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A review of leaf fiber reinforced polymer composites

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Abstract

The utilization of natural fiber-reinforced polymer composite has received greater attention in various fields due to its recyclability; inexpensive, nonabrasive, specific properties; light-weight, naturally decomposed, abundant availability; etc. Natural fibers are generally lignocellulosic and multicellular, a better alternate to the synthetic materials. Among the natural fibers, leaf fibers are hard fibers, used in the making of filaments, threads, ropes, mats, fabrics, etc. PALF, sisal, henequen, cantala, fique, alfa, and sansevieria family are the examples of the leaf fibers. The present comprehensive review aims to provide different types of leaf fibers, their properties, and their reinforced composites. The effect of various factors like fiber volume fraction, fiber aspect ratio (length/diameter), fiber orientation, packing arrangement, matrix content and coupling agents, and processing techniques towards the mechanical properties of leaf fiber-reinforced polymer composites, is discussed. The surface modification of fiber such as alkaline, silane, $KMnO_4$, and their effects on the mechanical properties is given. Scanning electron microscopy (SEM) and water absorption (WA) characteristics are also discussed.

Keywords: Leaf fibers, Polymer composites, Surface modification, Impact strength (IS), Impact energy (IE), Mechanical properties

Introduction

Natural fibers have been gaining much attention from the researchers, engineers, and industrialists and have been considered as a viable alternative to the synthetic counterparts. These fibers have many advantages such as light weight, available in nature, pollution-free, economical and eco-friendly, design flexibility, low pressure, and temperature requirement during manufacturing.

Natural fibers are referred to as vegetable fibers extracted from the plants and can be used as a filler or reinforcement in polymer matrices, and it is mainly consists of cellulose. Based on the strength, stiffness, and location of extraction, these fibers have been categorized into the following: (i) *leaf fibers* are hard fibers, obtained from the leaves or leaf stalks of various perennial, monocotyledonous plants, and the fiber lumen is larger in relation to the cell wall; (ii) *stem or bast fibers* occur in the phloem, typically low in elongation and recovery from stretch (jute, ramie, flax, banana, kenaf, hemp); (iii) *seed and fruit fibers* are attached to hairs or in the form of bundle or encased in a husk (coconut, cotton, kapok); (iv) *grass fibers* occur in stems and leaves (bagasse, elephant grass, bamboo); (v) *wood fiber* is extracted from trees, having high level of porosity used in the manufacture of hardboard and paperboard (*Eucalyptus*, pine, beech, birch); and (vi) *straw fibers*, an agricultural by-product, obtained from the stalks of cereal plants after the grains were removed (barley, wheat, oat, rice, corn). Based on the main sources, bast, leaf, seed, wood, and grass, the plant fibers which are categorized further into different types are presented in Fig. 1. These abundantly available plant fibers consist various properties such as reliable quality, inexpensive, light weight, and nontoxic which make these fibers more popular among the researchers, scientists, and industrialists for the purpose of enhancing their applicability.

The studies undertaken by various authors on the leaf fiber-reinforced composites are presented in this review. Different molding processes such as hand layup, compression, and injection twin-screw extruder and different leaf fibers and their reinforced composites have been studied by several authors. The most common matrix materials used in this review are thermoplastic and thermosets, i.e., epoxy, polyester, polypropylene (PP), and polyethylene (PE). Also, their mechanical properties were determined and compared to the properties of synthetic fibers.

Leaf fiber as reinforcing material

The contribution of plastics, problems at their end of lifetime, and the depletion of nonbiodegradable resources have emphasized the utilization of eco-friendly materials. Compared to synthetic fibers, there is a wide variety of natural fibers available throughout the world, which act as a sustainable and suitable reinforcing agent in the biodegradable composites. At the time of manufacturing, synthetic fibers such as glass and carbon could create different environmental and health hazard issues for the employees. With the help of nonhazardous plant fibers, these problems can be solved by combining, strengthening, and shaping composites in polymer matrix. The characteristic features of the plant fibers over the synthetic fibers are reduced tool wear, inexpensive, contribution of greener environment to the society, non-toxicity, low density and it is very easy to dispose at their end of life cycle, etc. Conversely, it has disadvantages too, i.e., low thermal and water resistance, lower durability, and hydrophilic nature of the plant fibers lead

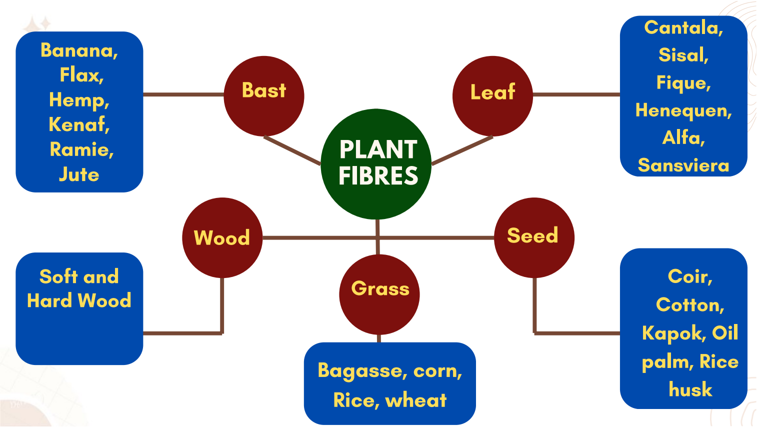

Fig. 1 Different type of plant fibers

poor fiber-matrix interfacial bonding. Many attempts are made by researchers and technologists [1–4] to utilize leaf fiber by mixing it with suitable matrix for the preparation of composite material. The surface modification of fiber can enhance fiber-matrix interfacial bonding, decrease the absorption of moisture, and could improve the mechanical property of the polymer composites.

Constituents and properties of leaf fiber

Leaf fibers are versatile materials, and their characteristics may vary with chemical constituents and physical structure. The physico-mechanical properties of leaf fibers are mainly influenced by the fiber extraction method, age of the plant, climatic conditions, moisture content, technical process involved during harvesting, retting, and decortication. Major components present in the fibers are as follows: (i) cellulose — a linear homopolymer made up of glucose units; (ii) hemicellulose — strengthen the cell wall of the fibers, hydrophilic in nature, and have bonding with the cellulose; (iii) lignin — a phenolic compound which conferred rigidness to plant cell wall; (iv) pectin — glues the elementary fibers to form bundles and found in the primary cell wall; and (v) wax — protects the primary wall, which is composed of cellulose crystalline fibrils. The mechanical properties of cellulose-based fibers are highly dependent upon the fibrillar angle and cellulose content present in the fibers. Table 1 displayed the chemical constituents of leaf fibers in which they significantly differed from leaf fiber types and origins. Generally, the primary composition, cellulose, is at 43 – 80%, hemicellulose 10 – 39%, lignin 3–15%, and the remaining parameters are given in Table 1. The leaf fibers exhibited a wide range of tensile strength ranging from 230 to 1627 MPa, Young's modulus 0.2 to 22 GPa, and density 0.8 to 1.4 g/cm^3 (Table 2). The TS values are generally lower than those of synthetic fibers such as E-glass fiber which has a TS of approximately 2000–3500 MPa [5].

Leaf fiber-reinforced polymer composites

There has been a growing interest in recent years to replace traditional synthetic fiber with leaf fiber to reinforce polymer resins as it eliminates the environmental issues and fossil fuel depletion. These leaf fibers have been gaining importance from materialists and scientists due to its ecological and economical attribution. Researchers extracted the fibers from leaves for their studies, and the typical view of different types of leaf with

Table 1 Chemical compositions of leaf fibers

Fiber type	Cellulose	Hemicellulose	Lignin	Pectin	Ash	Wax	Microfibrillar angle (°)	Reference
Alfa	45.4	38.5	14.9	-	2	5	-	[6]
Cantala	59.47	27.71	9.11	-	-	-	-	[7]
Fique	70	24.8–27.1	10.1	-	-	-	-	[8]
Henequen	60	28	8	-	1.3	2		[6]
PALF	56–62	16–19	9–13	2.0–2.5	2–3.0	4.7	14	[9]
Sansevieria ehrenbergii	80	11.25	7.8	-	0.6	0.45	19	[10]
Sansevieria cylindrica	79.7	10.13	3.8	-	-	0.09	-	[11]
Sansevieria roxburghiana	54	30	12	-	2	-	-	[12]
Sisal	43–78	10–13	4–12	0.8–2	1	2	20	[6]

their respective fibers is shown in Fig. 2A–J. Approximately, 30 million tons of plant fibers are annually generated and utilized as a constituent in various applications includes, automobile, construction, sports equipment, packaging and research industries. In the following section, the leaf fibers, such as alfa, cantala, fique, henequen, PALF, sisal, *Sansevieria cylindrica Sansevieria ehrenbergii*, *Sansevieria roxburghiana*, and *Sansevieria trifasciata*, reinforced polymer composites which are discussed.

Alfa fiber-reinforced polymer composite

Alfa belongs to the Gramineae family and is the esparto grass also called tussock grass, extracted from the leaves of *Stipa tenacissima* L. grass. The fiber bundles are characterized by a mean diameter of 113 µm (ranging from 90 to 120 µm) and a density of 0.89 g/cm^3 [17].

Mansour et al. [18] studied the impact of alkali (NaOH)-treated composites from alfa fiber included with polyester matrix. The treated fiber in 1%, 5%, and 10% NaOH solution for both periods of 24 h and 48 h was taken for the study. The flexural strength (FS) of 57 MPa was observed for the 10% NaOH-treated (for 24 h) fibers, which was nearly 60% greater than the untreated fiber composites. A similar pattern is observed in flexural modulus (FM) as that of FS, i.e., ≈62% increased for the 10% NaOH-treated fibers compared to untreated one. The same procedure is adopted for alfa fiber (20 wt% as fixed)-reinforced polypropylene (PP) composites. Arrakhiz et al [19] evaluated the influence of alkali, ethrification and esterification on the mechanical properties of the composites using hot pressing molding techniques. A significant enhancement in Young's modulus (1405 MPa) of alfa palm/polypropylene composites was noted, which is 35% greater than untreated fiber and two times greater than plain PP. Then significant improvement in thermal stability was noted for the etherification-treated alfa fibers with gains in the temperature up to 80 °C.

