Biomass Conversion and Biorefinery
https://doi.org/10.1007/s13399-024-05428-1

ORIGINAL ARTICLE

Characterization of novel cellulosic fiber from agro-waste *Licuala grandis* leaf stalk for sustainable reinforcement in bio-composites

Siga Selvin Deva Kumar[1] · Rajesh Resselian[1] · Dev Anand Manoharan[1]

Received: 4 January 2024 / Revised: 2 February 2024 / Accepted: 8 February 2024

Abstract

Bio-waste is the new source of raw materials focussed by composite industries to sort out the sustainability issues in their products and processes. This research portrays the characterization of *Licuala grandis* tree leaf stalk fibers (LGTLSFs) mined from leaf stalks of the *Licuala grandis* tree which is a floral waste. The comprehensive investigation aids in obtaining quantifiable data such as cellulose proportion (56.47 wt.%), least wax (0.27 wt.%), minimum density (1.36 g/cm^3), greater crystallinity index (49%), tensile strength (312–354 MPa), and Young's modulus (2.3–6.6 GPa) of LGTLSFs. The thermogravimetric (TGA/DTG) and differential scanning calorimetry (DSC) analysis helps in predicting the thermal behaviour of the LGTLSF and suggests thermal stability until 218 °C. Fourier transform infrared (FTIR) spectroscopy analysis aids in validating the results of chemical investigations. The exterior roughness of the LGTLSFs was analysed through a scanning electron microscope (SEM) to favour its possibility as a support material in polymer composites. Positive findings from the experiment indicate that LGTLSFs can be utilized as a supporting material in polymer composites used in structural applications.

Keywords Bio-waste · Eco-friendly reinforcement · Bio-composite · Waste management · Biodegradable

1 Introduction

Sustainability in industrial practices is the order of the day due to unbalance in ecosystems which reflects as global warming; pollution of air, water, and soil; and exhaustion of natural resources [1, 2]. Sustainable practices were further enforced by laws in view to protect and preserve nature and its ecosystem. Any industry that aspires to follow sustainable practices must give utmost care in the selection of raw materials [3]. Many industries were yet to initiate or merely just started their sustainable practices. The composite industry is the one that has initiated its sustainable practices and has been successful in its first steps. This gives scope to composite industries to make their products and processes completely sustainable. Hence, composite industries were in search of eco-friendly, sustainable, and biodegradable raw materials to initiate their sustainability cycle [4]. The identification of the best-suited raw material will help the composite industries to establish sustainable production practices [5, 6]. The main choice that remains viable for composite industries is the fibers existing in natural resources such as plants, minerals, and animals. Fibers from animal sources are not sufficient enough to meet the continuous demand of composite industries; on the other hand, mining of mineral fibers is costlier. For vegetative countries like India, composite industries can rely more on fibers from plants for their raw materials.

Even though the fibers from plants are advantageous in several ways such as minimal cost, easily biodegradable, plenty of sources to obtain from nature, and do not demand harmful and energy-consuming processing techniques, they

Highlights

- *Licuala grandis* tree leaf stalk fiber (LGTLSF) suggests potential in polymer composite industries.
- 56.47 wt.% of cellulose content in LGTLSF was identified through chemical analysis.
- The abrasive surface texture of LGTLSF aids in making interlocking bonds with the polymer matrix.
- Tensile strength (312–354 MPa) and density (1.36 g/cm^3) reveal specific mechanical characteristics.
- The appraised CI value of 49% confirms the adequate hydrophobic nature of LGTLSFs.

✉ Siga Selvin Deva Kumar
sigaselvin@gmail.com

[1] Department of Mechanical Engineering, Noorul Islam Centre for Higher Education, Kumaracoil, Tamil Nadu 629180, India

pose certain hurdles in maximizing the performance of the composite when reinforced [6]. Since these fibers need to be harvested directly from nature, their physical shape cannot be controlled. The fibers of varied physical shapes make the industrialist challenging to achieve specific characteristics for polymer composites with these fibers as reinforcement materials [7, 8]. Further, on dependence of the composite industries on natural fibers as raw materials being available from nature, its supply based on the demand cannot be regulated. If the natural fibers were harvested based on the demand, it might lead to deforestation, imposing another sustainable threat to the environment [9]. On the other hand, several agricultural wastes that are rich in natural fibers remain in landfills and propagate bad odour to the surrounding environment or are fired in open environments creating air pollution [10–12]. The usage of these fiber-rich agricultural wastes by composite industries results in better waste management and leads to a circular economy benefitting the farmers.

The necessary traits of natural fibers to be used by composite industries depend on the chemical constituent of the fiber, the weather condition in which the plant or tree is grown, the age of the flora, and the plant part from which the fiber is intended to be utilized [13, 14]. The process adapted to extract the fiber from the plant part also influences the quality of the fibers. Sergius et al. [15] investigated the stem fiber extracted from *Ficus benjamina* to know its suitability to be used in the textile and composite industries. Their experimentations report that the extracted fibers possessed a cellulose content of 68.71 wt.% and crystallinity of 58.5% which is suitable to be used in the composite and textile industries. Another fiber from the stem of *Cissus vitiginea* was investigated by Sudhir et al. with a view of utilizing it as a reinforcement material in composite industries [16]. They also noticed a good weight percentage of cellulose content (65.43 wt.%) with acceptable crystalline characteristics (30.5%) and a temperature-withstanding capability up to 304 °C finds scope to be used as support material by composite industries. The fibers extracted from the leaf of the purple bauhinia tree were characterized by Rajeshkumar et al. [17] to know its probable scope in using it as a strengthening material in the composite industries. The extracted leaf fibers possessed a tensile asset of 373.3 MPa which is a boon to be used as a support material in the composite industries. The ability of the fiber to withstand higher temperatures of up to 341 °C identified through their experimentations indicates the ability of the extracted leaf fiber to support the fabrication process of composites.

