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Review Article

A Review on Natural Fibre-Reinforced Biopolymer Composites: Properties and Applications

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In ongoing decades, material researchers and scientists are giving more consideration towards the improvement of biobased polymer composites as various employments of items arranged by natural fibres and petrochemical polymers prompt natural awkwardness. The goal of this review paper is to provide an intensive review and applications of the foremost appropriate commonly used biodegradable polymer composites. It is imperative to build up the completely/incompletely biodegradable polymer composites without bargaining the mechanical, physical, and thermal properties which are required for the end-use applications. This reality roused to create biocomposite with better execution alongside the least natural effect. The utilization of natural fibre-reinforced polymer composites is concerned with the mechanical properties that are highly dependent on the morphology, hydrophilic tendency, aspect ratio, and dimensional stability of the natural fibre. With this in-depth consideration of eco-friendly biocomposites, structural application materials in the infrastructure, automotive industry, and consumer applications of the following decade are attainable within the near future.

1. Introduction

In many engineering applications, the utilization of heavy metals reduces its performances of the products. To overcome this limitation, the use of polymer-based synthetic fibres composites started in many applications in 1930 on account of their high specific stiffness and strength [1–3]. However, the use of synthetic fibres in polymer composites is fading every day for the sake of its excessive processing cost, nonbiodegradability, and non-skin-friendliness behaviour [4–7]. Further, the numerous uses of nonbiodegradable polymer-based synthetic fibres in many engineering applications led to environmental imbalance. Therefore, the development of an eco-friendly and sustainable composite material (i.e., biocomposites) is needed to protect our environment. In this context, the researchers have successfully tried to replace these nonbiodegradable and non-eco-friendly synthetic fibres with natural fibres which can replace these synthetic fibres in many cases. These natural fibres over synthetic fibres have many advantages; an effective comparison between the natural and the synthetic fibres is given in Table 1 [8–11]. Polymeric composites that are reinforced by the biomass (i.e., natural fibres) in orientations, different sizes, shapes, and in wt.%/vol.% are biocomposites. Such suitable composites help in the minimization of environmental impact by replacing the synthetic fibres in polymeric composites and make them cost-effective.

The various types of polymers (i.e., thermoplastic, thermosets, soy-based polymers, starch, natural rubber, and biopolymers) can be utilized in a matrix as the production of the biocomposite materials. The interesting fact of biopolymers is they are naturally biodegradable polymers, and these are synthesized by living organisms. The biopolymer can transform the natural polymer since it can be obtained directly from the earth. Biopolymers can be produced from bioresources,

Table 1: Comparison of natural fibres with synthetic fibres.

Properties	Natural fibres	Synthetic fibres
Density	Low	Double of natural fibres
Origin	Nature	Man made
Fibre structure	Cannot be changed	Changed
Nature	Hydrophilic	Hydrophobic
Durability	Low	High
Cost	Low	High
Use	Low	High
Recyclability	Yes	No
Renewability	Yes	No
Distribution	Wide	High
Energy consumption	Low	High
Health risk	No	Yes
CO_2 neutral	Yes	No
Biodegradable	Yes	No
Specific strength & modulus	High	Low
Strength & modulus	Low	High

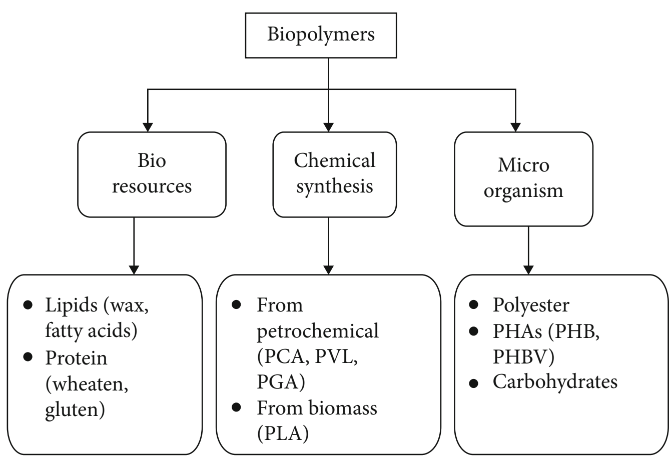

Figure 1: Schematic classification of biopolymers. PCA: *Polycaprolactone; PVL: Poly(δ-valerolactone); PGA: Poly-glutamic acid; PHA: Polyhydroxyalkanoates; PHB: Polyhydroxybutyrate.

chemical synthesis, and microorganism. A schematic classification of biopolymers based on their source is presented in Figure 1 [12]. Examples of biopolymer are polylactic acid (PLA), chitosan, cellulose esters, starch-based polymers, natural rubber, polyhydroxy butyrate (PHB), cellulose, and so on. Composite materials are classified as green composite primarily owes to their renewable and natural-based resources, degradable, and sustainable [13, 14]. These green composite materials can be simply disposed of without harming the surroundings [15]. Green composites consist of natural fibre reinforcement with bioderived resin to develop biocomposites.