Polypropylene incorporated with three natural fibers such as alfa, coir and bagasse composites with the effect of alkali-treated fiber on the mechanical properties [20]. Different fiber loadings at 5, 10, 15, 20, 25, and 30 wt% were taken for the studies. Compared to plain PP, the Young's modulus of all the three fiber composites have greater value, and tensile strength (TS) was lower value with increase in fiber loadings (at 30

Table 2 Physical and mechanical properties of leaf fibers

Fiber type	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Moisture uptake (%)	Reference
Alfa	0.89	350	22	5.8	-	[13]
Cantala	1.056	-	-	-	-	
Fique	0.87	237	8.01	6.02	12	[8]
Henequen	1.20	430–570	11.1–16.3	3.7–5.9	-	[13]
PALF	1.44	413–1627	34.5–82.5	1.6	11.8	[14]
Sansevieria ehrenbergii	0.887	278.82	9.71	2.81	10.55	[10]
Sansevieria cylindrica	0.915	585–676	0.2–11.2	11–14	3.08	[11]
Sansevieria trifasciata	1.414	349	15.3	2.3	105	[15]
Sansevieria roxburghiana	1.410	345.17	20.66	9.58	9.0	[16]
Sisal	1.45	468–640	9.4–22.0	3.9–7.0	11.0	[14]

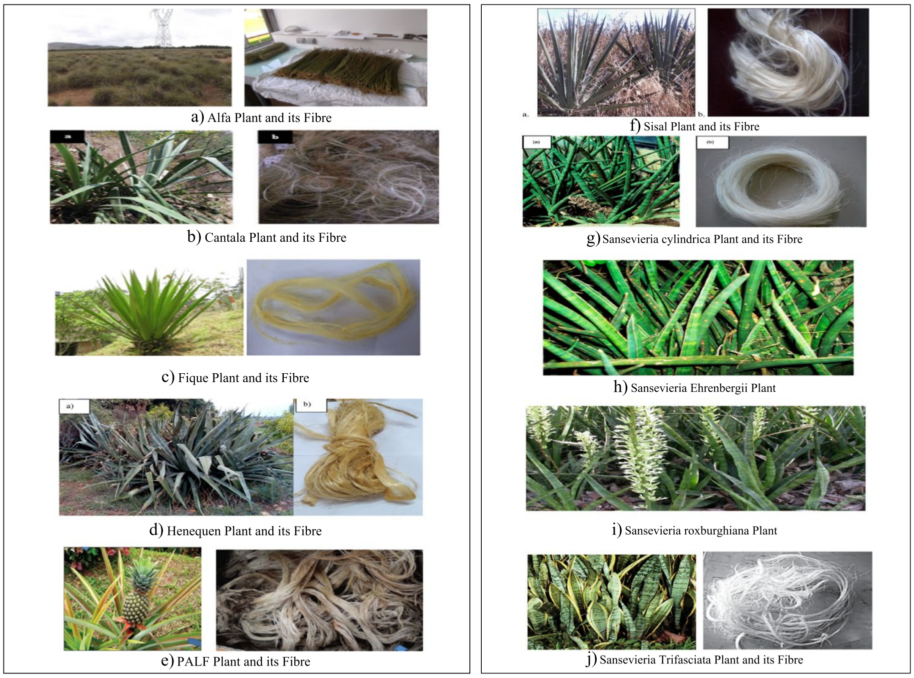

Fig. 2 **a** Alfa plant and its fiber. **b** Cantala plant and its fiber. **c** Fique plant and its fiber. **d** Henequen plant and its fiber. **e** PALF plant and its fiber. **f** Sisal plant and its fiber. **g** *Sansevieria cylindrica* plant and its fiber. **h** *Sansevieria ehrenbergii* plant. **i** *Sansevieria roxburghiana* plant. **j** *Sansevieria trifasciata* plant and its fiber

wt%). The FM for alfa coir and bagasse composites were 2077.5 MPa, 2088.5 MPa, and 1841 MPa, respectively, at 30 wt% of fiber loadings. According to FS, it remains constant for all the three composites from 5 to 30 wt% of fiber. A considerable enhancement in torsion modulus (in power law model) were noted with increasing frequency and fiber loadings; thus, the authors concluded that the prepared material behaved like an elastic solid.

Hybrid polymer composites based on PP reinforced with two fillers alfa fiber and clay particles were fabricated [21] by using injection molding techniques. The incorporation of clay in the PP composites improved the Young's modulus of 3120 MPa, i.e., an increase of 300% than plain PP. Contrarily, the TS had a greater value for the alfa fiber composite rather than clay-filled composites.

Sami Ben and Ridha Ben [22] prepared the alfa fiber incorporated with PE composites and investigated the mechanical properties with the effect of fiber orientation and fiber fraction of the composite. The longitudinal and transverse Young's modulus of alfa/PE composite were 12.3 GPa and 5 GPa, respectively, at 45% fiber loadings. The effect of fiber orientation on the composite mechanical properties denoted that the longitudinal Young's modulus and stress at break were decreased with increasing angle (0 to 90°). But Poisson's ratio increases with increasing angle up to 10° and then decreases considerably.

Using extrusion and injection molding process, El-Abbassi et al. [23] evaluated the impact of alkali-treated fiber on mechanical and water aging properties of alfa fiber blended polypropylene (AFRP) with respect to different fiber weight fractions (0%, 10%, 20%, & 30 wt%). After applying the alkali treatment on fibers, the Young's modulus and tensile strength were enhanced by 23% and 16%, respectively, and a significant reduction in WA properties was also noted.

Mechakra et al. [1] investigated the outcomes of optimizing parameters of alkaline treatment (24 and 48 h) and fiber volume fractions (0, 10, 20, 30) for the preparation of short alfa fiber blended with PP resin. In their studies, the authors found that the Young's modulus, TS, and breaking stress had a greater value for the PP charged with 30% alfa fiber treated at 24 and 48 h. As the volume of fiber increases, the mechanical property increases. Also, the treatment of alkaline indicated a significant raise in strength and decreases the breaking strain.

Med Amin et al. [24] observed that the wool-alfa-reinforced hybrid polyester composites exhibited a medium hydrophilicity through water contact angle $(62 \pm 2)°$ measurement. During the second heating run by the DSC analysis, the observed glass transition temperature (T_g) of the composite was 69.2 °C. From the TGA, the material is less thermally stable at 400 °C, and a 2.6% of mass loss at 84 °C was obtained due to the moist structure of the natural fibers.

Sair et al. [25] modified the alfa fiber surface by alkali treatment with different conc. of 0%, 5%, 7.%, 10%, and 12%. The effect of various volumes of fibers 5, 10, 15, 20, 25, and 30 wt% on the thermal, mechanical, and acoustical characteristics of the alfa fiber PU composites was determined. After applying the alkali treatment, the tensile test results showed that the tensile strength of treated fiber composites was enhanced, but for plain PU and untreated fiber, composite showed the reversed effects. The 20% of alkali-treated fiber was the optimum parameters for the composites where the Young's modulus and TS raised from 2.7 to 4 GPa and 14.3 to 24.9 MPa, i.e., an enhancement of 48.14% and 74.12%, respectively. A weak resistance between the fiber and matrix at 30% wt was noted for the composites too.

Cantala fiber (CF)-reinforced polymer composites

Cantala is a member of the *Agave* family (Agavaceae), which grows in a moist, humid soil. The fiber is lighter in color than other agaves, and its strength depends on its preparation. Wijang et al. [26] described the mechanical properties of cantala fiber and short cantala recycled HDPE composite with reference to the influence of treatments such as alkali, silane, and combination of both. Alkali-treated fiber exhibited superior FS (increased by 16%) than untreated composite; conversely, the TS of alkali-silane-treated fiber composite was lower than alkali-treated fibers. The highest surface energy of 45.37 mN/m was observed for the alkali treated (2 wt% NaOH), and for alkali-silane treatment (with 0.75 wt%), it showed the greater thermal stability (up to 507.1 °C) and interfacial shear strength (IFSS) value of 3.6 MPa.

Tipu Sultan et al. [2] modified the cantala leaf fiber with NaOH or sodium chlorite ($NaClO_2$) and fabricated the treated and untreated fiber PP composites using hot press molding process. The elastic modulus and thermal resistance of alkali-treated CF have higher value than the untreated fiber composites.

Ilham et al. [27] analyzed the effect on FS of the brake pad composite from CF (0, 4, 8, 12) reinforced with PP using the cold press cum hot press method. Increasing the volume fraction of CF increased the flexural properties of specimens. Fiber pullout occurs due to the lower interfacial bonding between the fiber, and the matrix was observed by SEM.

Wijang et al. [7] evaluated the influence of soaking time in alkali solution on the IFSS of cantala fiber recycled HDPE composites. The surface modification of CF by alkali was carried out on 2% conc. of NaOH, for a period of 0, 4, 8, 12, 16, 20, and 24 h. The IFSS (determined by the single fibre pullout test method) values of the modified fibre after different soaking hours were observed to be 2.44 MPa, 2.15 MPa, 2.93 MPa, 2.63 MPa, 2.80 MPa, and 3.42 MPa. Extending the duration of immersion would result in an elevation of the Interfacial Shear Strength (IFSS) value of the composites.

Fique fiber-reinforced polymer composites

Fique fibers or cabuya belongs to the Asparagaceae family, extracted from the *Furcraea andina* plant. It is used for making ropes, sacks, and handicrafts. An increase in the modulus of rigidity was noted from 2.5 to 7.2 GPa when alfa fiber treated with 5 wt% NaOH solution followed by starch-based polymer of 35 wt% [28]. Miguel et al. [29] studied the mechanical and thermal properties of biocomposites from linear LDPE-nonwoven industrial fique fiber (LLDPE-fique) and epoxy fique composites using resin film infusion process. Compared to neat LLDPE, LLDPE-fique has the higher tensile modulus (TM) of 1370 MPa, TS of 19.6 MPa, FM of 686 MPa, and FS of 16.2 MPa. Similar observation is followed for the epoxy fique than the plain epoxy. From the DSC analysis, a decrease in enthalpy from 144 to 118 J/g for LLDPE and LDPE-fique was noticed.

Catalina and Analía [30] prepared the unidirectional epoxy/fique composites with the treated (NaOH at 18 w/v%) and untreated fiber by pultrusion method. The parameters such as flexural properties were determined after 20 days of aging of composites which was subjected to various environments (in distilled water pH = 6.0, alkaline pH = 12.0, cement mortar). After the surface modification of fiber, the flexural properties were raised than matrix modification. Treated fiber epoxy has the lowest diffusion coefficient, and then the enhancement at the composite interface reduced the water and calcium hydroxide absorption by six times. The FM of epoxy fique composite was better than conventional wood such as oriented strand board (OHB); thus, the authors suggested that this material opened the new possibility to replace the conventional wood used in construction purposes.

Sandra and Diego [31] manufactured the natural rubber (NR)/butadiene styrene rubber (SBR)/polybutadiene (BR) matrix-reinforced fique fiber composites and evaluated its characteristics. A weight loss of 78% was observed from the TGA thermograms. As fiber loading increased from 0 to 40% of 10-mm length, the tensile loads, compressive loads, TS, and hardness were increased, while scratch time, cure time, elongation at break, and wear resistance were decreased for the composites.

Michelle et al. [32] conducted a study on dynamic mechanical properties of fique fabric-reinforced epoxy of different fique content of 15, 30, 40, and 50 vol%. A considerable increase in the storage modulus (5073 MPa) with increasing volume (at 50%) of fique fabric at the initial temperature of − 50 °C was noted. Loss modulus assigned to the T_g tend to be shifted to higher temperature of 83–89 °C, and it was higher for fique epoxy compared to polyester composite (28–52 °C).

Sergio et al. [33] gave a comparative study on the mechanical and dynamic vibratory properties of fique epoxy and glass fiber epoxy laminates. The TS and elastic modulus for E-glass epoxy were 153.5 MPa and 4290 MPa, whereas for fique epoxy it was 36.2 MPa and 1272.98 MPa. A slight increase in natural frequency (Hz) for E-glass composites was noted than the fique fiber composites. The poor bonding between the fique and the resin was evidenced by SEM, which was also reflected in the properties of fique epoxy compared to E-glass epoxy.

Michelle [34] studied the notch toughness evaluation of epoxy matrix composites reinforced with various fiber loadings (15, 30, 40, and 50 vol%). Composite enhanced with 40% of fique is good to notch toughness, whereas brittle fracture with poor impact energies for 15 and 30% of fiqu, were observed. At 50% fique, Izod and impact energy suffered a small decrease according to the Roger and Plumtree model.

Henequen fiber (HF)-reinforced polymer composites

Henequen fibers (*Agave fourcroydes*) are leaf fibers, used for the manufacture of twines and ropes. The leaves grows of 1.2 to 1.8 m long with a thick stem (reach 5 ft) and a terminal spine of 2–3 cm long. Surface treatments by steam explosion technology with the inclusion of polyethylene glycol (PEG) was given to the raw henequen fiber. The treated fiber-/PLA-reinforced composite was prepared by thermo-compression molding technology [35]. Compared to plain PLA, the degree of crystallinity is higher for PLA composite due to that this henequen fibers induced nucleating. Contrarily, the thermal degradation temperature was lower for fiber treated with PEG composite. An increase in tensile properties was observed for 90% PLA with 10% fiber without PEG. Lower flexural properties were noted for all composite than plain PLA.