Licuala grandis L. is a palm category tree that is grown as an ornamental plant and listed under the Arecaceae cluster. The wood of the *Licuala grandis* L. tree obtained from its trunk after maturity is utilized as a raw material for manufacturing wooden products. But the leaf stalk of the *Licuala grandis* L. tree which is rich in fiber remains unutilized and retained as landfills or burnt as waste. This natural floral waste rich in eco-friendly fibers requires further examination to verify its suitability to be used as a reinforcement material by composite industries. This inquiry specifies the examination of natural fibers mined from the leaf stalk of the *Licuala grandis* L. tree, a floral leftover to be used as a reinforcement material by composite industries. The *Licuala grandis* tree leaf stalk fibers (LGTLSFs) were subjected to physio-chemical and thermal experimentations to portray their mechanical, thermal, and chemical characteristics. The surface features of the LGTLSFs were examined with the help of a scanning electron microscope (SEM). The X-ray diffraction (XRD), thermogravimetric analysis (TGA), and Fourier transform infrared (FTIR) spectroscopy were performed on the LGTLSF to cross-examine its crystallinity, thermal stability, and existence of functional groups, respectively. The investigations on LGTLSF favour its use as a strengthening material in composite industries to increase the thermal and mechanical characteristics of polymer composites and help formulate the best waste management approach.

2 Materials and methods

2.1 Extraction of LGTLSFs

The leaf stalks of the *Licuala grandis* tree were picked from landfills of institutional and organizational campuses in and around Coimbatore, Tamil Nadu, India. The picked leaf stalks were cut to appropriate sizes as shown in Fig. 1 and immersed in water for 14 days to release its fibers [18]. The soaked leaf stalks were raked manually to segregate the LGTLSF from the pulp. The segregated LGTLSFs were splashed with water at several attempts to confiscate the pulp attached in the form of dust particles. Then the LGTLSFs were desiccated in sunshine for 3 days to lessen their wetness and warehoused for further investigation. The LGTLSF was characterized physically, mechanically, chemically, and by thermal means to ensure the possibility of utilizing it as a support material by composite industries.

2.2 Characterization of LGTLSF

The biochemical proportions of the LGTLSF such as cellulose, wax, lignin, and hemicellulose were accounted for by the well-established procedures followed in the literature [19]. The weight loss technique was followed to identify the moisture content of the LGTLSF. The mass-volume method was adhered to quantify the density of the LGTLSF. A single-fiber tensile test was conducted on LGTLSF as per ASTM D3822-07 norms to appraise its mechanical characteristics [20]. FTIR spectroscopy was

Fig. 1 Extraction of *Licuala grandis* tree leaf stalk fiber. **a** *Licuala grandis* tree, **b** collected leaf stalks of *Licuala grandis* tree, **c** soaking of leaf stalk, **d** fiber extraction, and **e** extracted *Licuala grandis* tree leaf stalk fibers

performed on LGTLSF at 4 cm^{-1} resolution and 32 scans/min to identify the occurrence of active groups in the fiber. Similarly, XRD spectroscopy analysis was conducted on LGTLSF with the vertical goniometer movement of 5°/min to plot the XRD spectrum over the Bragg angle (2θ) range of 10 to 80° [21]. The exterior features of the LGTLSF were best understood by viewing through SEM at a hastened power of 8 kV. The thermal nature of the LGTLSF was detailed by performing thermogravimetric analysis (TG and DTA) and differential scanning calorimetry (DSC) experiments by raising the temperature of the LGTLSF samples until 550 °C and 450 °C, respectively, at 10 °C/min [22].

3 Results and discussions

3.1 Chemical study of LGTLSF

The biochemical characteristics of the eco-friendly fibers depend on the weather conditions in which the plant or tree is grown, the age of the flora, and the herbal part from which the support material is mined. The outcomes of chemical investigation of natural fibers help to infer their physio-mechanical, crystalline, and surface texture characteristics. The surface texture of the natural support material plays a vital role in the mechanical assets of the polymer composite when reinforced [23]. Moreover, the specific traits of the natural fiber–strengthened polymer composite are highly dependent on the qualities of the reinforced fibers. The chemical proportions of LGTLSF have been portrayed in Table 1 measured as weight percentage (wt.%). The significant amount of 56.47 wt.% cellulose in LGTLSF, which is equivalent to its competitors, contributes to the fiber's mechanical properties. The crystalline nature of the LGLSF, which produces adequate hydrophobic properties of the fiber to be employed as support material in polymer composites, benefits from the larger amount of cellulose content.

When engaged as a strengthening material in polymer composites, the LGTLSF has a minimum hemicellulose concentration of 18.36 wt.%, which benefits the fiber's mechanical and bonding properties. When engaged as strengthening material in polymer composites, the 12.8 wt.% of lignin in the LGLSF works as a binder and encourages the contact with the matrix [24]. The LGLSF's fire resistance is supported by its 1.8 wt.% ash content. When engaged as strengthening material in polymer composites, the LGLSF's thermal durability to withstand damage to polymerization temperature is further supported by the same. Its usage as a strengthening material in polymer composites is encouraged by the satisfactory weight percentages of moisture (10.3 wt.%) and wax (0.27 wt.%).

