural fiber could resist thermal damage up to 332.8 °C which makes it a competitive candidate to be employed as firming material in polymer composites. Another floral fiber segregated from inflorescence bracts of banana plant with 56.48 wt% of cellulose possessed a tensile load–bearing capacity of 178.17 MPa recognized by single fiber tensile test [20]. The inflorescence bract fiber of banana plant with thermal resistance up to 200 °C with minimal wax of 1.05 wt% adds up the row of choice for reinforcement in polymer composites.

The *Dypsis lutescens* L. belongs to Arecaceae family of palm variety and is mainly grown as ornamental plant both indoor and outdoor for its air purifying characteristics. It bears an inflorescence with fruit which serves as food for birds. The inflorescences after passing the maturity stage get dried and fall down which is an agro-waste. The peduncle of inflorescence is rich in fibers and left unutilized which remains as landfill or burnt in ambient environment. The lignocellulosic fibers in the peduncle of *Dypsis lutescens* L., an agro-waste, need a comprehensive investigation for its utilization as firming materials in polymer composites. This investigation details the characterization of novel *Dypsis lutescens* peduncle fiber (DLPF) for its mechanical, physical, morphological, chemical, and thermal characteristics to ascertain its utilization as firming material in polymer composites. The surface characteristics of DLPF were intervened with the aid of scanning electron microscope (SEM). The data related to existence of functional groups and crystalline characteristics of DLPF were estimated by Fourier transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) spectrum, respectively. The observations of experiments and results of investigation make a positive note to utilize DLPFs as firming material in polymer composites. The utilization of DLPFs as firming material in polymer composites ensures the effective management of this agro-waste in an economical and sustainable way.

2 Experimentation

2.1 Extraction of DLPF

The inflorescence of *Dypsis lutescens* was collected from the landfills of industrial and institutional campuses in the vicinity of Coimbatore, Tamilnadu, India. The peduncle was separated from the gathered *Dypsis lutescens* inflorescence, and its outer skin was peeled off manually. Then, the skinless peduncles were drenched in water for 14 days to slacken the fibers [20]. The soaked peduncles were decanted, and fibers were extracted by mechanical combing process. The extracted DLPFs shown in Fig. 1 were sundried for 3 days to minimize its moisture and packed for further experimentations. The DLPF samples were exposed to physical, chemical, mechanical, thermal, and morphological characterization to identify its appropriateness to use as reinforcement material in polymer composites.

3 Characterization of DLPF

3.1 Chemical analysis

The weight percentage (wt%) of chemical constituents such as cellulose, hemicellulose, lignin, and wax in DLPF was estimated using the well-established procedures followed in literature [21]. The ash composition of DLPF was assessed as per ASTM E1755-61 standard [22]. The dampness composition of DLPF was assessed following the weight loss method.

3.2 FTIR analysis

The incidence of functional clusters in DLPF was assessed by conducting Fourier transform infrared spectroscopy (FTIR) analysis. The pulverised DLPF mixed with potassium

Fig. 1 Extraction of *Dypsis lutescens* peduncle fiber: **a** *Dypsis lutescens* tree, **b** collected peduncles of *Dypsis lutescens*, and **c** extracted *Dypsis lutescens* peduncle fibers

bromide and cast in the form of pellets were scanned in transmittance mode using FTIR spectrometer [22]. The data for FTIR spectrum was recorded at a scan frequency of 32 per min with a tenacity of 4 cm^{-1} between the wavenumbers 400 and 4000 cm^{-1}.

3.3 Morphological analysis

The surface texture of DLPF was explored using a scanning electron microscope (SEM) of model SUPRA 55 Zeiss. The DLPFs were placed on conductive carbon tap attached on aluminum ends by steel tape to avoid electron charge gathering. Then, a high vacuum of 3.99^{-4} Pa is attained, and the tungsten filament is switched ON for flow of electrons [23]. The images were taken at a hastened voltage of 8 kV.

3.4 XRD analysis

The crystalline characteristics of DLPF were recognized by X-Ray diffraction (XRD) spectroscopy examination. The data for XRD spectrum was recorded in the Bragg angle (2θ) between 0 and 80° while the goniometer was moving at a speed of 5°/min [24].