According to TAPPI standard T257, the chemical composition of henequen fibers was analyzed, and the values are 68.1% cellulose, 18.2% hemicellulose, 8.7% lignin, 1.3% ash, and 3.7% extractives, respectively [36]. The fiber strands were more 1 m long with diameter of 220.8 ± 106.45 μm. The TS of fiber was measured as 442 MPa and Weibull shape factor as 2.60 with a gauge length of 6.35 mm. Theoretical TS value of henequen fiber was 450.7 MPa with a gauge length of 485.04 μm. The critical fiber length from the IFSS by von Mises and Tresca was 360 and 414.7 μm, respectively. Also, the tensile characteristics of fiber PP composites were noticed with 4 wt% of coupling agent.

Biocomposites-reinforced henequen and silk fiber with the influence of poly(butylene succinate) were prepared using a compression molding method [37]. For the hygrothermal effect, the composite was placed in the chamber at 60 °C and 85 °C relative humidity for about 1000 h. In WA properties, the weight increase of biocomposites of both silk and henequen was noted and also absorb maximum amount of water within 50 h. The storage modulus of henequen composite was 4GPa and decreased with the duration (more than 500 h) resulting the half value of 2 GPa. The tan δ peak has been shifted to high temperature, and intensity was decreased for the henequen fiber, because the lesser polymer chains were participated in the transitions.

The fibers from henequen have been used as reinforcement for epoxy resin composites by compression molding process, and their mechanical properties were investigated [38]. The untreated fiber/epoxy showed a TS as 234 ± 11.3 MPa, FS as 197.32 ± 7.64 MPa, and impact strength as 116.04 ± 14.65 kJ/m^2, whereas for treated, it was 233 ± 11.98 MPa, 199.52 ± 7.42 MPa, and 90.81 ± 18.57 kJ/m^2. As shown, the experimental results for both forms (treated and untreated) of the composite are identical, and it can be inferred that their mechanical properties have not been enhanced by chemical treatment.

The density value of the alkali and alkali + heat-treated henequen fibers was larger than the raw fibers [39]. The alkali-treated fiber epoxy composite has higher TS of 49.04 MPa, whereas it was 18.16 MPa and 11.7568 MPa for untreated epoxy and plain epoxy composite respectively. For the fractured samples (SEM analysis), the presence of matrix to the fiber surface and uncoiling of microfibrils has been observed for the alkali-treated samples, whereas there is no trace of matrix to the fiber surface in case of untreated fiber composite. The TM (2.189 GPa) and FS (54.482 MPa) were higher for heat-treated fiber and alkali + heat-treated fiber epoxy composite respectively. By DTG analysis, the composites have high degree of crystallinity and thermally stable at 366 °C, 371 °C, 388 °C, and 369 °C for untreated, alkali, heat, and alkali + heat-treated fiber epoxy composites.

Pineapple leaf fiber (PALF)-reinforced polymer composites

PALF is obtained from the leaves of pineapple plant *Ananas comosus*, and a perennial herbaceous plant holds 80 leaves in its lifetime. The postharvest waste PALF is multicellular, lignocellulosic fiber in nature and can reduce negative environmental impacts in the preparation of composite work.

A comparative study on mechanical evaluation of coir fiber epoxy and PALF epoxy composites were given [40]. Compared to coir (30%wt) fiber epoxy composite strength (28.7 MPa), 30%wt PALF fiber epoxy (86.4 MPa) yielded greater strength. The impact strength (946 J/m), elastic modulus (7.97 GPa), and elongation (1.3%) were greater for PALF fiber composites. For multilayer armor system (MAS), coir fiber has the highest depth of penetration (DOP of 31.6 mm) with impact energy of 3.52 kJ, whereas PALF has DOP of 18.2 mm with 3.48-kJ impact energy.

Gabriel et al. [41] used the lignocellulosic fiber (PALF) to study the tensile properties of fiber-reinforced polyester (PE) composites. The fiber content of 10%, 20%, and 30% and diameters from 0.09 to 0.30 mm were taken for the composite preparation. An observation was made that the inclusion of 30wt% of fibre composites resulted in an augmentation of tensile strength (103.25 MPa), elastic modulus (1.99 GPa), and deformation (5.14%). The introduction of PALF would improve the tensile qualities, including TS, elastic modulus (EM), and elongation.

`The determination of FS by means of 3-point bend tests and Weibull statistical analysis for epoxy composites incorporated with continuous and aligned PALF fibers was analyzed [42]. The determination of Weibull parameters such as characteristic strength (θ is 101.5 MPa for 30 wt%), modulus (β-3.38 for 20 wt%), and precision adjustment ($R^2 = 0.9635$ for 10 wt%) was noted for the PALF-reinforced epoxy composites. Also, the rupture mechanisms associated with reinforcing were analyzed by the SEM.

Ridzuan et al. [43] studied the influence of PALF, napier, and hemp fibers with different fiber weight of 5, 7.5, and 10% on the scratch resistance of epoxy composites. Compared to PALF and hemp fiber-filled epoxy composites, the highest peak loads at 28.6 N (5%wt), 30.2 N (7.5 wt%), and 36.4 N (10 wt%) were obtained for napier epoxy composites. The coefficient of friction (COF 0.703), fracture toughness (4.24), and scratch hardness were also higher for napier composites. Conversely, the density and porosity have the lowest value for napier fibers. Hence, the lower porosity might be the reason for obtaining the higher scratching resistance.

Indra et al. [44] conducted an experiment study on the mechanical characteristics of hybrid (jute, PALF, and glass) fiber-reinforced epoxy polymer composites. The ratio of each fiber is 1:1:1, with 0.18 to 0.42 wt% of fibers and 1.5% content of resins which were used for the preparation of composites by hand lay-up process. The TS (71.66 MPa), FS (239.37 MPa), and TM (> 800 MPa), respectively, were noticed for the maximum fiber content of 0.42%. As the fiber content raised in the epoxy composites, the mechanical properties also increased.

Using compression molding technique, the PALF-reinforced PE composites were fabricated, and the samples were tested [45]. The obtained results showed the crosshead, speed of 5 mm/min, and gauge length of 50 mm yielded highest TS (33.13 MPa), TM (1.553 GPa), and elongation at break (4.11%) respectively for 45wt% fiber loading. At the same time, the flexural strength (82.97 MPa) and modulus (6.37 GPa) showed an increasing trend, with an increase in fiber content of the PALF composites.

Pujari et al. [46] suggested that PALF-reinforced natural rubber matrix composites could be successfully used to transformer applications. The specimens containing a different volume fraction of fibers, i.e., 5, 10, 15, 20, 25, and 30 wt%, have been selected for the thermal, physical, and dielectric studies. The WA coefficient (%), oil absorption coefficient (%), and dielectric strength (kV/mm) of the composites were increased, whereas the thermal conductivity (W/m˚k) value decreased, as the volume fraction of the fiber increases.

Parameswara et al. [47] revealed that the influence of fiber orientation (0°, 30°, 45°, 60°, and 90°) on dynamic mechanical properties of hybrid PALF reinforced with basalt epoxy composites. The orientation of the fiber played a major role, because it gave the effect on storage modulus and loss tangent along with mechanical characteristics. At frequencies, 0.1 Hz, 1 Hz, and 10 Hz, the storage modulus were~ 3.86 GPa,~ 4.26 GPa, and 4.23 GPa and lost tangent as 0.16, 0.12, and 0.09, respectively. The composite with 0° fiber orientation of thickness 2.87 mm has good damping properties; also, the similar resulting pattern was followed for mechanical properties including Young's modulus and flexural modulus.

Ayu et al. [48] developed the PALF-reinforced polypropylene (PP) composites on different fiber volume ratio of 30, 40, 50, 60, and 70 wt%. Using compression molding technique with random orientation, the composites were prepared for the treated (alkaline) and untreated fibers. At 30 wt% of fiber, the tensile strength was increased with 12.9% with increase of fibers and decreased drastically by − 76.4% with the inclusion of fiber fraction (up to 70 wt%). It was found that the higher tensile strength (16.71 MPa), hardness (62.8 shore-D), and density (0.93 g/cm^3) at 30% fiber weight were noted, and this is the optimum parameters (30 wt%) for the preparation of composites.

Sisal fiber-reinforced polymer composites

Sisal is a hard, rigid, and highly resistant fiber obtained from the leaves of sisal plant (*Agave sisalana*). Depending upon the climatic conditions, soil, and method of extraction, each plant produces 120–240 leaves, in its lifetime. A single leaf consists of about

1000 fibers, cuticle (0.75%), dry matter (8%), water (87.25%), and fiber (4%) [49]. The diameter and length of sisal fiber are 100 ± 300 μm and 1–1.5 m, respectively [50]. Several works have been reported on the utilization of sisal fiber as a reinforcement material in polymer matrices such as PE, PP, and PU [51–54].

Krutibash et al. [55] studied the experimental analysis on the impact of fiber loading (0%, 10%, 15%, 30 wt%) and surface treatment of natural fibers (jute and sisal for NaOH at 2 h) on the mechanical and WA properties of glass/jute/sisal (GF/JF/SF) fiber PP composites. The hybrid fibers (each fibers 10% and PP 70%) specimens has the highest TS (33.18 MPa), TM (3282.09 MPa), hardness (100.1 R/scale), and impact strength (44.155 J/m), whereas the other fiber loading composites treated has lowest mechanical properties. The flexural strength (61.39 MPa) and modulus (3453.15 MPa) were obtained for the hybrid (glass—15%, jute—15%, PP—70%) fiber composites. WA were found to be lower for all polymer composite, and hybrid samples have below 0.3% (by weight).

Pramod et al. [56] concentrated his work on the compression and WA characteristics of banana and sisal hybrid fiber epoxy composites using hand lay-up process. The fiber was modified by alkali with 5% for 24 h and various fiber loading taken as banana: sisal were 25:15, 15:25, 20:20, and 10:30. The compressive strength of 430 MPa was observed for 10:30 (% of banana & sisal) treated fiber epoxy, whereas for untreated, it was 322 MPa. WA properties of the above said samples were minimum than the treated and other proportion fiber samples.

Changes in the mechanical properties of sisal fiber and human hair-based hybrid epoxy were noticed [57]. By hand lay-up process, the composites were prepared with various percentage of fiber (5, 10, 15%) and epoxy resin (95, 90, 85%). From the experimental results, it was clearly seen that, as the percentage of fiber increased, the quality of mechanical properties was also increased. The ultimate tensile strength (27.7 N/mm^2), impact energy (46.182 J/m), FM (963.86 MPa), and flexural stress at maximum flexural load (38.158 MPa) were higher for 15% of fiber composites, whereas hardness (82 HRB) was higher for 5% fiber samples.

Sandeep et al. [58] focused the influence of mustard cakes and pink needles on TS, impact energy, and abrasion of sisal fiber-based hybrid polyester composites. Among the various proportion of fillers, particulates, and fibers, the (55% PE, 40% sisal, and 5% pine needles) hybrid PE composites have the highest value of TS (41.45 MPa), void fraction, impact energy (8 J), and lowest specific wear rate (3.019×10^{-7} mm^3 N/m).

Composites from sisal(S), waste tea fibers (T), and glass fibers (GF) reinforced with epoxy-based hybrid composites were prepared and studied their acoustical, mechanical, and chemical properties [59]. The TS (75.6 MPa), impact energy (95 kJ/m^2), and modulus (5.82 GPa) were higher for hybrid (2%S and 10%T) epoxy, and the specimens with high sisal and glass fiber exhibits more flexural strength. Regarding acoustic behavior, the weak sound (for 20 wt.% of sisal fibers and 5 wt.% of tea fiber) and high sound (20 wt.% of tea fiber and 5 wt.% of sisal) absorption were measured. By varying the frequencies range from 63 to 6300 Hz, the sound absorption coefficient (α) value varies between 0.03 and 0.27. Surface treatment and hybrid effect enhanced more adhesion between the fiber, and the resin used in the specimens was analyzed by SEM.