3.2 FTIR analysis of LGTLSF

The FTIR observations of LGTLSF are displayed in graphical form in Fig. 2. The graphical plot provides an idea on the presence of notable functional groups in the LGTLSF. The trench seen at a frequency of 532 cm^{-1} attributes to the oscillations of alkyl halide which is an organic functional cluster [26]. The deep trench viewed at the wavelength of 1018 cm^{-1} belongs to the oscillating alkene cluster which is again an organic functional group symbolized as = C-H. The instabilities in the FTIR plot visible until 1377 cm^{-1} ensure the existence of polysaccharides of cellulose in the LGTLSF

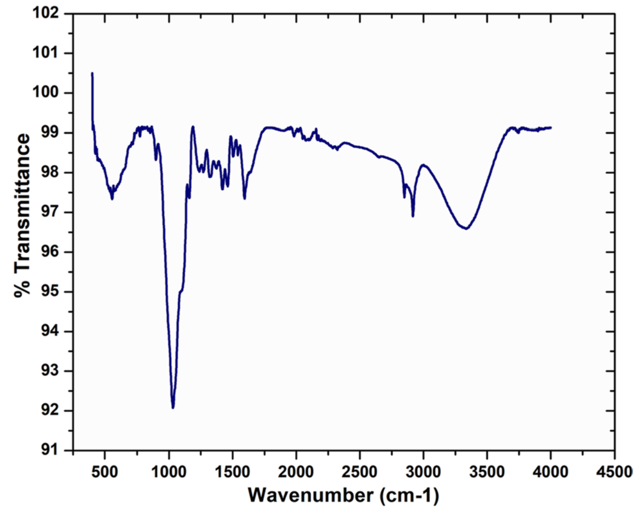

Fig. 2 FTIR spectrum of *Licuala grandis* tree leaf stalk fiber

[27]. The carbonyl functional cluster symbolized as C-O is indicated by the trench at 1603 cm^{-1}. The oscillations in the FTIR spectrum in the wavelength range between 1848 and 2124 cm^{-1} represent the occurrence of lignin and hemicellulose in the LGTLSF [28]. The prevalence of alkaline functional cluster promotes the symmetric bending of C-H which is represented by the trench at 2898 cm^{-1}. The broader trench seen at 3288 cm^{-1} in the FTIR plot of LGTLSF is attributed to the flaring of OH impregnated around the cellulose. The observations of FTIR analysis ratify the outcomes of the chemical analysis of LGTLSF.

3.3 Morphological and anatomical analysis of LGTLSF

The LGTLSF's physical characteristics are shown in Table 2. These values were obtained by repeating the experiment at least thrice. Lignin and cellulose make up

Table 1 Chemical and physio-mechanical features of *Licuala grandis* leaf stalk fiber in comparison with its other natural and synthetic counterparts [25]

Fiber name	Cellulose (wt.%)	Hemicellulose (wt.%)	Lignin (wt.%)	Wax (wt.%)	Density (g/cm^3)	Elongation at break (%)	Tensile strength (MPa)	Young's modulus (GPa)
LGTLSF*	**56.47**	**18.36**	**12.8**	**0.27**	**1.36**	**3.5–4.4**	**312–354**	**2.3–6.6**
Areca tree peduncle fiber	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
Raffia textilis	148–660				0.75	2	148–660	28–36
Acacia leucophloea	76.69	3.81	13.67	0.13	1.43	1.91–5.88	357–1809	10.45–87.57

Table 2 Physical features of *Licuala grandis* leaf stalk fiber

Property	Value
Thickness of primary cell wall (μm)	1.630
Thickness of secondary cell wall (μm)	0.548
Thickness of middle lamellae (μm)	4.318
Thickness of cell lumen (μm)	10.079
Fiber diameter (μm)	419.5 ± 38.7
Fiber density (g·cm^{-3})	1.36

the secondary and primary cell walls of the LGTLSF, which heavily influences the physical features of the eco-friendly material [29]. The neighbouring cells in the LGTLSF are connected by the lignin and hemicellulose found in the lamellae, which act as connective tissue. When mined, support materials are used to strengthen polymer composite materials; the lumen, or empty space inside the cells of the LGLSF, aids in the natural fibers' ability to retain less density and adds to the lightweight nature of the polymer composite.

Figure 3 displays the exterior and cross-sectional views of the LGTLSF as seen via SEM. When utilized as a support material in polymer composites, the observations from Fig. 3a demonstrate that the surface of the LGTLSF is rough with greater crest and trough, which favours the bonding of LGTLSF with the matrix [30]. On strengthening in polymer composites, the LGTLSF exterior with more crest and trough enhances the surface area of contact between the LGTLSF and matrix, which is beneficial for having stronger interfacial bonding properties. The SEM pictures also show the presence of lignin, a binder substance, and tiny fibrils that connect parenchyma cells. The microfibril angle has an influence on the physical nature of the LGTLSF as well. The microfibril angle of LGTLSF is calculated using Eq. (1) and is 6.01° ± 0.12°.

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

where ε is the strain, α is the microfibril angle (°), ΔL is the elongation at break (mm), and L_o is the gauge length (mm). When reinforced in polymer composites, LGTLSF's microfibril angle must be as small as possible in order for the matrix and LGTLSF to transfer stress effectively.