3.5 Physico-mechanical analysis

The density of DLPF was estimated using the mass-volume procedure. For this purpose, DLPF pulverised in powder form was stuffed in a vessel of cylindrical shape for which the weight has been already noted. Based on the weight and volume of materials, the density of DLPF was computed. The diameter and other anatomical dimensions of DLPF were measured using the parallel and cross-sectional SEM images with the aid of Image J software. The tensile asset of DLPF was appraised using single fiber tensile test adhering to ASTM D3822-07 standard at a cross-head movement of 5 mm/min [25].

3.6 Thermogravimetric analysis

The thermally stable nature of DLPF was appraised by conducting thermogravimetric analysis (TGA-DTG) using Pyris 6 thermo gravimetric analyzer (TGA 4000) integrated with Pyris software. Crushed fibers of 10 to 20 mg are kept in the alumina crucible, and the temperature is raised from ambient temperature to 550 °C at an increase rate of 10 °C/min [26]. The examination was performed in a nitrogen atmosphere at the nitrogen stream flow of 20 mL/min, to eradicate oxidation phenomenon.

3.7 DSC analysis

The differential scanning calorimetry (DSC) examination was done on DLPFs with the aid of Jupiter simultaneous differential scanning calorimeter (STA 449 F3). Ten to 15 mg of pulverised DLPFs was placed in the alumina receptacle and sealed. Then, its temperature is raised form ambient temperature to 450 °C at an increase rate of 10 °C/min in the nitrogen atmosphere [27]. The behavior of DLPF sample at different temperatures is recorded using Proteus software.

4 Results and discussions

4.1 Chemical analysis of DLPF

The chemical composition of plant fibers varies depending on the maturity of the plant, plant part from which the fiber is sourced, geographical location, and the environmental condition in which the plant exist. The physico-mechanical, surface morphological, and hydrophilic nature of fibers extracted from plants are highly influenced by its chemical constituents. The surface texture of fibers decides the interaction among the fiber and the matrix when utilized as firming material in polymer composites [27]. The functionality of the polymer composites strengthened with floral fibers highly depends on the characteristics of the reinforced fibers. Table 1 portrays the chemical constituents of DLPF in contrast with other natural and artificial materials utilized as firming material in polymer composites. The cellulose content of 51.11 wt% which is equivalent to its counterparts contributes to the mechanical characteristics of DLPF. The greater the wt% of cellulose composition in DLPF favors the crystalline features of fiber and subsides the hydrophilic characteristics favoring its utilization as firming material in polymer composites.

The lesser wt% of hemicellulose content (12.22 wt%) in DLPF helps in achieving superior interaction features with the matrix when utilized as firming material in polymer composites [30]. The apt wt% of lignin content (23.71 wt%) in DLPF serves as a binder and helps in achieving better interfacial features with the polymer when strengthened in polymer composites. The ash composition of 1.57 wt% reveals the fire-resistant capability of DLPF. This further endorses the thermal stability of DLPF to survive polymerization temperature when employed as firming material in polymer composites [31]. The bearable wt% of wax content (0.31 wt%) and moisture content (11.07 wt%) in DLPF make a positive note that it can be employed as firming material in polymer composites.

4.2 FTIR analysis of DLPF

Figure 2 portrays the FTIR curve of DLPF indicating the prevalence of major functional groups. The trough visible in wave numbers 897 cm^{-1} relates to expanding pulsations of alkyl halide a part of organic operational group. The valleys

Table 1 Chemical and mechanical characteristics of *Dypsis lutescens* peduncle fiber in comparison with other natural and synthetic materials utilized as firming material in polymer composites [28, 29]