Natural fibre is getting consideration in the industries as well as the researchers on its utilization in various polymer composite-based products in par with the environmental awareness in customer's aspects and guideline of the government in certain countries globally. This paper plans to survey the most present improvements in the field of biocomposites. The particular target of this survey is to distinguish and address the performance of biocomposites.

2. Natural Fibre as Reinforcement

The ongoing development in ecological awareness, as well as the guideline of the government in replacing the synthetic fibre with the utilization of reinforced natural fibre, got more noteworthy consideration in the manufacturing industries with composite materials. The alluring highlights in the natural fibres are their ease, high specific modulus, and light weightiness, which pulled in numerous researchers to utilize these fibres. The classification of fibre is presented in Figure 2. The average prices of natural fibres are outlined in Table 2, and the physical, chemical, and mechanical properties of natural fibre are illustrated in Tables 3 and 4.

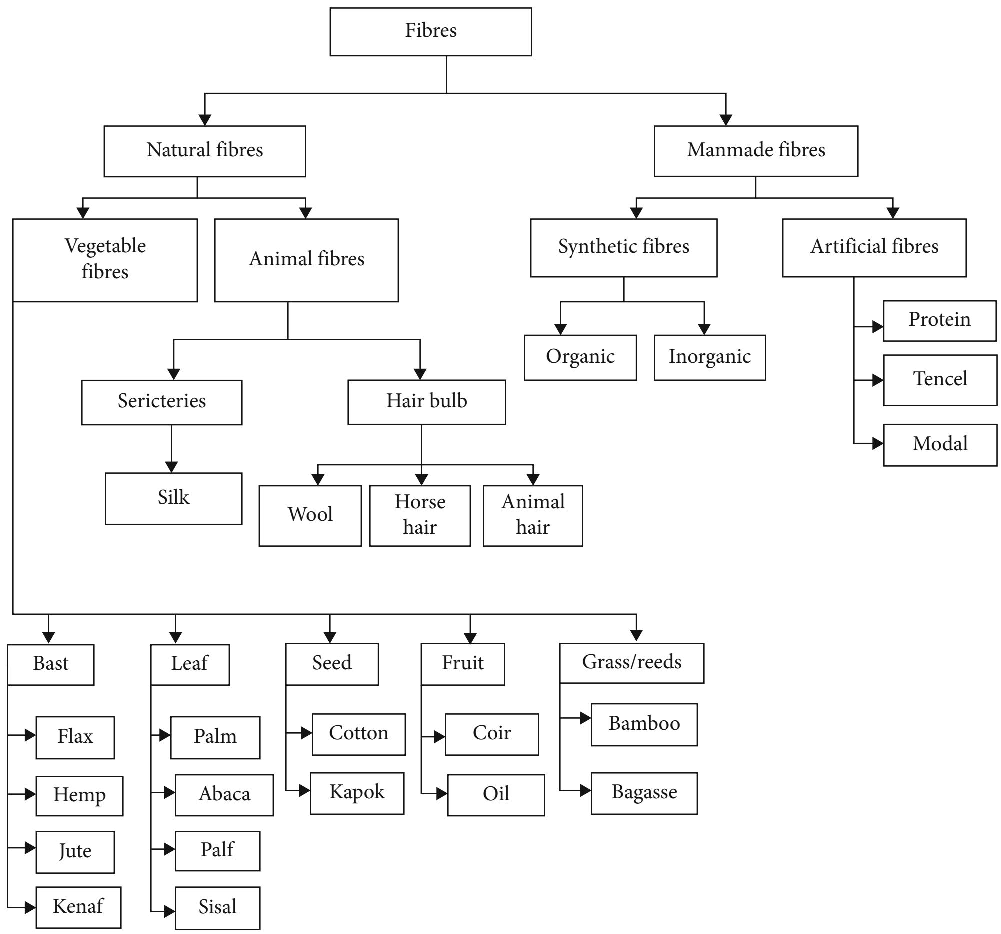

Figure 2: Types and source of fibres.