Laminated composites were developed with the help of sisal, banana fibers, and polyester resin using compression molding techniques [60]. The effects of fiber weight (%)

and fiber surface treatment on flexural properties and damping factor for 50 wt% of fiber were analyzed. The increased FM (N/mm^2) were noticed for 50 wt% of banana, sisal, and hybrid fibers. The natural frequency and damping factor were higher for the treated fiber composites.

Physico-mechanical and micrographs were examined under different situations such as effect of silica microparticles, volume fraction of sisal, and maleic anhydride of unidirectional sisal fiber epoxy hybrid composites [61]. It was revealed that, at low weight fraction of fiber, the composites provided better tensile properties, but maleic anhydride treatment affected the flexural properties, WA, and apparent porosity. The authors also suggested that these composites opened an alternative material for engineering applications.

In order to improve the adhesion between the fiber and matrix, alkaline treatment was given, then the static and dynamic properties of three different fiber composites that are sisal, jute, and sisal/jute reinforced epoxy composites [62]. From the three different samples, the hybrid (sisal/jute) epoxy has the highest TS, FS, and damping factor. Successive resonance sets and accelerance level confirmed the good dynamic properties of hybrid composites.

Similar results were observed from Asokan et al. [63]; they prepared the hybrid composites from sisal and hemp fiber reinforced with polylactic acid (PLA) through injection molding process. From the experimental analysis, the largest value of density (1.2 g/cm^3), elongation at break (0.93 ± 0.35%), WA (1.06 ± 0.18%), TS (42.25a), Young's modulus (6.1 GPa), specific TS (38.86), FS (94.83 MPa), FM (6.04 GPa), and specific FS (79.76) were noticed for hybrid fiber composites.

Sivakandhan et al. [64] conducted a study on mechanical and morphological analysis of sisal and jute fiber hybrid sandwich epoxy composites. The coaxial TS and FS were 22.53 N/mm^2 and 56.31 N/mm^2, respectively, for the hybrid epoxy increased with increasing jute fiber content. The transaxial TS and impact strength were increased by 17.99 N/mm^2 and 0.8 5 J for the hybrid epoxy with increase of sisal fiber.

Senthil et al. [65] studied the effect of different stacking sequence of hemp and sisal fiber-reinforced hybrid epoxy composites on the mechanical properties. The pure hemp fiber epoxy has the TS of 31.997 MPa, modulus of 1158.95 MPa, ILSS of 4.68 ± 0.33, and compressive strength of 41.088 MPa, which was higher than the pure sisal epoxy and hybrid fiber epoxy composites. A poor compatibility between the two fibers and poor adhesion between the sisal epoxy-hemp hybrid reinforced composites could be the reason for lower mechanical properties of hybrid composites.

Physical and morphological studies were determined [51] for the composites, prepared from sisal fiber as a filler and epoxy as a matrix. The mechanical properties such as TS, FS, IS, and WA were increased with the increasing fiber content. Three types of immersing agents (ordinary, sea, and distilled water) were used to study the WA test, and the result revealed that the composites absorb more in the ordinary and distilled water compared to seawater.

Arun et al. [52] conducted a comparative studies of the mechanical characteristics of epoxy composites made from sisal and jute. The experimental research revealed that sisal epoxy exhibited a much higher impact of energy (7.02 kJ/m), ultimate TS

(35.52 MPa), and FS (69.41 MPa). On the other hand, both sisal and jute epoxies had a greater hardness value (95 MPa). The SEM analysis revealed the presence of fibre pullout and cracks in the matrix. The prepared material offers a superior alternative to NFPC.

Athith et al. [66] examined the mechanical and tribological studies of composites from jute/sisal/E-glass fabric blended with matrix such as NR and epoxy. The different proportion of fibers and matrix filled with different proportion of tungsten carbide were taken for the preparation of composites. From their findings, it was noticed that the filler loading could increase the mechanical properties especially in the glass fiber epoxy at the same time the wear rate was decreased with increase in abrading distance.

The improvement of PP/sisal fiber bonding was done [53] with the aid of chemical treatments by using polymeric diphenylmethane di-isocyanate (PMDI) and gamma aminopropyl triethoxysilane (silane A1100). Yield strength more than 50% and T_g up to 6.8 °C increased for the PP-sisal composite with PMDI treatment. A good agreement between the theoretical model and experimental results of treated and untreated sisal fiber-PP samples was proved by Halpi-Tsai and Nielson mathematical model.

Senthil et al. [67] investigated the mechanical and free vibration properties with possible trilayering sequence of sisal (S) and coconut sheath (CS) hybrid PE composites. The influence of alkali treated (ATC) and trichlorovinyl silane treated (STC) on the composite was studied. Among the various stacking sequence of fibers, the CS/sisal/CS hybrid stack had the better performance of mechanical and damping factor. Also, the fracture morphology of the fiber and PE resin was analyzed by SEM.

Phiri et al. [3] addressed the mechanical and thermal properties of sisal fiber-kenaf fiber (SF-KF)-reinforced injection molded composites. The addition of fiber content increases the impact strength for SFC than KF composite. Increase in TS and Young's modulus and decrease in strain at break were noticed. The incorporation of water glass (WG) showed higher T_g of KFC and has a positive influence on the flammability. In the same way, WG gave a negative on the mechanical properties.

Priyadharshini and Ramakrishna [68] used two parameters of rheological analysis such as flow rate and cohesion (by vane shear rate). The effect of water/cement ratio, polymer volume, and fiber content with and without treatment on sisal fiber-reinforced cement mortar composites was performed. From the studies, it was noted that the increase of fiber content decreases the flow value but increases the cohesion of the composite and vice versa for the increase of polymer dosage. Compared to treated composite, untreated fiber exhibited larger flow rate and lower cohesion.

Various fibers, such as sisal, jute, and glass reinforced polyester composites, were prepared by hand lay-up process and studied its properties [55]. The study demonstrated that the jute fiber PE has the maximum TS of 229.54 MPa. The hybrid (glass + sisal + jute) composite had maximum FS with a displacement of 14.2 mm and 3.00-kN load, whereas the sisal PE has the highest impact values of 18.67 J. Incomplete distribution of fiber and matrix, void formed in the fracture surface, was analyzed by SEM.

Sansevieria cylindrica fiber (SCF)-reinforced polymer composites

SCF belong to the family Asparagaceae, a stemless, rigid, cylindrical snake plant which can yield 100–150 leaves before flowering. *Sansevieria cylindrica* leaf yields a strong white elastic fiber (5%), cuticle (1%), dry matter (10%), and water (84%) and can be used as reinforcement in cement and polymer matrix [69]. The fibers were identified and extracted from the leaves [70]. The hierarchical cell structure of the fiber was analyzed through polarized light microscopy and SEM. Microstructural analysis of leaves exhibited the presence of two types of fibers (structural and arch). The cross-sectional area, porosity fraction, density, fineness, TS, and TM were 0.0245 mm^2, 37%, 0.915 g/cm^3, 9 Tex, 658 MPa, and 7 GPa for fibers with elongation at break between 10 and 12%. Also, the presence of I_β with a crystallinity index of 60% was analyzed by X-ray diffraction method.

A study was conducted to analyse the erosion characteristics of both treated (alkali) and untreated SCF vinyl ester composite (SCFVEC) [71]. Fibre lengths of 30 and 40 mm were used, along with fibre concentrations of 30%, 40%, and 50% wt, for both treated and untreated SCFVEC samples. These samples were then subjected to an erosion test using an abrasive air jet erosion rig. Using the Taguchi analysis, the optimized erosion parameters of fiber length 30 mm, fiber content 40 wt%, impingement angle 90, impact velocity 41 m/s, erodent discharge 4 g/min, and exposure time of 15 min were noted for prepared SCEVEC.

Sreenivasan et al. [72] experimented the mechanical characterization of *Sansevieria cylindrica* fiber-reinforced polyester composites (SCFRPC) by compression molding technique. The tensile strength (ASTM D 3039) was 76 MPa, modulus as 1.1 GPa, the flexural strength (ASTM 790–86) was 84 MPa and modulus as 3 GPa, elongation at break was lied between 7% and 8.3%, and the impact test (ASTM 256–98) was 9.5 J/cm^2, respectively. Compared with the theoretical projections, the experimental tensile strengths were found to be in perfect agreement with Hirsch's model. An X-ray diffraction (XRD) analysis possessed the presence of cellulose IV ($2\theta = 22.5°$) with a crystallinity index of 60% and large crystallite size of 68 nm.

Ramachandra et al. [73] conducted a study on tensile and flexural behavior of epoxy tamarind fruit (TF) fiber and *S. cylindrica* fiber (SCF) hybrid composite with different fiber ratios (as 0:20, 5:15, 10:10, 15:5, 20:0). A considerable increase in flexural strength, modulus, and dielectric strength were noted for epoxy filled with TF fiber and SCF composite. The optimum strength enhanced with the composition 10 wt% of TF, and 10 wt% of SC was observed for the filled epoxy hybrid composite.

The effect of layering (three) sequence of alkali and silane-treated SCF/coconut sheath (CS)/PE composite on the mechanical and vibration behavior was investigated [74]. For the untreated coconut, sheath (three layers)/PE has better TS and impact strength than the SCF (3 layers) composite, whereas alkali treated reverse effect was observed. The dynamic behavior and mechanical strength of SCF/CSF/PE were found to be significantly influenced by layering sequence and chemical treatment (alkali and silane).

In order to possess the better mechanical strength over the prepared SCFP composites [11], various treatments were given to the fibers such as alkali, benzoyl peroxide, potassium permanganate ($KMnO_4$), and stearic acid. Compared with the other treated SCFP composites, $KMnO_4$-treated *Sansevieria cylindrica* fiber/polyester composites (PSCFP) achieved the optimum tensile strength (141.9 MPa), Young's modulus (1.2 GPa), elongation at break (11.51%), FS (150.8 MPa), FM (11 GPa), impact strength (23.4 J/cm^2), and hardness (96), respectively.

Sansevieria ehrenbergii fiber (SEF)-reinforced polymer composites

SEF belongs to the family of Dracaenaceae, a snake grass plant, traditionally used for antiseptic and for making baskets, roofs, and clothes. Each leaf consists of 100–200 fibrils approximately fiber (8%), cuticle (1%), dry matter (12%), and water (81%). Identification and characterization of new cellulose *Sansevieria ehrenbergii* (SE) fibers for polymer composites were studied [75]. Using optical microscopy, the diameter of longitudinal and transverse section of the raw fiber was around 25–250 µm and 20–240 µm, whereas it was 40–165 µm for SEM analysis. The cross-sectional area and density were 0.0215 mm^2 and 0.887 g/cm^3 respectively for the raw fibers. The presence of I_β cellulose and semicrystalline nature of fiber were analyzed by X-ray diffraction.

Sathishkumar [76] prepared the *Sansevieria ehrenbergii* fiber (SEF) with PE composites. The static, dynamic, thermal, and mechanical properties on the alkali treated, $KMnO_4$ treated and untreated fiber PE composite by using hand layup followed by compression molding process. The tensile, flexural, storage modulus, and impact test of $KMnO_4$-treated composite were higher than paperboard, plywood, and hardboard sheet. According to tan δ, peak width was maximum, and WA is lower for $KMnO_4$-treated composite. The author was concluded that this SEF samples could be replaced the wood-based composites imperial applications.

Sathishkumar et al. [77] analyzed that alkali, benzoyl peroxide (BP), benzoyl chloride (BC), $KMnO_4$, and stearic acid (SA) treatments increase the physico-mechanical properties of SEF/isophthalic PE composites. According to their work, mechanical properties have a maximum value, and WA has lower value for the chemically treated composite than the untreated composite. SEM evaluated that a rough surface was formed on the fiber when it was chemically treated, and this was attributed to the removal of lignocellulose part of the fiber. The same author continued his work [78] with the randomly and longitudinally arranged SEF/PE composites with and without WA (swelling time variation at 4, 8, 12, 16, 20, & 24 h). The percentage of WA increased, and TS was decreased with respect to water swelling time. The chemically treated composite has the possibility to utilize as automotive and household applications.