3.4 XRD study of LGTLSF

The XRD observations of LGTLSF are displayed in graphical form in Fig. 4. The graphical plot provides an idea on the crystalline characteristics of the LGTLSF. The semi-crystalline features of LGTLSF were endorsed by the resilient crown at a Bragg angle (2θ) of 21.3° [31]. The preceding peak of mild intensity seen at a Bragg angle (2θ) of 15.8° is attributed to the amorphous components in the LGTLSF. The broader peak at 21.3° of 2θ corresponding to the crystalline contents of LGTLSF belongs to the crystallographic plane (2 0 0). The cellulose in this crystallographic plane possesses a monoclinic structure belonging to the category cellulose-I [32]. On the other hand, the peak at 15.8° of 2θ relating to the amorphous contents of LGTLSF fits the (1 1 0) crystallographic plane. The crystallinity index (CI) of the LGTLSF was quantified by

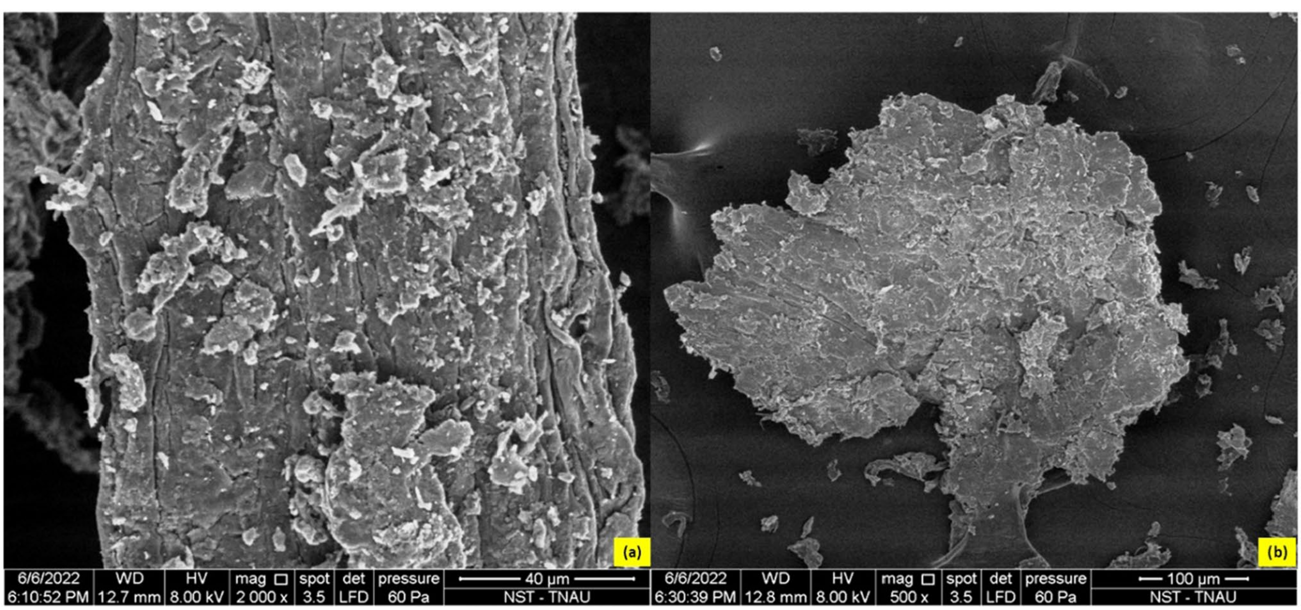

Fig. 3 SEM image of *Licuala grandis* leaf stalk fiber: **a** parallel view 2000 × and **b** cross-sectional view 500 ×

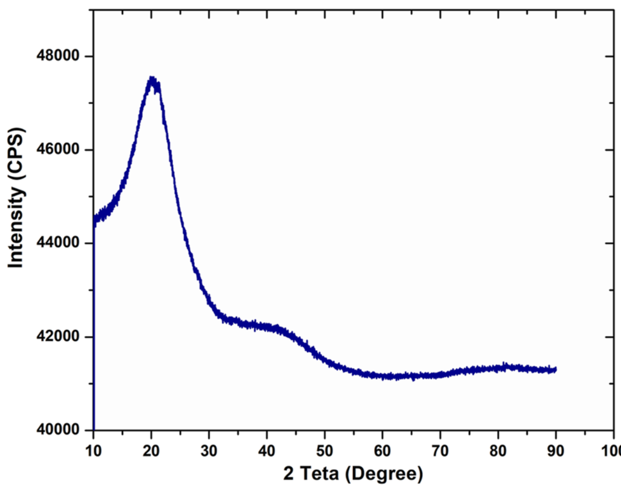

Fig. 4 XRD spectrum of *Licuala grandis* tree leaf stalk fiber

Eq. (2) [32] as 49%. The higher CI value obtained among its counterparts ensures the stiffness of the LGTLSF.

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

where I_c is the maximum intensity of crystalline peak at $2\theta = 21.3°$, and I_{am} is the intensity of amorphous peak at $2\theta = 15.8°$. The assessed CI numeric of LGTLSF ensures its crystalline nature and required physical qualities to be castoff as a support material in polymer composites. Equation (3) [32] proposed by Scherrer was used to assess the crystallite size (CS) of the LGTLSF as 1.14 nm. The lesser CS value obtained for LGTLSF when compared with its counterparts enhances the mechanical and hydrophobic characteristics of the fiber.

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

where $K = 0.89$ is Scherrer's constant, λ is the wavelength 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 numerical value quantified for CS endorses the hydrophobic nature of the LGTLSF which is sufficient to be castoff as a strengthening material in polymer composites.