Fiber name	Cellulose(wt%)	Hemicellulose (wt%)	Lignin (wt%)	Wax (wt%)	Density (g/cm^3)	Elongation at break (%)	Tensile strength (MPa)	Young's modulus (GPa)
DLPF*	**51.11**	**12.22**	**23.71**	**0.31**	**1.35**	**3.26 ± 0.9**	**169.4 ± 38**	**4.62 ± 0.7**
ACFPF	53.10	11.40	23.62	0.28	0.80–1.10	3.90–8.10	107–182	1.70–6.20
Cissus quadrangularis stem	82.73	7.96	11.27	0.18	1.22	3.75–11.14	2300–5479	56–234
Areca fiber	57.35	13–15.42	23.17–24.16	0.12	0.7–0.8	10.23–13.15	147–322	1.12–3.15
Acacia leucophloea	76.69	3.81	13.67	0.13	1.43	1.91–5.88	357–1809	10.45–87.57
Sansevieria cylindrica	79.90	10.13	3.80	0.09	0.91	12.30–13.70	666–706	6–8
Carbon	-	-	-	-	1.40	1.40–1.80	4000	230–240
E-glass	-	-	-	-	2.50	0.50	2000–3500	70

*Bolded one represents the present study

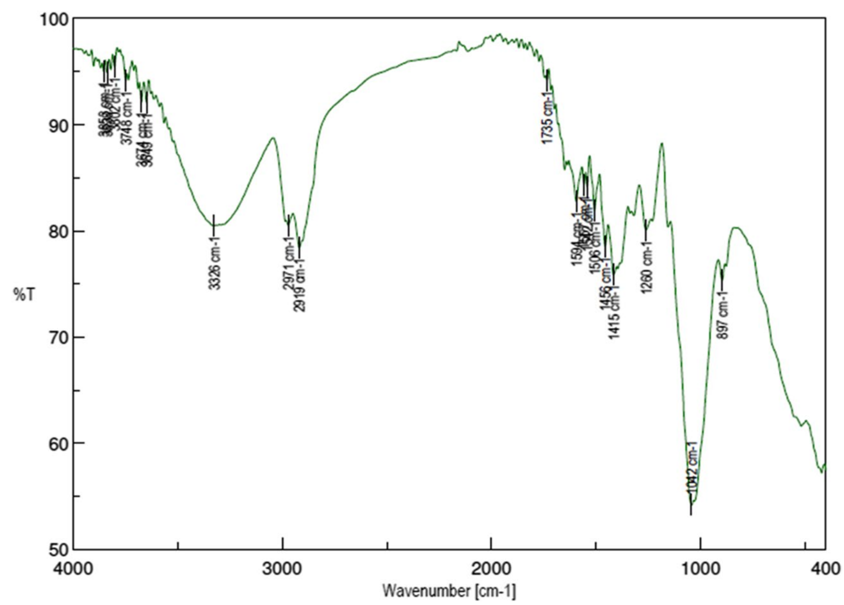


Fig. 2 FTIR spectrum of *Dypsis lutescens* peduncle fiber

visible in the wave numbers 1042 cm^{-1} and 1260 cm^{-1} affiliate to the twisting vibrations of alkene organic operational cluster =C-H. The oscillations in FTIR spectrum visible till 1415 cm^{-1} endorse the presence of polysaccharides associated with the cellulose in DLPF. The trough seen at 1594 cm^{-1} relates to carbonyl functional group C-O. The subsequent troughs in the wavenumbers 1735 cm^{-1} and 2919 cm^{-1} indicate existence of hemicellulose and lignin in DLPF, respectively. Another trough at 2971 cm^{-1} relates to C-H symmetric bending influence of alkaline operational cluster. The expanded trough visible at 3326 cm^{-1} attributes to the broadening of OH present in the cellulose of DLPF. The troughs noticed in FTIR spectrum endorse the biochemical components identified in chemical examination of DLPF.

4.3 Morphological and anatomical analysis of DLPF

The physical parameters of DLPF are presented in Table 2. The mechanical features of DLPF are extremely influenced by the presence of cellulose in the primary wall and lignin in secondary wall [32]. The lamellae of plant cell houses the hemicellulose and lignin which serve as a connective tissue which bonds the neighboring cells in DLPF. The presence of void space named as lumen in DLPF helps in retaining lesser

Table 2 Physical characteristics of *Dypsis lutescens* peduncle fiber

Property	Value
Thickness of primary cell wall (μm)	0. 642 ± 0.0012
Thickness of secondary cell wall (μm)	0.429 ± 0.0014
Thickness of middle lamellae (μm)	2.564 ± 0.0022
Thickness of cell lumen (μm)	5.721 ± 0.0024
Fiber diameter (μm)	202.76 ± 27.02
Fiber density (g·cm^{-3})	1.35 ± 0.0023

density, and hence it is suitable for fabricating light weight natural fiber–strengthened polymer composites.