Sansevieria roxburghiana fiber (SRF)-reinforced polymer composites

SRF (Agaveceae) is a rigid, stemless, perennial, medicinal plant and used for making bowstrings, cordage, and mats. Mangesh and Akshay [79] studied the chemical composition and physical and structural properties of SRF (untreated and treated with 2, 5, 10, 15, 20% NaOH). The hemicellulose, ash, and moisture content was found to be decreased from 30 to 17%, 2 to 0.5%, and 9.0 to 6.5%, respectively. The cellulose and lignin content were increased from 54 to 65% and 12 to 17%, respectively. Then the crystallinity index and TS were increased from 72 to 76% and 260 to 311 MPa, from untreated to treated (2 to 15% NaOH) fibers.

Among the various varieties and abundant availability of plant fiber, Ramanaiah et al. [10] was selected the SRF to reinforced PE unidirectional composites. It was inferred that the TS (92.6 MPa), impact strength (206 J/m), and specific heat capacity (1464.83 J/kg) were maximum for the SRF/PE composites. The lowest thermal diffusivity of 0.9948E-07 m^2/s was noted. The result also indicated that as the volume of fiber increases, thermal conductivity decreases, and the prepared composites could be used in construction and automobile industries.

Using hand lay-up process, the composites were prepared [80] by SRF and *Calotropis procera* (PCF) treated it with and without lignite fly ash (LFA). The tensile strength (13.92 MPa), compressive strength (48.13 MPa), FS (44.71 MPa), and hardness (98 RHN) were higher for SRF/epoxy, CPF + LFA/epoxy, CPF/epoxy, and SRF + LFA/epoxy composites, respectively. Compared to the other composites, SRF has less wear rate and frictional force due to the effect of fly ash. The presence of voids, lignite fly ash, and fiber breakage in the composites was evidenced by SEM analysis.

***Sansevieria trifasciata* fiber (STF)-reinforced polymer composites**

STF belongs to the family Asparagaceae, commonly called the snake plant. Mature leaves are dark green with light gray-green cross-banding and usually range between 70–90 cm in length and 5–6 cm in width. Tensile test and TGA analysis were used to measure the raw and alkali treated (1, 3, & 5 wt% for 2 h). It was inferred that the increase in TS for raw STF as 647 MPa and 902 MPa for 5% NaOH treated one. Similarly, TGA showed the increase in thermal resistance as 288 °C for raw STF and 307 °C for 5% NaOH fiber. The experiment also proved that the chemical treatment affects the tensile and thermal properties of STF.

Thanesh et al. [81] obtained fibres from Sansevieria trifasciata Laurentii plants (STF) and fabricated composites by combining these fibres with PE resin using a manual lay-up procedure. The tensile, flexural, and impact properties were evaluated by altering the weight percentage of fibres (10, 20, and 30%) and the fibre length (10, 20, 30 & 40 mm). The authors discovered that a fibre size of 40 mm and a fibre fraction of 20 wt% yielded superior properties and were deemed to be the optimal size among the four sizes selected.

Similar procedure was adopted [82] for randomly oriented short STF-blended epoxy composites. The authors varied the fiber length as 10, 20, 30, and 40 mm and weight as 30, 35, 40, and 45%. The results indicated an increase in mechanical properties until 40% of fiber weight and then gradually decreased for 45% wt. The TS (75.22 MPa), Young's modulus (1.05 GPa), elongation at break (10.07%), FS (82.33 MPa), FM (3 GPa), and impact strength (8.97 J/cm^2) were noticed for fiber length of 30 mm and 40% of fiber weight, respectively.

Rangga et al. [12] investigated the mechanical properties of STF vinyl ester composites. In order to enhance the quality of composites, first it was given by alkali (NaOH 3% conc. for 2 h) treatment followed by maleic anhydride (for 2 h). The samples were prepared by solution casting process with the different fiber fraction of 0, 2.5, 5, 7.5, and 10%. The study showed that the addition of fiber fraction (from 2.5 to 10%) decreases the volume fraction of void (7.9, 6.87, 3.49, and 2.55%). The actual density (1173 kg/m^3), TS (57.45 MPa), and modulus of elasticity (3472.5 MPa) were achieved higher for 10 wt% fraction of composites. Also, the surface treatment has improved the interfacial bonding between STF and vinyl ester matrix of the composites.

Yanzur and Azizah [16] analyzed that the chemical treatments using NaOH (2% conc. for 1 h) followed by silane with 1H, 1H, 2H, and 2H-perfluorooctyltriethoxsysilane (POTS) at 1, 3, and 5% conc. (for 2 h) increase water contact angle (WCA is 1150), flexural (≈33 MPa), and impact strength (≈3.4 GPa) of the STF/PP composites. The authors suggested that the treated composite (3% POTS) fiber has greater strength and lowest WA (20.90%) when compared to untreated fiber composite.

Samson et al. [83] reported the extraction method (STF fiber), fabrication, and properties of STF-banana pseudostem fiber (BF) epoxy resin composite. The prepared BF epoxy has better property than STF epoxy composite. Three parameters like storage modulus, loss modulus, and damping factor (tan δ) were determined by DMA. The results indicated that compared to STF epoxy composites, the higher storage modulus of 5.4 GPa and T_g as 120 °C was noted for banana woven epoxy. Similarly, the loss modulus was higher for banana epoxy composites. According to damping factor, the STF composites had a better interfacial bonding between the matrix and fiber, and the value is $\tan\delta = 0.35$.

Raghava et al. [84] manufactured and explained the mechanical, thermal, and morphological properties of randomly oriented STF-carbon fiber (CF)-reinforced hybrid vinyl ester composites using hand lay-up method. The composites were prepared with different proportions of clay filled at 0, 1, 3, and 5 wt%. At 3% wt of clay content, the maximum tensile strength and thermal stability at 352–356 °C (at 5%wt) were found for the composites.

Nurzam et al. [85] studied the mechanical, morphological, and thermal properties of STF/natural rubber (NR)/HDPE composites by hot pressing process. The specimens were prepared, using the following parameters that is fiber loadings of 10–40% and fiber sizes of 1 mm, 500 µm, 250 µm, and 125 µm. From their findings, it was observed that the overall performance of the specimen was strongly influenced by the fiber size. STF at 125 µm gave the highest TS and TM. Thermal analysis was not affected much, and no crystallinity peak in DSC was observed by varying the fiber size. The SEM micrograph was utilised to analyse the fractured samples that exhibited a strong interaction between the STF and matrix.

Evaluation of mechanical behavior of leaf fiber-reinforced polymer composites

Several researchers have evaluated the mechanical properties of various leaf-based matrix composites. From Table 3, it is inferred that the authors have analyzed the influence of fiber treatment, fiber type, fiber length, fiber loading, fiber orientations, resin types, processing techniques, etc. It was highlighted that the surface treatment of fibers and fiber loading, significantly increased the mechanical properties of leaf fiber-reinforced polymer composites (Table 3). Most of the research works are based on, especially, the fiber content and fiber surface modifications. Sakuri et al. (2020) showed that 6% soaking time of alkali treatment has to be found, enhancing the mechanical characteristics of the composites. A greatest TS is noticed for fique/LDPE-AI composites, due to the pre-impregnation treatments as well as the fiber contents, which is illustrated in Fig. 3. In the same way, the 30% wt of *Furcraea foetida* with epoxy combination has the highest strength of 170.47 MPa. The effect of fiber orientation is determined for warp and weft direction with woven PALF layers (2, 3, 4) of the composites.

Table 3 Mechanical properties of various leaf fiber-reinforced polymer composites