3.5 Physicomechanical study of LGTLSF

Table 1 summarizes the physicomechanical parameters of the LGTLSF. Powdered LGTLSF specimens were securely crammed in a cylindrical flask with an identified mass in order to calculate the LGTLSF's density. As a result, 1.36 g/cm^3 was calculated as the LGTLSF's density on a mass-volume basis. When employed as reinforcement, LGTLSF's lower density guarantees that the natural fiber–reinforced polymer composite will be lightweight [33]. LGTLSF reinforcement in polymer matrix composites aids in the fabrication of composites with certain properties. With the aid of the ImageJ program and an optical microscope, the diametric width of the LGTLSF was measured. As shown in Table 3, the diameter of the LGTLSF varied from 397.96 to 442.37 µm. Despite the LGTLSF's cross-section's non-uniform size and shape, it is assumed to be circular for the purposes of calculating the diameter using Eq. (4).

$$D_f = \sqrt{\frac{L_f}{9000 \times M_d \times 0.7855}} \tag{4}$$

where D_f is the LGTLSF's diameter, L_f is its linear mass density in denier, which is a measure of the LGTLSF's fineness determined in accordance with ASTM D1577-07 norm, and M_d is its mass density in grams per cubic centimeter. Equation (4) yields a diameter for the LGTLSF of 436.12 µm, which is within the range of values discovered using the ImageJ program.

The tensile asset of the LGTLSF, which is shown in Table 3, ranges from 312 to 354 MPa. Comparable to other eco-friendly support materials used as strengthening components in polymer composites, LGTLSF has tensile strength values [34]. The LGTLSF's cross-section varies in size and form over its length, which accounts for the variability in physical features detected over the variation in gauge length. The lower Young's modulus and higher elongation at break values of the LGTLSF demonstrate the LGTLSF's superior load-bearing capacity [35]. The LGTLSF is capable of serving as a strengthening material in polymer composites due to its estimated and measured physicomechanical properties. Since natural fibers are the primary

Table 3 Mechanical assets of *Licuala grandis* leaf stalk fiber attained as per ASTM norms

Gauge length (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Strain to failure (%)	Diameter (µm)
10	312 ± 23	2.3 ± 0.4	4.4 ± 1.4	442.37 ± 30.11
20	321 ± 33	4.4 ± 0.5	4.1 ± 1.2	431.79 ± 25.26
30	336 ± 40	5.2 ± 0.8	3.8 ± 0.8	413.84 ± 22.71
40	354 ± 44	6.6 ± 1.1	3.5 ± 0.7	397.96 ± 20.23

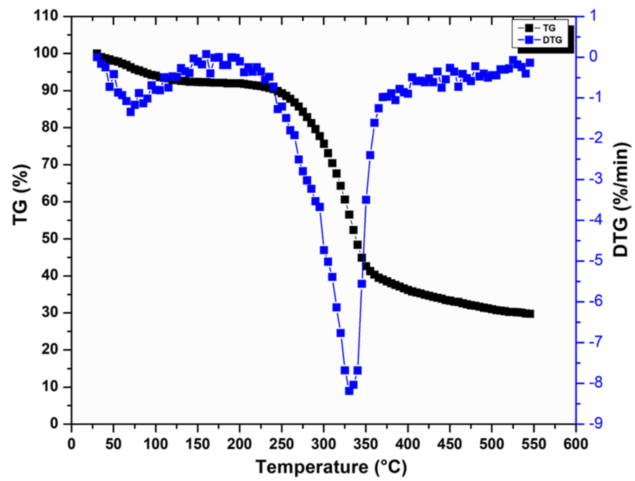

Fig. 5 TGA-DTG curve of *Licuala grandis* leaf stalk fiber

load-bearing component of eco-friendly, mined, support-material-strengthened polymer composites, the LGTLSF with higher tensile characteristics can be an appropriate reinforcement material.

3.6 TGA study of LGTLSF

The thermal observations of LGTLSF are displayed in graphical form in Fig. 5. The graphical plot provides an idea on the thermal stability of the LGTLSF. The dehydration of the LGTLSF with a rise in temperature is reflected as weight loss until 108 °C in the thermogravimetric curve. After dehydration of the LGTLSF, the fiber sample showed good resistance to temperature until 218 °C indicating a minor weight loss [36]. The components of the LGTLSF such as cellulose, lignin, and hemicellulose started to disintegrate on a subsequent increase in temperature through the depolymerisation method. This incurs a reduction in the weight of the LGTLSF sample of about 13.9% until 291 °C. An extensive reduction in weight of the LGTLSF sample in the temperature array of 292 to 367 °C represents the comprehensive dilapidation of cellulose in the mined fiber sample [37]. The weight loss witnessed after 368 °C indicates the deprivation of a portion of lignin and wax in the mined fiber sample.

The variations of the DTG plot designate an infliction point at about 331.5 °C accompanied by a difference in mass of about 51.63% representing that the cellulose in the LGTLSF undergoes pyrolysis and breakdown of molecular structure. The fire retardant ability of the LGTLSF is predictable from the residual char attained at 550 °C which is quantified as 14.31%. Broido's Eq. (5) [38] was utilized to estimate the kinetic activation energy (E) of the LGTLSF as 72.71 kJ/mol.