Table 2: Natural fibres' average prices [16].

Fibres	Price (US$/kg)
Bamboo	0.5
Coir	0.3-0.5
Flax	2.1-4.2
Feather	1.1-2.0
Hemp	1.0-2.1
Jute	0.4-1.5
Kenaf	0.3-0.5
Sisal	0.6-0.7
Wool	1.6-2.4

3. Types and Sources of the Natural Fibre

The classification of natural fibres can be of two kinds: plant-based fibres and animal-based fibres. Animal-based fibres are chicken feather, wool, and silk which are used in biomedical applications like implants. These bioproducts should be either biodegradable which implies the capacity to break down and absorb back into the body or biocompatible to dodge being destructive to the human body. Plant-based fibres are hemp, sisal, kenaf, jute, flax, coir, banana, and bamboo that are used to produce biocomposites for making domestic product. These natural fibres are classified as renewable sources that can be extracted from the nature without any damage to the environment. Sources of plant and animals fibres are given in Figure 3.

3.1. Structure of Natural Fibres. There are multiwall structures and longitudinal shape (cylindrical) of natural fibre. There are four components in each fibre cell: primary wall, thick secondary wall, tertiary wall, and lumen. Each cell wall comprises a few layers of a fibrillar structure having fibrillae. The diametrical average of the primary wall is found to be 23 μm. In the primary wall (W1), fibrillae have a reticulated structure. The outer secondary wall (W2) is found in the interior of the primary wall. In the secondary wall, the fibrillae are organized in spirals with a 40-degree spiral angle. In the internal secondary wall (W3), the fibrillae are spiral with a sharper slope inclination of 18 to 25 degree. The deep innermost tertiary wall (W4) is more slender with a parallel fibrillar structure [23]. The innermost tertiary wall encased with an average diameter of 11 μm as the lumen.

Table 3: Natural fibres and their chemical composition.

Origin	Fibre	Cellulose (%)	Hemi celluloses (%)	Lignin (%)	Pectin (%)	Moisture (%)	MFA (degree)	Wax (%)	Reference
Bast	Flax	64.1–71.9	16.7–20.6	2.0–2.2	1.8–2.3	8–12	5–10	1.7	[17]
	Kenaf	31-39	21.5	15-19		—	11	—	[17]
	Jute	61–71.5	12.0-20.4	11.8-13	0.2	12.5–13.7	—	0.5	[17]
	Hemp	70.2–74.4	17.9–22.4	3.7–5.7	0.9	6.2–12	2–6.2	0.8	[17]
Fruit	Coir	32–43	0.15–0.25	40–45	3–4	8	8	—	[17]
Stalk	Sisal	67-78	10-14.2	8-11	10	—	—	2	[18]
	Banana	63–64	10–19	5	—	10-12	—	—	[19]
	Bamboo	26–43	30	21-31	—	—	—	—	[17]
Animal	Wool	—	—	—	—	—	—	—	—
	Feather	—	—	—	—	—	—	—	—

MFA: *microfibril angle.

Table 4: Natural plant fibres and their physical and mechanical properties.

Origin	Fibre	Diameter (μm)	Density (g/cm^3)	TS (MPa)	TM (GPa)	Elongation (%)	References
Bast	Hemp	25-600	1.47	690	70	2.0-4.0	[16]
	Flax	25	1.5	500-1500	27.6	2.7-3.2	[20]
	Kenaf	40-90	1.22-1.4	295-930	22-53	3.7-6.9	[21]
	Jute	25-250	1.3-1.49	393-800	13-26.5	1.16-1.5	[18]
Leaf	Banana	100-250	0.8	161.8	8.5	2.0	[16]
	Sisal	100-300	1.3-1.5	507-955	9-28	2-2.9	[18]
Fruit	Coir	150-250	1.2	175	4-6	30	[19]
	Oil palm	—	1.55	248	3.2	25	[16]
Grass	Bamboo	240-330	0.91	441	35.9	1.3	[18]
	Bagasse	200-400	1.25	96.24	6.42	4.03	[18]
Animal	Wool	—	1.3	120-174	2.3-3.4	25-35	[22]
	Feather	—	0.9	50-315	—	13.2-35	[22]

TS: *tensile strength; TM: *tensile modulus.