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Alfa fiber (AF)	5% filler (AF-graphene nanoplatelets)	Polycaprolactone (PCL)	1, 3, and 5 wt% AF-GNPs	TS—14.18 MPa YM—431.15 MPa	Mold casting	The TS of the PCL has increased from 13.23 to 14.18 MPa, while the Young's modulus has been enhanced from 248.75 to 431.15 MPa These composites provide an ecologically advantageous alternative to conventional, petroleum-derived, and finite composites in a wide range of applications	[86]
Date palm fiber	Fiber loading	Unsaturated polyester	Different fiber contents (0%, 10%, 20%, 30% (w))	UTS—27 MPa TM—3.69 GPa, UFS—35.4, FM—2507 MPa IS—39.5 kJ/m^2 Hardness—64 HB	Compression molding	The findings indicated that the 20% DPF/sheep wool hybrid reinforced polyester exhibited the most favorable outcomes. These novel hybrid composites can be utilized in various applications such as high-performance, affordable insulating building systems, vehicle parts, aircraft, sports equipment, and home furniture	[87]
Cantala fiber		Unsaturated polyester	Fiber treated with fumigation for 5 h, 10 h, and 15 h	TS—70.56 MPa	Mold casting	Composite tensile strength increased after a 10-h fumigation trial. According to this study, fumigation treatment has the ability to improve the strength of fibers, adhesion, and the ability of materials to withstand stretching forces in composites	[88]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Cantala fiber	Fiber treatment	Unsaturated polyester	Sodium hydroxide (NaOH) for soaking times 3 h, 6 h, 9 h, 12 h, and 15 h	ISS—3.67 MPa FS—102.34 MPa	Vacuum infusion	Interface shear strength tests demonstrate that the fiber, treated with a 6% solution and soaked for 6 h, has the highest strength of 3.67 MPa, and increase of 47.39% if compared before treatment. The application of alkali treatment and the incorporation of microcrystalline cellulose resulted in an enhancement of both flexural strength and modulus of elasticity. From the findings, it was inferred that the use of microcrystalline reinforcement in natural fibers is highly recommended as it has the potential to greatly enhance flexural strength, making it a promising avenue for future material development	[89]
Alfa	Fiber treatment	Unsaturated polyester	NaOH solution of 5% concentration at different times (1, 3, 5, and 24 h)	FS—64.37 MPa FM—5.21 GPa	Layup	The study suggests that treating alfa fibers with NaOH at the optimal time can result in composites that have outstanding mechanical performance and comparable properties to synthetic fibers. Additionally, these composites have the advantage of being made from renewable and cost-effective raw materials	[90]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Alfa	Fiber modifications	Polypropylene with Cereplast	Soda, saltwater retting, hot-water treatments, and enzymatic treatment using xylanase	TS—30.4 MPa, YM—1488 MPa, FS—39 MPa, FM—693 MPa, IS—12.9 kJ/m^2	Twin-screw extruder and injection molding	Specific degradation of alfa fibers through a combination of alkaline and xylanase treatment resulted in fibers that were most compatible with enhancing the strength of Cereplast resin, as demonstrated by their superior mechanical properties	[91]
Alfa	Fiber length (2 and 3 cm) Different volume concentrations: 1%, 2%, and 5%	Cement		Compressive strength—26 MPa	Hand layup	The increase in concentration of treated alfa fibers does not result in a decrease in flexural strength. This is an exceptional scenario where the flexural strength remains unaffected, unlike other natural fibers Alfa-treated short fibers are suitable for secondary structural applications that experience compressive and low-bending pressures, such as paving applications	[92]
Fique	Resin type	Epoxy and hardener	Orientation of 0°/90° and 45°/45° sequentially alternated up to 11 layers and 10-mm sample thickness	IS—26.12 kJ/m^2 FS—55.4 MPa		The potential of composites made with this form of reinforcement depends on the economic conditions of the country, especially in the automobile industry. In this industry, the key factors for evaluation are dependability, weight reduction, cost reduction, and availability of materials	[93]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Date palm mat	Fiber content	Polystyrene	5, 10, 15, 20, and 25 wt%	BS—47.38 MPa TS—39.07 MPa	Compression molding	The investigation revealed that composites containing 10% fiber content exhibited enhanced mechanical and thermal properties in comparison to the other composites. Evidence has demonstrated that the mechanical properties of composites made from date palm mat fiber indicate that they could be a viable option for many applications	[94]
Fique	Resin type	Epoxy	20% fiber by weight	TS—16.6 MPa, TM—1074 MPa, FS—12.9 MPa, FM—390 MPa	Thermo compression and resin film infusion	The results of the tensile and flexural tests showed that the composites reinforced with nonwoven fique had a higher modulus and strength. Fique fibers possess a significant capacity as a reinforcement material, making them very suitable for the production of biocomposites in the automotive industry	[95]
		LLDPE		TS—19.6 MPa, TM—1370 MPa, FS—16.2 MPa, FM—686 MPa			
Fique	Fiber content	(LDPE)-Al	Fique treated with NaOH + silane + Pre-impregnation	TS—373.58 MPa YM—7.83 GPa FS—39.90 MPa	Hot compression molding	The mechanical characteristics of the various composite materials indicated that the pre-impregnation treatment resulted in a notable enhancement in both the tensile and flexural capabilities compared to the fiber-reinforced composite without any surface modification	[96]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
PALF	Fiber orientation and fiber layers	Epoxy	Warp and weft direction, 2, 3, and 4 layers of woven PALF	TS—34.40 MPa TM—1.16 GPa FS—79.25 MPa	Hand layup	The results indicated that the 3-layer woven PALF exhibited superior tensile and flexural capabilities compared to the other layers. Additionally, it was found that the orientation of the composite is slightly greater in the warp direction compared to the weft direction. PALF is presently employed across various industries, including textiles, sporting goods, luggage, vehicles, cabinets, and mats	[97]
Furcraea foetida (FF)	Fiber content	Epoxy	10, 20, and 30% wt fiber	TS—170.47 MPa FS—80.23 MPa Density—0.903 g/cm^3	Hand layup	FF reinforcement significantly enhanced the mechanical characteristics of the epoxy material. Moreover, the application of chemical treatments to FF fiber is anticipated to augment the characteristics of the composite by enhancing its quality. The FF/E composite, which has been developed, demonstrates encouraging outcomes and has the potential to be utilized in the creation of economical materials for various environmentally friendly purposes	[98]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Sansevieria trifasciata	Fiber weight 5–50% and fiber lengths 5–50 mm	Epoxy		TS—78.26 MPa, YM—11.8 GPa, FS—82.33 MPa, FM—3 GPa, IS—8.97 J/cm^2	Hand layup	The investigation indicated that STFPs demonstrated an augmentation in qualities when the weight percentage of fibers was below 40% and, subsequently, a decline in attributes as the fiber percentage above that threshold. The results suggest that it is possible to create high-performance composite materials using locally available resources	[99]
Sansevieria cylindrica (SC)	Fiber weight	Polyester	20%, 30%, 40%, and 50% of fiber weight	TS—85.7 MPa IS—9.4 J/cm^2	Compression molding	The measured results indicate that the greatest tensile strength attained in 40 wt% of treated SC fiber composites is 85.7 MPa. The highest level of hardness is observed in composites containing 40 wt% of both treated and untreated fibers. According to this study, the fiber treatment enhances the strength of the fiber compared to untreated. The treated SC fibers exhibit enhanced tensile strength and excellent adhesion between the fiber and matrix, resulting in the production of high-quality composite materials	[100]
Sansevieria trifasciata	Ceramic filler	Polyester	SiO_2 and B_4C, fiber content 20%	TS—44.92 MPa, FS—103.58 MPa, IS—27.4 kJ/m^2	Compression molding	Due to their excellent mechanical properties, the resulting composites can be considered as a cost-effective, lightweight, and eco-friendly brake pad composite	[101]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Sansevieria ehrenbergii	Fiber surface treatments, randomly oriented fiber arrangements	*Isophthalic polyester*	Treatments: Alkali, benzoyl peroxide, benzoyl chloride, permanganate, and stearic acid (fiber length 30 mm, fiber weight 30%)	FS—112.69 MPa FM—27.68 GPa, TS—68.95 MPa, YM—8.93 GPa	*Hand layup*	The SRGC treated with $KMnO_4$ exhibited superior mechanical qualities in comparison to composites treated with NaOH, SA, BP, and BC. The mechanical properties of the treated fiber-reinforced polyester composites are improved as a result of strong physical bonding between the fiber and polymer matrix. The chemically treated fiber exhibits reduced water absorption in comparison to untreated fiber composites	[77]
Sansevieria roxburghiana	Fiber weight	Epoxy	10, 20, 30, and 40 weight% of fiber	TS—21.1 Mpa, FS—65.6 Mpa, and IS—18.37 kJ/m^2	compression molding	The findings indicate that a fiber loading of 30 weight% exhibited the highest mechanical properties. The experimental results demonstrate that the leaf fibers of *Sansevieria roxburghiana* have the ability to serve as reinforcements in polymer composites, making them appropriate for lightweight and household applications	[102]
Henequen fibers	Fiber weight	Polyester resin	15, 20, and 25% of fiber	TS—24.14 Mpa, IS—24.5 7 kJ/m^2	Cold compression molding	Based on the findings of this study, the tensile test demonstrated that the material with 25% fiber exhibited the highest value, while the material with 20% fiber displayed the greatest impact resistance. Henequen fibers exert a beneficial effect when used as reinforcement in a thermoset polymer matrix	[103]

Table 3 (continued)

Leaf fiber	Specification	Polymer	Parameters	Mechanical properties	Techniques used	Observations and applications	References
Date palm leaf (DPL)	Various fiber treatment and fiber weight%	Polyvinyl alcohol (PVA)	Alkaline, benzoylation, permanganate, peroxide, maleic anhydride, and acrylic acid	TS—20.19 Mpa, YM—1183 Mpa, FS—36.29 Mpa, IS—4.31 kJ/m^2	Injection molding	The most favorable mechanical characteristics of PVA/DPL biocomposites were seen when the fiber loading reached 28 wt%. The mechanical properties were enhanced due to the better interfacial interaction between polymers and fibers	[104]
Cantala fiber	Fiber treatment		Alkaline treatment (0, 3, 6, 9, 12 h), microcrystalline cellulose 5%, fiber volume 30%	TS—77.81 MPa EM—4.58 GPa Density—1.22 g/cm^3	Compression molding	The findings demonstrated that subjecting the composites to 6-h alkaline treatment yielded the greatest density, tensile strength, and elastic modulus. The alkali treatment and addition of MCC significantly enhance the strength and modulus of elasticity of these composites, making them suitable for a wide range of load-bearing constructions	[105]

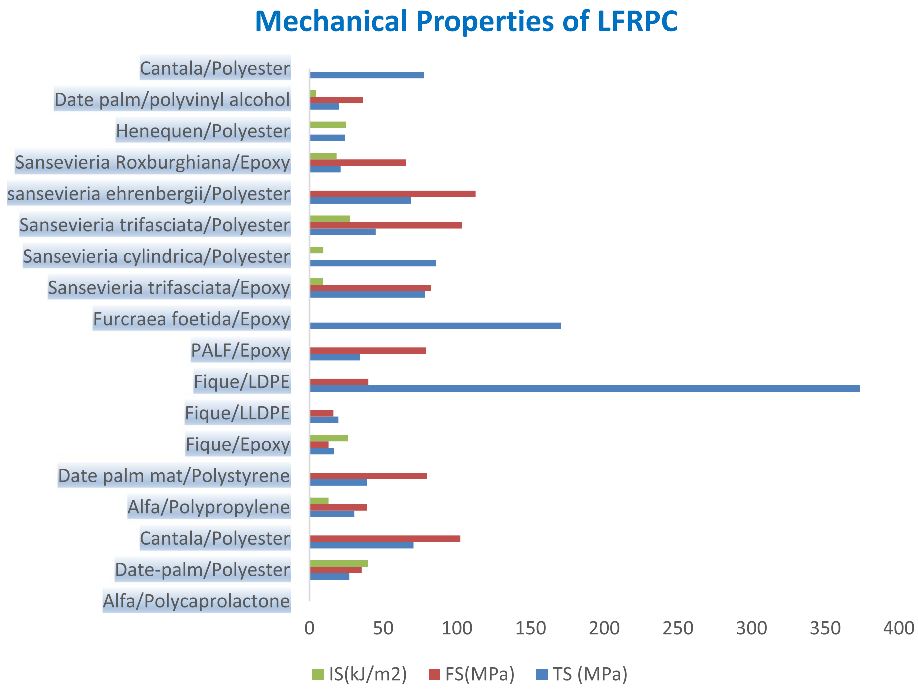

Fig. 3 Histogram of various leaf fiber/matrix composites and its mechanical properties

It was revealed that three-layer woven PALF with warp direction has greater mechanical properties than the weft direction (Hadi et al. 2022). In another research work, the effect of surface modification on mechanical properties of *Sansevieria ehrenbergii*/polyester composites is studied (Sathishkumar et al. 2014). It is observed that among the various treatments, $KMnO_4$-treated fiber composites depicted superior mechanical characteristics. The figure indicates that there is a significant body of studies focused on leaf fibers and leaf fiber-based hybrid composite materials. These materials have a wide range of applications across many manufacturing industries.

Conclusions

Leaf fibers obtained from agricultural waste can be turned into new composite products through proper technology. Fiber-reinforced polymer composites have replaced synthetic materials to a greater extent because of its biodegradability, low density, ease to dispose, and less expensive. The favorable properties of this composites are affording positive benefits to the environment too, i.e., harmless to health during manufacturing and CO_2 neutral balance. The usage of leaf fibre composite has been prevalent in several industries such as automotive (for door panels, roof and dashboard), construction (for fences, park benches and indoor ornamental boards), and even in packaging and household appliances, which are increasingly being recognised as potential applications in the field of composites [106]. The utilisation of leaf fibre as a reinforcing material in polymer composites has demonstrated a beneficial impact on the mechanical characteristics.

This review article explored the following findings:

i)The various types of leaf fibers used as a reinforcing material are discussed.

ii) The major components present and their physico-mechanical properties of leaf fibers are presented through table and figures.
iii) Various researchers prepared the composites by adopting various processing techniques, variety of leaf fibers, and fiber parameters (length, orientation) which are discussed in the leaf fiber-reinforced polymer composite section.
iv) Several studies have focused on the mechanical properties (such as TS, YM, FS, FM, and IS), the effects of surface modifications, different matrices used in composite preparation, and an overview of the performance of composites reinforced with leaf fibres.
v) The effect of various leaf fibers and their hybrid composites is also the focused in this review.

Finally, as world is moving towards usage of environmental friendly materials, conduct of research for the increased utilization of leaf fiber, which is abundantly available, is of timely needed one. This review of research over the period of one decade shows positive sign towards increasing the utility of leaf fibers in various industries, household appliances, construction, etc. The researches on influence of surface modification and fiber loadings on mechanical performance of leaf fiber-reinforced polymer composites show favorable signs in the composite world.