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

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

3.7 DSC study of LGTLSF

The DSC observations of LGTLSF are displayed in graphical form in Fig. 6. The graphical plot provides an idea on the heat flow in the LGTLSF sample with a rise in temperature. The dehydration of the LGTLSF sample associated with the water particles attached to cellulose is shown as an endothermic curve in the DSC plot. The reluctantly attached water particles in the cellulose of the LGTLSF get dehydrated closer to above 100 °C [39]. Subsequently, further rise in temperature of the LGTLSF sample dehydrates the water particles which are closely attached to cellulose until 129.8 °C representing the endothermic part of the DSC curve. The degeneration of wax in the LGTLSF sample is indicated by the exothermic curve at 169.4 °C [40]. The damage caused to cellulose in the LGTLSF sample is attributed to the endothermic peak at 267.2 °C. The pyrolysis experienced by hemicellulose and lignin affiliates to the exothermic peaks at 283.7 and 379.1 °C, respectively. Further endothermic and exothermic fluctuations seen at higher temperatures in the DSC curve denote the degeneration of hemicellulose and lignin in the LGTLSF [41]. The endothermic and exothermic fluctuations witnessed in the LGTLSF sample on heating ensure that the LGTLSF-strengthened

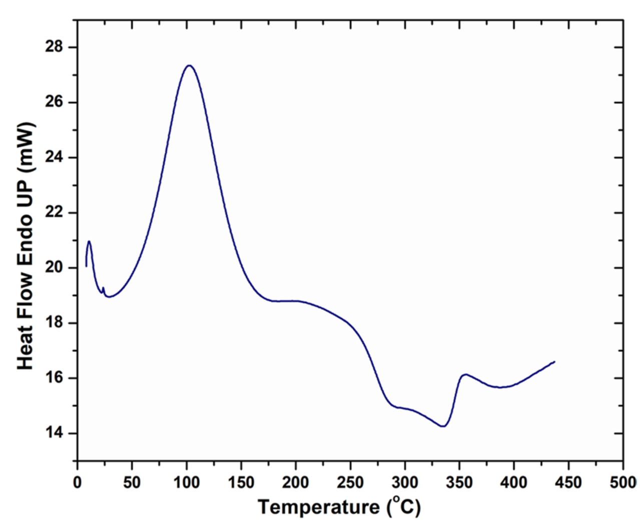

Fig. 6 DSC plot of *Licuala grandis* leaf stalk fiber

polymer composites can be employed in industrial environments having higher ambient temperatures.

4 Conclusions

The observations of the experimentations on LGTLSF strongly suggest its use as a support material in polymer composites by composite industries. This aids in minimizing the sustainability issues in their products and processes by composite industries and initiates a better agro-waste management approach. The 56.47 wt.% of cellulose content in the LGTLSF identified through chemical analysis supports the adequate mechanical physiognomies to be castoff as a support material in polymer composites. The results of chemical analysis were further endorsed by the identification of major functional groups through FTIR analysis. The abrasive surface texture of the LGTLSF aids in making interlocking bonds with the polymer matrix when reinforced. The tensile strength (312–354 MPa) and density (1.36 g/cm^3) of the LGTLSF reveal its specific mechanical characteristics. The appraised CI value of 49% confirms the adequate hydrophobic nature of the LGTLSF. The endothermic and exothermic behaviour on the rise in temperature of the LGTLSF and thermal stability until 218 °C favours LGTLSF-embedded polymer composites in high ambient temperature applications. The thermo-mechanical observations of LGTLSF warrant the use of LGTLSF-supported polymer composite in lightweight structural applications in high ambient temperature environments.

Author contribution Siga Selvin Deva Kumar: investigation (lead), resources, and support; Rajesh Resselian: writing—original draft and reviewing; Dev Anand Manoharan: 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 authors demonstrate that they have adhered to the accepted ethical standards of a genuine research study. Also, individual consent from all authors was undertaken to publish the data prior to submitting it to the 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.