4. Natural Fibre-Reinforced Biocomposites

Over the most recent two decades, numerous inquiries about investigators are centred on conatural fibre composites that are blended as polymer resins. Natural fibre-reinforced biocomposites had pulled liberal significance with potential structural material in the packing and furniture enterprises and private lodging development [24]. The flax, sisal, banana, kenaf, hemp, bamboo, jute, feather, and wool fibre composite-reinforced polymers are examined in detail as takes after:

4.1. Sisal Fibre-Reinforced Biocomposites. Sisal fibre is extremely hard and strong leaf fibre which is mostly manufactured in South America and East Africa. These fibres have great potential as reinforcement in the manufacture of the composites. Varghese et al. [25] evaluated on dynamic mechanical behaviour of the composites reinforced with acetylated short sisal fibre. The continuous increase in fibre loading with diminished rise in temperature increased by mechanical loss and storage moduli. Joseph et al. [26] observed the utilized benzoyl chlorite with sodium hydroxide solution for the treatment of sisal fibres for improving hydrophobicity. Joseph et al. [27] experimented with varying concentrations of benzoyl peroxide and dicumyl peroxide-treated sisal fibres. The tensile strength of polyethylene based sisal composites assessed with improvement after treatment on optimal concentration of and 4% dicumyl peroxide and 6% benzoyl peroxide further the tensile strength remains unchanged. Asaithambi et al. [21] evidenced on improved compatibility with the fibres and PLA matrix through cross-linking fetched with benzoyl peroxide prepared with the hybrid composite utilization with polylactic acid on banana and sisal fibres. Sreekumar et al. [28] prepared the composite subjected to reinforcement treated sisal fibre and polyester as matrix. Alkali-treated sisal fibres have superior value of flexural strength than untreated sisal fibre composites on permanganate treatment concluded. The interaction among fibres and resin is explained by Paul et al. and Datta and Kopczyńska [29, 30]. A positive

(a)

(b)

(c)

(d)

(e)

(f)

(g)

Figure 3: Continued.

(h)

(i)

(j)

Figure 3: Sources of plant and animals fibres: (a) sisal, (b) kenaf, (c) flax, (d) hemp, (e) coir, (f) banana, (g) bamboo, (h) jute, (i) wool, and (j) feather [16].

consequence of surface modification by eco-friendly treatment (i.e., sodium bicarbonate treatment) and eco-friendly coating (i.e., PLA coating) of sisal fibres was perceived in terms of improvement in tensile and flexural properties of its composite. The tensile strength of the sisal composite was found lower than those of modified sisal composites as mentioned in Figures 4–6, but the trend of the impact test result was found reverse to the results of tensile and flexural test as illustrated in Figure 7 [11].

5. Kenaf Fibre-Reinforced Biocomposites

The scientific name of kenaf bast fibre is Hibiscus cannabinus L. and the family of Malvaceae. It is an industrial yield in Malaysia and conveyed economically in another piece of the world for various purposes. It takes a short farm cycle and is adaptable to ecological conditions, so it gains a favourable position when compared with different yields.

The work revealed by Nishino et al. [31] biodegradable green composite was developed utilizing kenaf fibre as reinforcement into poly-L-lactic acid to examine the performance and found that kenaf fibre is a good candidate for the reinforcement for production of green biocomposites. Ismail et al. [32] evidenced the role of fibre arrangement and the number of layers on the ultimate tensile strength by preparing the biocomposites using kenaf fibre and polyester resin.

Nosbi et al. [33] analyzed the impact of the water absorption on the mechanical behaviour of ready biocomposites and noted the significant behaviour of water absorption in the kenaf/polyester biocomposite to follow Fickian behaviour in the seawater, acidic solutions, and distilled water at a normal room temperature. Salleh et al. [34] increased the mechanical behaviour and surface adhesion properties of kenaf fibre bolstered high-density composite polythene by the addition of the maleic chemical compound grafted high-density polyethylene. 8% maleic anhydride grafted high-density polyethylene (MA-HDPE) obtained peak gain in flexural and tensile properties showed the addition of chemical maleic compound ends up insensible adhesion with the matrix and the fibres. Anuar and Zuraida [35] additionally noted that the addition of maleic chemical compound in kenaf fibre polypropene composite significantly amplified the mechanical properties. Fairuz et al. [36] examined the impact of filler loading on mechanical properties of kenaf/vinyl organic compound composites associated with degree and noted an improvement within the mechanical properties up to a remarkable extent after mechanical properties began to drop owing to the event of viscousness within the matrix. Results make sure the noteworthy boost in the storage modulus, tensile strength, and the flexural strength in poly(furfuryl alcohol)/kenaf composite primarily as a result of bigger matrix fibre adhesion [37]. Mutasher et al. [38] developed the epoxy-based mostly kenaf fibre composites to explore the consequence on the composite with alkali treatment of fibre. The authors ascertained that alkali-treated fibre composites offered higher progress than untreated fibre. The improvement in the flexural and tensile strength was noted at pure kenaf fibre composites whereas