Abbreviations

TS	Tensile strength
TM	Tensile modulus
FS	Flexural strength
FM	Flexural modulus
IFSS	Interfacial shear strength
WA	Water absorption
IS	Impact strength
IE	Impact energy
SEM	Scanning electron microscopy

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References

1. Mechakra H, Nour A, Lecheb S, Chellil A (2015) Mechanical characterizations of composite material with short alfa fibers reinforcement. Compos Struct 124:152–162
2. Tipu Sultan Md, Md Minhaz-Ul HM, Maniruzzaman Ashraful A (2013) Composites of polypropylene with pulque fibres: morphology, thermal and mechanical properties. J Thermoplast Compos Mater 28:1615–1626

3. Phiri G, Khoathane MC, Sadiku ER (2013) Effect of fibre loading on mechanical and thermal properties of sisal and kenaf fibre-reinforced injection moulded composites. J Reinf Plast Comp 33:283–293
4. Sreenivasan VS, Somasundaram S, Ravindran D, Manikandan V, Narayanasamy R (2011) Microstructural, physico-chemical and mechanical characterisation of Sansevieria cylindrica fibres – an exploratory investigation. Mater Des 32:453–461
5. Neto J, Queiroz H, Aguiar R, Lima R, Cavalcanti D (2022) A review of recent advances in hybrid natural fiber reinforced polymer composites. J Renew Mater 10:561–589
6. Mwaikambo LY (2006) Review of the history, properties and application of plant fibres. African Journal of Science and Technology. Sci Eng Series 7:120–133
7. Wijang WR, Rudy S, Yudy SI, Agus S (2017) Improvement in mechanical properties of cantala fiber and short cantala/recycled high-density polyethylene composite through chemical treatment. Preprints. https://doi.org/10.20944/preprints201710.0134.v1
8. Piedad G, Inaki M (2002) Surface modification of fique fibers. Effects on their physico-mechanical properties. Polym Compos 23:383–394
9. Yu C. Properties and processing of plant fiber, Proceedings of the New Frontiers in Fibre Science 2001, 23–25 May 2001, The Fiber Society, USA Raleigh, NC.
10. Ramanaiah K, Ratna PAV, Hema CRK (2013) Mechanical, thermophysical and fire properties of Sansevieria fiber-reinforced polyester composites. Mater Des 49:986–991
11. Sreenivasan VS, Ravindran D, Manikandan V, Narayanasamy R (2012) Influence of fibre treatments on mechanical properties of short Sansevieria cylindrica/polyester composites. Mater Des 37:111–121
12. Rangga P, Mardiyati S, Ikhsan P (2017) Effect of maleic anhydride treatment on the mechanical properties of Sansevieria fiber/vinyl ester composites. AIP Conf Proc 1823:020097. https://doi.org/10.1063/1.4978170
13. John MJ, Anandjiwala RD (2008) Recent developments in chemical modification and characterization of natural fiber-reinforced composites. Polym Compos 29:187–207
14. Ketnawa S, Chaiwut P, Rawdkuen S (2012) Pineapple wastes: a potential source for bromelain extraction. Food Bioprod Process 90:385–391
15. Samson R, Blanka, (2012) Morphological, thermal, and mechanical characterization of Sansevieria trifasciata fibers. J Nat Fibers 12:201–210
16. Yanzur MA, Azizah B (2018) Effect of fibre treatment using fluorosilane on Sansevieria trifasciata/polypropylene composite. AIP Conf Proc 1940:020106. https://doi.org/10.1063/1.5028021
17. Bessadok A, Roudesli S, Marais S, Follain N, Lebrun L (2009) Alfa fibres for unsaturated polyester composites reinforcement: effects of chemical treatments on mechanical and permeation properties. Compos Part A 40:184–195
18. Mansour RHO, Abdellatif I, Noureddine B (2011) Effect of chemical treatment on flexure properties of natural fiber-reinforced polyester composite. Procedia Eng 10:2092–2097
19. Arrakhiz FZ, Elachaby M, Bouhfid R, Vaudreuil S, Essassi M, Qaiss A (2012) Mechanical and thermal properties of polypropylene reinforced with alfa fiber under different chemical treatment. Mater Des 35:318–322
20. Arrakhiz FZ, Malha M, Bouhfid R, Benmoussa K, Qaiss A (2013) Tensile, flexural and torsional properties of chemically treated alfa, coir and bagasse reinforced polypropylene. Compos Part B-Eng 47:35–41
21. Radouane B, Charles AK, Souad N, Hamid E, Mohammed-Ouadi B, Denis Rachid B, Abou KQ (2017) Alfa fibers/clay hybrid composites based on polypropylene: mechanical, thermal, and structural properties. J Thermoplast Compos Mater 31:974–991
22. Sami BB, Ridha BC (2007) Influence of fibre orientation and volume fraction on the tensile properties of unidirectional alfa-polyester composite. Compos Sci Technol 67:140–147
23. El-Abbassi FE, Assarar M, Ayad R, Lamdouar N (2015) Effect of alkali treatment on alfa fibre as reinforcement for polypropylene based eco-composites: mechanical behaviour and water ageing. Compos Struct 133:451–457
24. Med Amin OA, Triki MG, Med Ben H, Arous M, Bulou A (2016) Effect of wool fibers on thermal and dielectric properties of alfa fibers reinforced polyester composite. Mater Chem Phys 170:312–318
25. Sair S, Mansouri S, Tanane O, Abboud Y, El Bouari A (2019) Alfa fiber-polyurethane composite as a thermal and acoustic insulation material for building applications. SN Applied Sciences 1:667
26. Wijang WR, Rudy S, Yudy SI, Agus S (2018) The influence of chemical treatments on cantala fiber properties and interfacial bonding of cantala fiber/recycled high density polyethylene (rHDPE). J Nat Fibers 15:98–111
27. Ilham TM, Andy PR, Eko S, Nurul M, Wijang WR (2018) Effect of the cantala fiber on flexural strength of composite friction brake. AIP Conference Proceedings doi 10(1063/1):5042951
28. Espinach FX, Julián F, Alcalà M, Tresserras J, Mutjé P (2014) High stiffness performance alpha-grass pulp fiber reinforced thermoplastic starch-based fully biodegradable composites. BioResources 9:738–755
29. Miguel A, Hidalgo-Salazar JPC (2018) Mechanical and thermal properties of biocomposites from nonwoven industrial fique fiber mats with epoxy resin and linear low density polyethylene. Results Phys 8:461–467
30. Catalina GH, Analía V (2012) Flexural properties loss of unidirectional epoxy/fique composites immersed in water and alkaline medium for construction application. Compos Part B-Eng 43:3120–3130
31. Sandra VNC, Diego G (2017) Characterization of fique fibers and evaluation of mechanical properties, abrasive wear resistance, and processability of NR/SBR/BR-fique fibers composites. J Elastom Plast 50:435–447
32. Michelle SO, da Fabio CGF, Fernanda SL, Luana CCD, Artur CP, Henry AC, Lucio FCN, Sergio NM (2019) Evaluation of dynamic mechanical properties of fique fabric/epoxy composites. Mater Res 22(suppl. 1):e20190125
33. Sergio G, Bladimir R, Rolando G (2018) Comparative study of the mechanical and vibratory properties of a composite reinforced with fique fibers versus a composite with E-glass fibers. Revista UIS Ingenierias 17:43–50
34. Michelle SO, Fabio CGF, Fernanda SL, Artur CP, Luana CCD, Lucio FCN, Henry ACL, Sergio NM (2019) Statistical analysis of notch toughness of epoxy matrix composites reinforced with fique fabric. J Mater Res Technol 8:6051–6057
35. Moscoso SFJ, Alvarado A, Martínez-Chávez L, Hernández-Montelongo R, Fernández Escamilla VV, Canche EG (2019) The effects of henequen cellulose treated with polyethylene glycol on properties of polylactic acid composites. BioResources 14:2707–2726

36. Quim T, Fabiola V, Pedro J, Herrera-Franco F, Xavier E, Marc Delgado-Aguilar Pere M (2019) Interface and micromechanical characterization of tensile strength of biobased composites from polypropylene and henequen strands. Ind Crops Prod 132:319–326
37. Seong OH, Ho JA, Donghwan C (2009) Hygrothermal effect on henequen or silk fiber reinforced poly(butylene succinate) biocomposites. Compos Part B-Eng 41:491–497
38. Gonzalez MC, Ansell MP (2009) Mechanical properties of henequen fibre/epoxy resin composites. Mech Compos Mater 45:435–442
39. Pathan YM, Venkata R, Krishna VC, Pradeep KA (2019) Study of continuous henequen/epoxy composites. Mater Today 18:3798–3811
40. Fernanda SL, Flávio JH, Tommasini VR, Lucio FCN, Ben-Hur A, da SF, Sergio NM, (2018) Critical length and interfacial strength of PALF and coir fiber incorporated in epoxy resin matrix. J Mater Res Technol 7:528–534
41. Gabriel OG, Maria CAT, Felipe PDL, Carlos MFV, Frederico MM, Sergio NM (2017) Tensile strength of polyester composites reinforced with PALF. J Mater Res Technol 6:401–405
42. Gabriel OG, Maria CAT, Anna CCN, Carlos MFV, Felipe PDL, Maycon AG, Frederico MM, Sergio NM (2017) Bending test in epoxy composites reinforced with continuous and aligned PALF fibers. J Mater Res Technol 6:411–416
43. Ridzuan MJM, Abdul MMS, Khasri A, Gan EHD, Razlan ZM, Syahrullail S (2019) Effect of pineapple leaf (PALF), napier, and hemp fibres as filler on the scratch resistance of epoxy composites. J Mater Res Technol 8:5384–5395
44. Indra RM, Anil KM, Rama Bhadri R (2018) Tensile and flexural properties of jute, pineapple leaf and glass fiber reinforced polymer matrix hybrid composites. Mater Today 5:458–462
45. Senthilkumar K, Saba N, Chandrasekar M, Jawaid M, Rajini N, Alothman O, Suchart Siengchin Y (2019) Evaluation of mechanical and free vibration properties of the pineapple leaf fibre reinforced polyester composites. Constr Build Mater 195:423–431
46. Pujari SM, Daniel S, Kumar AS, Bhanu P, Dilip SP (2020) Investigation on behavioural aspects of pine apple leaf fiber–latex composites used for transformer applications. Mater Today. https://doi.org/10.1016/j.matpr.2019.12.348
47. Parameswara RVD, Ratnam C, Siva PD (2020) Effect of fiber orientation on dynamic mechanical properties of PALF hybridized with basalt reinforced epoxy composites. Mater Res Express 7:015329
48. Ayu NK, Mohd ZS, Nabila A, Siti NS, Mohd AMD, Ridhwan J, Suhaila S (2015) Effect of pineapple leaf fiber loading on the mechanical properties of pineapple leaf fiber – polypropylene composite. Jurnal Teknologi (Sciences & Engineering) 77:117–123
49. Joseph K, Tolêdo FRD, James B, Thomas S, Carvalho LH (1993) A review on sisal fiber reinforced polymer composites. Rev Bras Eng Agrícola Ambient 3:367–379
50. Bisanda E, Ansell MP (1991) The effect of silane treatment on the mechanical and physical properties of sisal-epoxy composites. Compos Sci Technol 41:165–178
51. Vishnuvardhan R, Rahul RK, Sivakumar S (2019) Experimental investigation on mechanical properties of sisal fiber reinforced epoxy composite. Mater Today 18:4176–4181
52. Arun M, Vincent S, Karthikeyan R (2020) Development and characterization of sisal and jute cellulose reinforced polymer composite. Mater Today. https://doi.org/10.1016/j.matpr.2019.12.218
53. Bassyouni M (2018) Dynamic mechanical properties and characterization of chemically treated sisal fiber-reinforced polypropylene biocomposites. J Reinf Plast Comp 37:1402–1417
54. Ramesh M, Palanikumar K, Hemachandra RK (2013) Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites. Compos Part B-Eng 48:1–9
55. Krutibash R, Hemalata P, Anup KS, Bibhudatta P, Sourabh M, Asit S, Suryakanta R (2020) Glass/jute/sisal fiber reinforced hybrid polypropylene polymer composites: fabrication and analysis of mechanical and water absorption properties. Mater Today. https://doi.org/10.1016/j.matpr.2020.02.964
56. Pramod VB, Manjunatha TS, Gurushanth BV, Praveen KC (2020) Compression and water absorption behaviour of banana and sisal hybrid fiber polymer composites. Mater Today. https://doi.org/10.1016/j.matpr.2020.02.695
57. Anas AA, Dhakad PASK (2020) Investigation of mechanical properties of sisal fibre and human hair reinforced with epoxy resin hybrid polymer composite. Mater Today. https://doi.org/10.1016/j.matpr.2020.02.513
58. Sandeep K, Yogesh K, Brijesh G, Vinay KP (2017) Effects of agro-waste and bio-particulate fillers on mechanical and wear properties of sisal fibre based polymer composites. Mater Today 4:10144–10147
59. Prabhu L, Krishnaraj V, Gokulkumar S, Sathish S, Ramesh M (2019) Mechanical, chemical and acoustical behavior of sisal – tea waste – glass fiber reinforced epoxy based hybrid polymer composites. Mater Today 16:653–660
60. Rajesh M, Jeyaraj P, Rajini N (2016) Free vibration characteristics of banana/sisal natural fibers reinforced hybrid polymer composite beam. Procedia Eng 144:1055–1059
61. Leandro JS, Túlio HP, Vânia RV, André LC, Fabrizio S (2012) Hybrid polymeric composites reinforced with sisal fibres and silica microparticles. Compos Part B-Eng 43:3436–3444
62. Dhinesh KM, Senthamaraikannan C, Jayasrinivasan S, Aushwin S (2020) Study on static and dynamic behavior of jute/sisal fiber reinforced epoxy composites. Mater Today. https://doi.org/10.1016/j.matpr.2020.03.064
63. Asokan P, Kim LP, Vijay KT (2019) Manufacturing and characterization of sustainable hybrid composites using sisal and hemp fibres as reinforcement of poly (lactic acid) via injection moulding. Ind Crops Prod 137:260–269
64. Sivakandhan C, Murali G, Tamiloli N, Ravikumar L (2020) Studies on mechanical properties of sisal and jute fiber hybrid sandwich composite. Mater Today 21:404–407
65. Senthil MKT, Senthilkumar K, Chandrasekar M, JirattiT RN, Suchart S, Sikiru OI (2019) Investigation into mechanical, absorption and swelling behaviour of hemp/sisal fibre reinforced bioepoxy hybrid composites: effects of stacking sequences. Int J Biol Macromol 140:637–646
66. Athith D, Sanjay MR, Yashas GTG, Madhu P, Arpitha GR, Yogesha B, Med Amin O (2019) Effect of tungsten carbide on mechanical and tribological properties of jute/sisal/E-glass fabrics reinforced natural rubber/epoxy composites. J Ind Text 48:713–737
67. Senthil KK, Siva I, Rajini N, Jeyaraj P, Winowlin JJT (2014) Tensile, impact, and vibration properties of coconut sheath/sisal hybrid composites: effect of stacking sequence. J Reinf Plast Comp 33:1802–1812