Figure 3 presents the surface view and cross-sectional view of DLPF observed through SEM. The surface view of DLPF presents in Fig. 3a exhibits more rougher surfaces with several peaks and valleys favoring the improved interaction features of DLPF with the polymer when utilized as firming material in polymer composites. The exterior of the DLPF with more peaks and valleys when firmed in polymer composites enhances the exterior surface area of contact among the DLPF and the matrix in polymer matrix composite [33]. This helps in achieving improved attachment strength among the DLPF and matrix when DLPF is embedded in polymer composites. The occurrence of lignin which serves as binder material is revealed in the cross-sectional SEM image shown in Fig. 3b. The micro fibrils associated with parenchyma cells and its angle greatly influence the mechanical characteristics of DLPF. The micro fibril angle of DLPF is determined using Eq. (1) as 5.27° ± 24°.

$$\varepsilon = \ln\left[1 + \frac{\Delta L}{L_0}\right] = -\ln\ (\cos\alpha) \tag{1}$$

where ε is the strain, α is the micro fibril angle (degree), ΔL is the elongation at break (mm), and L_o is the gauge length (mm). The smaller micro fibril angle of DLPF enhances stress transfer characteristics between the matrix and the DLPF when employed as firming material in polymer composites.

4.4 XRD analysis of DLPF

Figure 4 presents the XRD spectrum of DLPF. The strong identifiable crown at Bragg angle (2θ) of 22.7° endorses the semi-crystalline properties of DLPF. The preceding peak of minor intensity noticed at 17.2° associates with the amorphous constituents like hemicellulose, lignin, and wax in DLPF. The crests identified at Bragg angles (2θ) of 17.2° and 22.7° for amorphous and crystalline components in DLPF respectively attribute to the crystallographic planes (1 1 0) and (2 0 0) correspondingly [34]. The crystallographic plane (2 0 0) attributes to cellulose-I which comprises of monoclinic assembly. The other oscillations in the XRD spectrum of DLPF are owing to the existence of contaminations in DLPF.

The crystallinity index (CI) of DLPF was computed using Eq. (2) (Segal. 1959) as 49%

$$\mathrm{CI} = \frac{\left(I_c - I_{am}\right)}{I_c} \tag{2}$$

where I_c is the maximum intensity of crystalline peak at $2\theta = 22.7°$, and I_{am} is the intensity of amorphous peak at $2\theta = 17.2°$. The determined CI value of DLPF ratifies the adequate mechanical features and compact stuffing of DLPF with matrix when utilized as reinforcement in polymer composites. The crystallite size (CS) of the DLPF was calculated using Scherrer's equation (Eq. (3)) as 1.28 nm.

$$\mathrm{CS} = \frac{K\lambda}{\beta\cos\theta} \tag{3}$$

where $K = 0.89$ is Scherrer's constant, λ is the wave length of the radiation, β is the peak's full-width at half-maximum (FWHM) expressed in radians, and θ is the Bragg's diffraction angle. The lesser CS of DLPF ensures its better