References

1. Arul Marcel Moshi A, Ravindran D, Sundara BS, Padma SR, Indran S, Divya D, (2020) Characterization of natural cellulosic fiber extracted from Grewia damine flowering plant's stem. Int J Biol Macromol 154:1246–1255. https://doi.org/10.1016/j.ijbiomac.2020.07.225
2. Chakkour M, Ould Moussa M, Khay I, Balli M, Ben Zineb T (2023) Towards widespread properties of cellulosic fibers composites: a comprehensive review. J Reinf Plast Compos 42(5–6):222–263. https://doi.org/10.1177/07316844221112974
3. Shi Y, Jiang J, Ye H, Sheng Y, Zhou Y, Foong SY, Sonne C, Chong WWF, Lam SS, Xie Y, Li J, Ge S (2023) Transforming municipal cotton waste into a multilayer fibre biocomposite with high strength. Environ Res 218:114967. https://doi.org/10.1016/j.envres.2022.114967
4. Singh SP, Dutt A, Hirwani CK (2023) Experimental and numerical analysis of different natural fiber polymer composite. Mater Manuf 38:322–332. https://doi.org/10.1080/10426914.2022.2136379
5. Sanjay MR, Madhu P, Jawaid M, Senthamaraikannan P, Senthil S, Pradeep S (2018) Characterization and properties of natural fiber polymer composites: a comprehensive review. J Clean Prod 172:566–581. https://doi.org/10.1016/j.jclepro.2017.10.101
6. Siva R, Valarmathi TN, Palanikumar K, Antony VS (2020) Study on a novel natural cellulosic fiber from Kigelia africana fruit: characterization and analysis. Carbohydr Polym 244:116494. https://doi.org/10.1016/j.carbpol.2020.116494
7. Aref YM, Othaman R, Anuar FH, Ku Zarina Ku, Ahmad AB (2023) Superhydrophobic modification of Sansevieria trifasciata natural fibres: a promising reinforcement for wood plastic composites. Polymers 15:594–606. https://doi.org/10.3390/polym15030594
8. Sahu S, Sahu SBBPJ, Nayak S, Mohapatra J, Khuntia SK, Malla C, Samal P, Patra SK, Swain S (2023) Characterization of natural fiber extracted from Bauhinia vahlii bast subjected to different surface treatments: a potential reinforcement in polymer composite. J Nat Fibers 20:2162185. https://doi.org/10.1080/15440478.2022.2162185
9. Msahli S, Jaouadi M, Sakli F, Drean JY (2015) Study of the mechanical properties of fibers extracted from Tunisian Agave americana L. J Nat Fibers 12:552–560. https://doi.org/10.1080/15440478.2014.984046
10. Imraan M, Ilyas RA, Norfarhana AS, Bangar SP, Knight VF, Norrrahim MNF (2023) Sugar palm (Arenga pinnata) fibers: new emerging natural fibre and its relevant properties, treatments and potential applications. J Mater Res Technol 24:4551–4572. https://doi.org/10.1016/j.jmrt.2023.04.056
11. Raju JSN, Depoures MV, Kumaran P (2021) Comprehensive characterization of raw and alkali (NaOH) treated natural fibers from Symphirema involucratum stem. Int J Biol Macromol 186:886–896. https://doi.org/10.1016/j.ijbiomac.2021.07.061
12. Mohan Prasad M, Sutharsan SM, Ganesan K, Ramesh Babu N, Maridurai T (2022) Role of sugarcane bagasse biogenic silica on cellulosic Opuntia dillenii fibre-reinforced epoxy resin biocomposite: mechanical, thermal and laminar shear strength properties. Biomass Conv Bioref https://doi.org/10.1007/s13399-021-02154-w
13. Li T, Zhang Y, Jin Y, Bao L, Dong L, Zheng Y, Xia J, Jiang L, Kang Y, Wang J (2023) Thermoplastic and biodegradable sugarcane lignin-based biocomposites prepared via a wholly solvent-free method. J Clean Prod 386:135834. https://doi.org/10.1016/j.jclepro.2022.135834
14. Zhou S, Xia L, Zhang K, Zhuan Fu, Wang Y, Zhang Q, Zhai L, Mao Y, Weilin Xu (2021) Titanium dioxide decorated natural cellulosic Juncus effusus fiber for highly efficient photo-degradation towards dyes. Carbohydr Polym 232:115830. https://doi.org/10.1016/j.carbpol.2020.115830
15. Sergius Joe1 M, Prince Sahaya Sudherson D, Indran Suyambulingam, Suchart Siengchin (2023) Extraction and characterization of novel biomass–based cellulosic plant fiber from Ficus benjamina L. stem for a potential polymeric composite reinforcement. Biomass Conv Bioref https://doi.org/10.1007/s13399-023-03759-z