68. Priyadharshini S, Ramakrishna G (2018) A novel approach for the rheological behaviour of polymer modified untreated and treated sisal fibre reinforced cement mortar composites. Mater Today 5:12927–12939
69. Hill Albert F (1952) Economic botany: a text book of useful plants and plant products. Mc Graw Hill Book Co., New York, pp 38–39
70. Sreenivasan VS, Ravindran D, Manikandan V, Narayanasamy R (2011) Mechanical properties of randomly oriented short Sansevieria cylindrica fibre/polyester composites. Mater Des 32:2444–2455
71. Deepak JJR, Arumugaprabu V, Uthayakumar M, Vigneshwaran S, Manikandan V, Bennet C (2018) Erosion performance studies on Sansevieria cylindrica reinforced vinylester composite. Mater Res Express 5:035309
72. Sreenivasan VS, Ravindran D, Manikandan V, Narayanasamy R (2010) Mechanical properties of randomly oriented short Sansevieria cylindrica fibre/polyester composites. Mater Des 32:2444–2455
73. Ramachandra RG, Mala AK, Jarugala J (2014) Biodegradable Sansevieria cylindrica leaves fiber/tamarind fruit fiber based polymer hybrid composites on characterization. Int Lett Chem Phys Astronomy 39:116–128
74. Bennet C, Rajini N, Winowlin JJT, Siva I, Sreenivasan VS, Amico SC (2015) Effect of the stacking sequence on vibrational behavior of Sansevieria cylindrica/coconut sheath polyester hybrid composites. J Reinf Plast Comp 34:293–306
75. Sathishkumar TP, Navaneethakrishnan P, Shankar S, Rajasekar R (2013) Characterization of new cellulose Sansevieria ehrenbergii fibers for polymer composites. Compos Interfaces 20:575–593
76. Sathishkumar TP (2014) Comparison of Sansevieria ehrenbergii fiber-reinforced polymer composites with wood and wood fiber composites. J Reinf Plast Comp 33:1704–1716
77. Sathishkumar TP, Navaneethakrishnan P, Shankar S, Rajasekar R (2014) Investigation of chemically treated randomly oriented Sansevieria ehrenbergii fiber reinforced isophthallic polyester composites. J Compos Mater 48:2961–2975
78. Sathishkumar TP (2016) Influence of cellulose water absorption on the tensile properties of polyester composites reinforced with Sansevieria ehrenbergii fibers. J Ind Text 45:1674–1688
79. Mangesh T, Akshay J (2017) Study on the chemical composition, physical properties and structural analysis of raw and alkali treated Sansevieria roxburghiana fibre. Aust J Basic Appl Sci 11:35–45
80. Ashok KG, Udhayakumar P, Sathish Kumar GK (2015) Evaluation on mechanical properties of natural fibers/ lignite fly ash reinforced epoxy composites. Proceedings of International Conference on Advances in Materials, Manufacturing and Applications, April 9–11, 2015.
81. Thanesh A, Palani S, Alagu S, Pandian Selvam M, Harish KA (2017) Mechanical properties of Sancevaria trifasciata Laurent II polyester composites. Int J Pure Appl Math 116(23):215–222
82. Kumar MA, Ramachandra RGH, Reddy NS, Hemachandra K, Mohana YV (2011) Mechanical properties of randomly oriented short Sansevieria trifasciata fibre/epoxy composites. Metall Mater Trans A 53:85–95
83. Samson R, Joe O, Godfrey H (2014) Comparative evaluation of dynamic mechanical properties of epoxy composites reinforced with woven fabrics from Sansevieria (Sansevieria trifasciata) fibres and banana (Musa sapientum) fibres. Tekstilec letn 57:315–320
84. Raghava KSB, Ashok M, Nikill MV, Karthikeyan N (2015) Development of Sansevieria trifasciata - carbon fiber reinforced polymer hybrid nanocomposites. Int Lett Chem Phys Astronomy 50:179–187
85. Nurzam EZ, Ishak A, Wan ZWM, Azizah B (2018) Effects of fibre size on Sansevieria trifasciata/natural rubber/ high density polyethylene biocomposites. Malaysian J Anal Sci 22:1057–1064
86. Ammar B, Djalal T, Slimane B, Amir A, Mohammed SR, Sabri T, Kamel K (2023) A facile preparation strategy and characterization of polymer composite-based on polycaprolactone and alfa fibers/graphene nanoplatelets hybrids. Mater Lett 337:133940
87. Mohammed YA, Mustafa GS, Hamzah A, Abdel-Jaber GT, Ahmed HB (2023) Characteristic properties of date-palm fibre/sheep wool reinforced polyester composites. J Bioresour Bioprod 8:430–443
88. Sakuri S, Eko S, Dody A, Aditya RP (2020) Experimental investigation on mechanical characteristics of composite reinforced cantala fiber (CF) subjected to microcrystalline cellulose and fumigation treatments. Compos Commun 21:100419
89. Sakuri S, Eko S, Dody A (2020) Thermogravimetry and interfacial characterization of alkaline treated cantala fiber/ microcrystalline cellulose-composite. Procedia Struct Integr 27:85–92
90. Yakout A, Azzedine B, Nouri L, Nadir, (2022) Effect of alkaline treatment time on flexural properties of alfa fiber/ unsaturated polyester composite. Cellul Chem Technol 56:1081–1088
91. Werchefani M, Lacoste C, Belguith H, Bradai C (2021) Alfa fibers for Cereplast bio-composites reinforcement: effects of chemical and biological treatments on the mechanical properties. Polym Polym Compos 29:S441–S449
92. Sofiene H, Achref G, Mohamed AK, Moez C (2023) Natural cellulosic alfa fiber (Stipa tenacissima L.) improved with environment-friendly treatment cementitious composites with a stable flexural strength. Civ Eng Archit 11:1632–1644
93. Julian R, Mario FB, Sergio NM, Gloria IE, Henry AC (2021) Impact behavior of laminated composites built with fique fibers and epoxy resin: a mechanical analysis using impact and flexural behaviour. J Mater Res Technol 14:428–438
94. Most AK, Shahin S, Mohammad SK, Sahadat H, Husna PN, Chowdhury AMS (2023) Preparation and characterization of short date palm mat (DPM) fiber reinforced polystyrene composites: effect of gamma radiation. Heliyon 9:e21373
95. Miguel AH, Juan PC (2018) Mechanical and thermal properties of biocomposites from nonwoven industrial fique fiber mats with epoxy resin and linear low density polyethylene. Results Phys 8:461–467
96. Muñoz-Vélez MF, Hidalgo-Salazar MA, Mina-Hernández JH (2018) Effect of content and surface modification of fique fibers on the properties of a low-density polyethylene (LDPE)-Al/fique composite. Polymers (Basel) 10:1050
97. Hadi AE, Siregar JP, Cionita T, Norlaila MB, Badari MAM, Irawan AP, Jaafar J, Rihayat T, Junid R, Fitriyana DF (2022) Potentiality of utilizing woven pineapple leaf fibre for polymer composites. Polymers 14:2744
98. Madival AS, Doreswamy D, Maddasani S, Shettar M, Shetty R, Processing, (2022) Characterization of Furcraea foetida (FF) fiber and investigation of physical/mechanical properties of FF/epoxy composite. Polymers 14:1476

99. Fantin IR, Appadurai LP, Chithambara T (2023) Mechanical characterization of randomly oriented short Sansevieria Trifasciata natural fibre composites. Int Polym Process 38:564–581
100. Balasubramani S, Manickavasagam VM, Paul TR, Raj PAC, Bharath VG, Madhusudhanan J, Amit KS, Pravin P, Gizachew BA (2022) Investigation of mechanical properties of *Sansevieria cylindrica* fiber/polyester composites. Adv Mater Sci Eng Article ID 2180614.
101. Hariprasad P, Kannan M, Ramesh C, Felix SA, Jenish I, Fayaz H, Nidhal BK, Attia B, Suresh V (2022) Mechanical and morphological studies of *Sansevieria trifasciata* fiber-reinforced polyester composites with the addition of SiO_2 and B_4C. Adv Mater Sci Eng Article ID 1634670.
102. Kailasanathan C, Gopi KM, NagarajaGanesh B (2022) Investigation of mechanical and thermal conductivity properties of Sansevieria roxburghiana leaf fibers reinforced composites: effect of fiber loading. J Nat Fibers 19:13401–13414
103. Guerra-Silva Y, Valin Rivera JL, Fernández-Abreu ME, Wiebeck H, Álvarez AA, Valenzuela Díaz FR, Gonçalves E, Mendelo-Garcia FJ (2017) Characterization of the composite interface of thermoset polymeric matrix reinforced with Cuban henequen fibers. Rev cienc téc agropecu 26:26–39
104. Swain SK, Sahoo G, Sarkar N (2015) Manufacturing of chemically modified date palm leaf fibre-reinforced polymer composites. In: Salit, M., Jawaid, M., Yusoff, N., Hoque, M. (eds) Manufacturing of natural fibre reinforced polymer composites. Springer, Cham. https://doi.org/10.1007/978-3-319-07944-8_14
105. Raharjo WP, Ariawan D, Diharjo KR, Wijang W, Kusharjanta B (2023) Effect of alkaline treatment time of fibers and microcrystalline cellulose addition on mechanical properties of unsaturated polyester composites reinforced by cantala fibers. Rev Adv Mater Sci 62:20230103
106. Zhanying S (2018) Progress in the research and applications of natural fiber-reinforced polymer matrix composites. Sci Eng Compos Mater 25:835–846

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