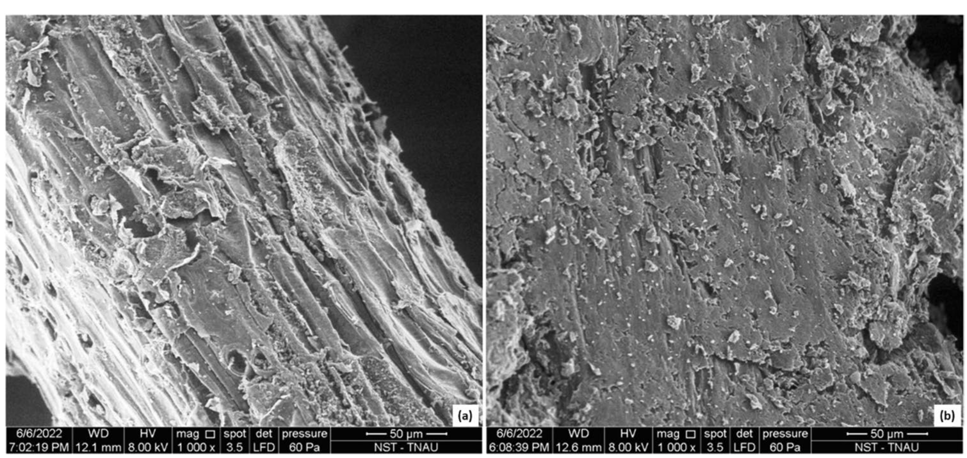
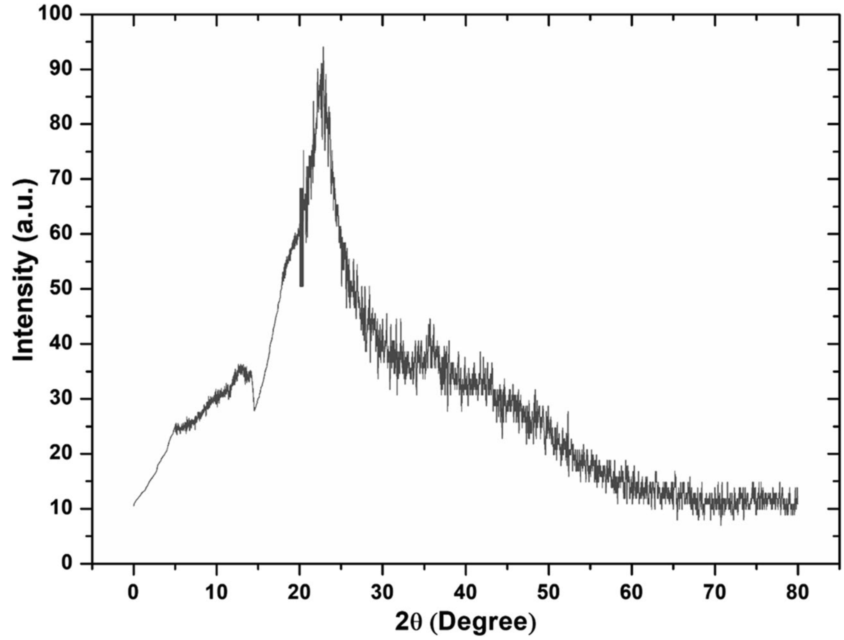


Fig. 3 SEM image of *Dypsis lutescens* peduncle fiber: **a** parallel view ×1000 and **b** Sectioned view ×1000

Fig. 4 XRD spectra of *Dypsis lutescens* peduncle fiber



hydrophobic chemically stable nature when employed as firming material in polymer composites.

4.5 Physico-mechanical analysis of DLPF

The physico-mechanical assets of DLPF are presented in Table 1. To identify the density of DLPF, DLPF pulverised in powder form was stuffed in a vessel of cylindrical shape for which the weight has been already noted. Based on the mass-volume basis, the density of DLPF was computed as 1.35 g/cm^3. The least density of DLPF confirms the light weight of the polymer matrix composite material when DLPF is utilized as firming material in polymer composites [35]. The specific characteristics of polymer matrix composite material for notable applications can be achieved through the right quantitative reinforcement of DLPF. The diameter of the DLPF was scaled using the SEM images in association with the image J software. The diameter of DLPF extended between 152.89 ± 19.13 μm and 256.63 ± 31.12 μm as depicted in Table 3. Even though there is irregularity in size and shape of the cross-section of DLPF, to compute the diameter of DLPF using Eq. (4). it is considered to be circular.

$$D_f = \sqrt{\frac{L_f}{9000 \times M_d \times 0.7855}} \quad (4)$$

where D_f is the diameter of DLPF, L_f is the linear mass density of DLPF in denier which is a quantity of fineness of DLPF evaluated as per ASTM D1577-07 standard, and M_d is the mass density in g/cm^3. Equation (4) estimates the diameter of DLPF to be 206.29 μm, which falls within the range of measured values depicted in Table 3.