16. Sudhir Chakravarthy K, Madhu S, Raju JSN, Jabihulla Shariff Md (2020) Characterization of novel natural cellulosic fiber extracted from the stem of Cissus vitiginea plant. Int J Biol Macromol 161:1358–1370. https://doi.org/10.1016/j.ijbiomac.2020.07.230
17. Rajeshkumar G, Devnani GL, Prakash Maran J, Sanjay MR, Siengchin S, Al-Dhabi NA, Ponmurugan K (2021) Characterization of novel natural cellulosic fibers from purple bauhinia for potential reinforcement in polymer composites. Cellulose 28:5373–5385. https://doi.org/10.1007/s10570-021-03919-2
18. Madhu P, Sanjay MR, Jawaid M, Siengchin S, Khan A, Pruncu CI (2020) A new study on effect of various chemical treatments on Agave americana fiber for composite reinforcement: physicochemical, thermal, mechanical and morphological properties. Polym Test 85:106437. https://doi.org/10.1016/j.polymertesting.2020.106437
19. Cheng D, Weng B, Chen Y, Zhai S, Wang C, Xua R, Guo J, Lv Y, Shi L, Guo Y (2020) Characterization of potential cellulose fiber from Luffa vine: a study on physicochemical and structural properties. Int J Biol Macromol 164:2247–2257. https://doi.org/10.1016/j.ijbiomac.2020.08.098
20. Ding L, Han X, Cao L, Chen Y, Ling Z, Han J, He S, Jiang S (2022) Characterization of natural fiber from manau rattan (Calamus manan) as a potential reinforcement for polymer-based composites. J Bioresour Bioprod 7:190–200. https://doi.org/10.1016/j.jobab.2021.11.002
21. Amutha K, Sudha A, Saravanan D (2022) Characterization of natural fibers extracted from banana inflorescence bracts. J Nat Fibers 19:872–881. https://doi.org/10.1080/15440478.2020.1764437
22. Njoku CE, Omotoyinbo JA, Alaneme KK, Daramola MO (2022) Characterization of Urena lobata fibers after alkaline treatment for use in polymer composites. J Nat Fibers 19(2):485–496. https://doi.org/10.1080/15440478.2020.1745127
23. Poomathi S, Roji SSS (2022) Experimental investigations on Palmyra sprout fiber and biosilica-toughened epoxy bio composite. Biomass Conv Bioref https://doi.org/10.1007/s13399-022-02867-6
24 Suárez Luis, Barczewski Mateusz, Kosmela Paulina, Marrero María D, Ortega Zaida (2023) Giant reed (Arundo donax L.) fiber extraction and characterization for its use in polymer composites. J Nat Fibers 20:2131687. https://doi.org/10.1080/15440478.2022.2131687
25. Moshi AAM, Ravindran D, Bharathi SRSRS, Indran S, Saravanakumar SS, Liu Y (2020) Characterization of a new cellulosic natural fiber extracted from the root of Ficus religiosa tree. Int J Biol Macromol 142:212–221. https://doi.org/10.1016/j.ijbiomac.2019.09.094
26. Aziz K, El Achaby M, Mamouni R, Saffaj N, Aziz F (2023) A novel hydrogel beads based copper-doped Cerastoderma edule shells@alginate biocomposite for highly fungicide sorption from aqueous medium. Chemosphere 311(1):136932. https://doi.org/10.1016/j.chemosphere.2022.136932
27. Lendvai László, Omastova Maria, Patnaik Amar, Dogossy Gábor, Singh Tej (2023) Valorization of waste wood flour and rice husk in poly(lactic acid)-based hybrid biocomposites. J Polym Environ 31:541–551. https://doi.org/10.1007/s10924-022-02633-9
28. French AD (2014) Idealized powder diffraction patterns for cellulose polymorphs. Cellulose 21:885–896. https://doi.org/10.1007/s10570-013-0030-4
29. Selvaraj M, Akash S, Mylsamy B (2023) Characterization of new natural fiber from the stem of Tithonia diversifolia plant. J Bionic Eng 20:2167144. https://doi.org/10.1080/15440478.2023.2167144
30. Brailson Mansingh B, Binoj JS, Hassan SA, Mariatti M, Siengchin S, Sanjay MR, Bharath KN (2022) Characterization of natural cellulosic fiber from Cocos nucifera peduncle for sustainable biocomposites. J Nat Fibers 19:9373–9383. https://doi.org/10.1080/15440478.2021.1982827
31. Joseph Selvi Binoj, Mariatti Jaafar, Bright Brailson Mansingh, Govindarajan Bharathiraja (2023) Extraction and characterization of novel cellulosic biofiber from peduncle of Areca catechu L. biowaste for sustainable biocomposites. Biomass Conv Bioref https://doi.org/10.1007/s13399-023-04081-4
32. Segal L, Creely JJ, Martin AE Jr, Conrad CM (1959) An empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer. Text Res J 29:786–794. https://doi.org/10.1177/004051755902901003
33. Palaniyappan Sabarinathan, Annamalai VE, Rajkumar K, Vishal K, Veeman Dhinakaran (2022) Synthesis and characterization of randomly oriented silane-grafted novel bio-cellulosic fish tail palm fiber–reinforced vinyl ester composite. Biomass Conv Bioref https://doi.org/10.1007/s13399-022-02459-4
34. French AD (2020) Increment in evolution of cellulose crystallinity analysis. Cellulose 27:5445–5448. https://doi.org/10.1007/s10570-020-03172-z
35. Anand PB, Lakshmikanthan A, Chandrashekarappa MPG, Selvan CP, Pimenov DY, Giasin K (2022) Experimental investigation of effect of fiber length on mechanical, wear, and morphological behavior of silane-treated pineapple leaf fiber reinforced polymer composites. Fibers 10(7):56–69. https://doi.org/10.3390/fib10070056
36. Ilaiya Perumal C, Sarala R (2020) Characterization of a new natural cellulosic fiber extracted from Derris scandens stem. Int J Biol Macromol 165:2303–2313. https://doi.org/10.1016/j.ijbiomac.2020.10.086
37. Jayaraj Mahalingam, Rama Thirumurugan, Shanmugam Dharmalingam, Vijayakkannan Kaliyappan (2023) Effect of alkali treatment on novel natural fiber extracted from palmyra palm primary flower leaf stalk for polymer composite applications. Biomass Conv Bioref https://doi.org/10.1007/s13399-023-04641-8
38. Khalili H, Bahloul A, Ablouh E-H, Sehaqui H, Kassab Z, Hassani F-Z, El Achaby M (2023) Starch biocomposites based on cellulose microfibers and nanocrystals extracted from alfa fibers (Stipa tenacissima). Int J Biol Macromol 226:345–356. https://doi.org/10.1016/j.ijbiomac.2022.11.313
39. Prabhu P, Jayabalakrishnan D, Balaji V, Bhaskar K, Maridurai T, Arun Prakash VR (2022) Mechanical, tribology, dielectric, thermal conductivity, and water absorption behaviour of Caryota urens woven fibre-reinforced coconut husk biochar toughened wood-plastic composite. Biomass Conv Bioref https://doi.org/10.1007/s13399-021-02177-3
40. Thooyavan Y, Kumaraswamidhas LA, Edwin Raj R, Binoj JS, Brailson Mansingh B (2022) Failure analysis of basalt bidirectional mat reinforced micro/nano SiC particle filled vinyl ester polymer composites. Eng Fail Anal 136:e106227. https://doi.org/10.1016/j.engfailanal.2022.106227
41. Anne Kavitha S, Krishna Priya R, Arunachalam KP, Avudaiappan S, Maureira-Carsalade N, Roco-Videla Á (2023) Investigation on properties of raw and alkali treated novel cellulosic root fibres of Zea mays for polymeric composites. Polymers 15:1802–1814. https://doi.org/10.3390/polym15071802

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.