Table 3 Mechanical properties of *Dypsis lutescens* peduncle fiber

Gauge length (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Strain to failure (%)	Diameter (μm)
10	122 ± 23	2.3 ± 0.3	4.3 ± 1.4	256.63 ± 31.12
20	146 ± 32	4.4 ± 0.6	3.5 ± 1.2	242.87 ± 24.63
30	176 ± 39	5.2 ± 0.7	3.2 ± 0.6	173.38 ± 21.18
40	198 ± 43	5.8 ± 0.8	2.6 ± 0.4	152.89 ± 19.13

The values from Table 3 reveal that the tensile strength of DLPF ranged between 122 ± 23 MPa and 198 ± 43 MPa. The numerical values of tensile strength obtained for DLPF are equivalent to the other natural fibers utilized as firming material in polymer composites. The deviation in physical features of DLPF witnessed over the range of gauge length is owing to the contrasts in shape and size of the cross-section of DLPF over its length [36]. The smaller Young's modulus and higher elongation at break values of DLPF indicate its load bearing capacity. The quantified physico-mechanical properties of DLPF confirm its capability to be utilized as firming material in polymer composites. In polymer composites with natural fibers as reinforcement material, the reinforcement materials are major load bearing member. The DLPF with sufficient tensile strength suits to be utilized as firming material in polymer composites.

4.6 TGA analysis of DLPF

The thermal characteristics of DLPF with increase in temperature are shown in Fig. 5. The decline in weight of DLPF witnessed till 108 °C relates to vaporization of water molecules from the fiber. On further escalation of temperature, the DLPF was found to be thermally stable showing insignificant weight loss till 224 °C. Subsequent increase in temperature starts deterioration of hemicellulose, lignin, and cellulose along with the depolymerisation process [37]. This phenomenon causes a significant reduction in weight of around 13.9% till 279 °C. The major weight loss observed for DLPF between 280 and 386 °C attributes to the comprehensive degradation of cellulose in DLPF. The further reduction in weight of DLPF on escalating the temperature relates to partial deterioration of lignin and wax. The infliction point witnessed in the DTG curve at about 327.4 °C with mass variation of 51.63% endorses the pyrolysis and disintegration of molecular assembly in the cellulose of DLPF. The fire-resistant characteristics of DLPF are indicated by the residual char of 14.32% remained at about 550 °C. The kinetic initiation energy (E) of DLPF specimen was appraised following the Broido's equation (Eq. (5)) as 73.65 KJ/mol.

$$\ln\left[\ln\left[\frac{1}{y}\right]\right] = -\left(\frac{E}{R}\right)\left[\left(\frac{1}{T}\right) + K\right] \quad (5)$$

where R is the universal gas constant (8.314 J·mol^{-1} K^{-1}), T is the temperature in kelvin, y is the normalized weight (w_t/w_o), w_t is the weight of the sample at any time t, w_0 is the initial sample weight, and k is Boltzmann's constant (1.3806 × 10^{-23}J·K^{-1}). The estimated E value guarantees the capability of DLPF to resist polymerization temperature while fabricating polymer composites.

4.7 DSC analysis of DLPF

The DSC spectra of DLPF are depicted in Fig. 6. The endothermic crown perceived in the temperatures amid 31 °C and 145 °C specifies the energy expended to eliminate the moistness from DLPF. Sequential exothermic crown evident in the temperatures amid 145 °C and 184 °C designates the depolymerization of lignin and hemicellulose from the fibers. Additional exothermic crown recognized in the temperatures amid 269 °C and 304 °C relates to the degradation of crystalline constituents in DLPF. The last exothermic crown

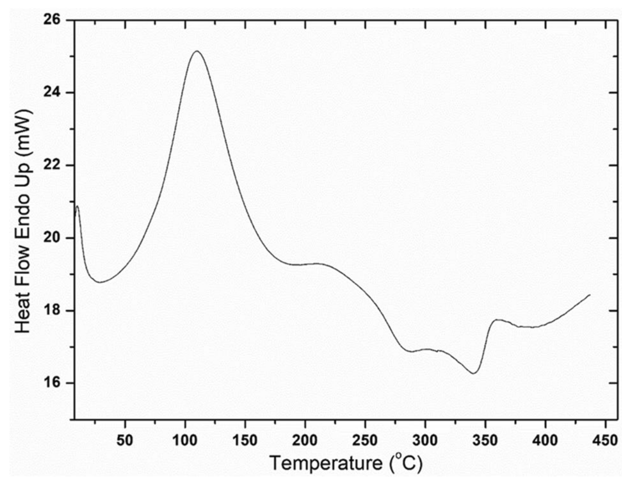
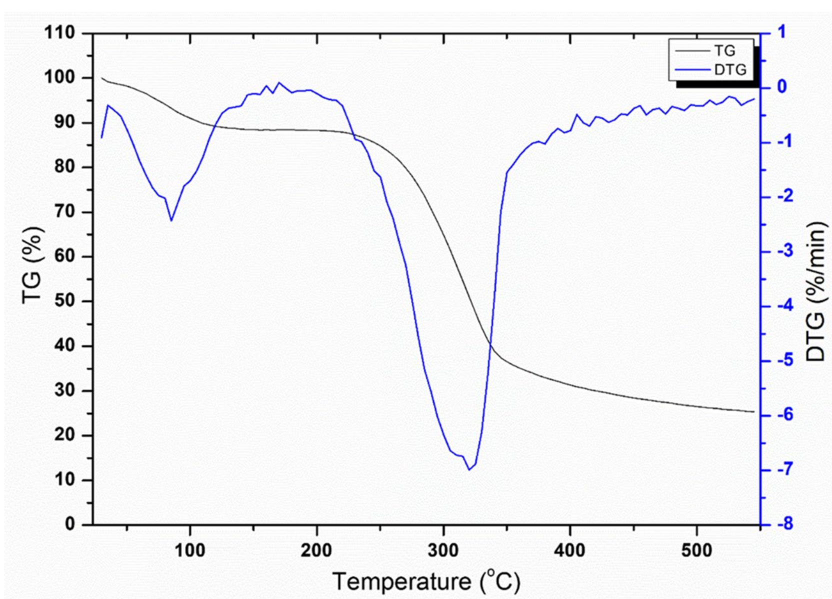


Fig. 6 DSC plot of *Dypsis lutescens* peduncle fiber

Fig. 5 TGA-DTG curve of *Dypsis lutescens* peduncle fiber



perceptible in the temperatures amid 319 to 359 °C corresponds to the disintegration of wax and fraction of lignin in the fiber. The instabilities perceived after 377 °C in DSC plot specify the volatilization of wax and lignin in DLPF [9]. The annotations of DSC plot demonstrate that the energy essential for deprivation of DLPF is higher compared to the polymerization process endorsing the ability of DLPF to resist thermal damage during the polymer matrix composite fabrication process.

5 Conclusions

The measurable and qualitative outcomes of characterization of DLPF, an agro-waste, ensure its utilization as firming material in polymer composites and thus favors the agro-waste management aspects. The adequate cellulose content of 51.11 wt% and uneven surface texture of DLPF provide adequate mechanical and morphological features to attain good interaction features with the matrix when utilized as firming material in polymer composites. The tensile capability of 169.4 MPa and least density of 1.35 g/cm^3 reveal the specific mechanical characteristics of DLPF and can contribute to the mechanical characteristics of the polymer matrix composite when reinforced. This inspires the reinforcing of DLPF in polymer composites employed for light weight structural utilities. The acceptable hydrophilic nature and existence of functional groups in DLPF were verified through XRD and FTIR analysis correspondingly. This authorizes the usage of DLPF–reinforced polymer composites in humid operating environments. The surface characteristics of DLPF were intervened with the aid of SEM. The thermally stable nature of 224 °C of DLPF encourages the usage of DLPF–reinforced polymer composites in high temperature geographical locations and industries having higher ambient temperature. The use of DLPF as firming material in polymer composites employed in light weight structural applications not only improves the sustainability of composite material but also helps in managing the agro-waste in an economical manner.

Author contribution ASFB: investigation (lead), resources, and supporting. NRP: resources and supporting. BBM: writing—original draft. RD: resources and supporting. AAMMS: investigation and writing—original draft. JSB: writing—original draft and reviewing.

Data availability This is an ongoing research work and hence the data cannot be shared at this moment.

Declarations

Ethics approval and consent to participate All the authors demonstrate that they have adhered to the accepted ethical standards of a genuine research study. Also, individual consent from all the authors was undertaken to publish the data prior submitting to journal.

Consent for publication Written formal consent ensures that the publisher has the author's permission to publish research findings.

Competing interests The authors declare no competing interests.

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