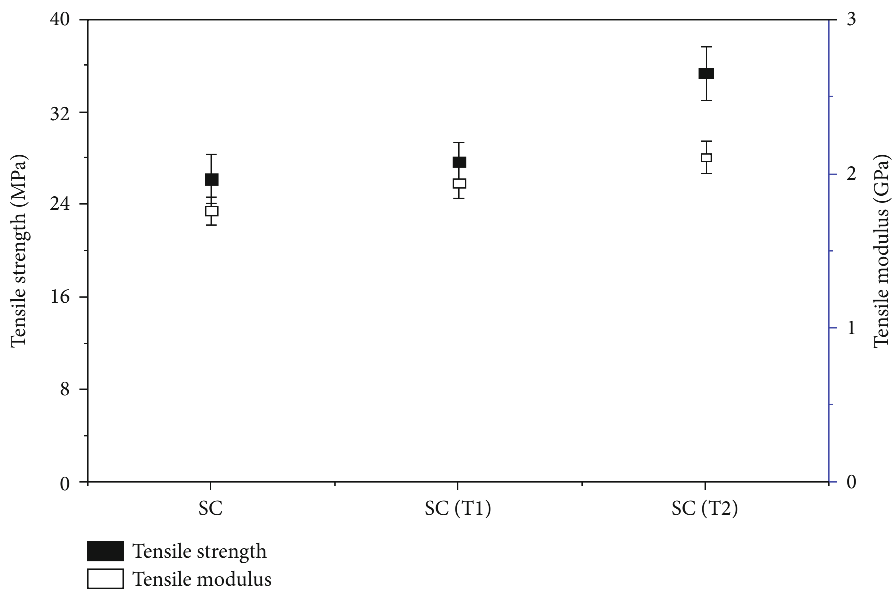

Figure 4: Tensile strength and modulus of pure and modified sisal composites [11].

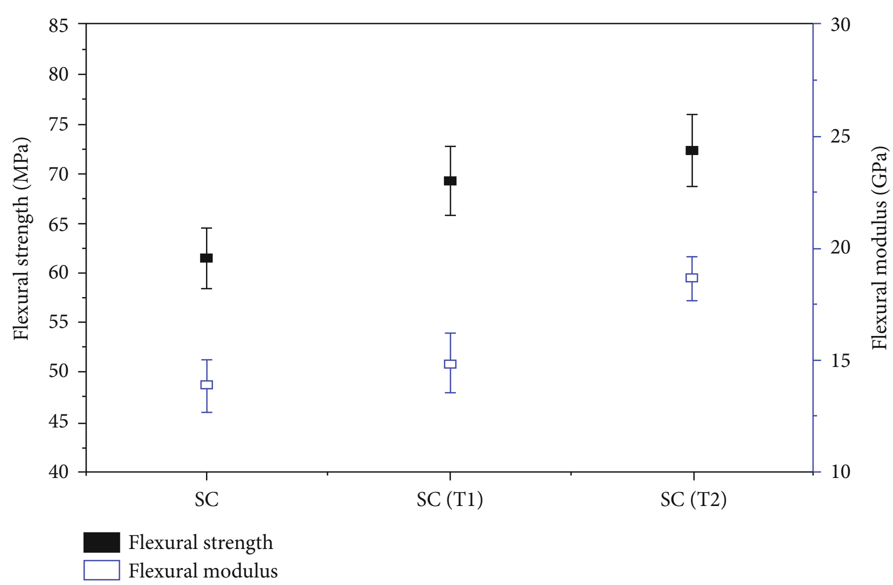

Figure 5: Flexural strength and modulus of pure and modified sisal composites [11].

the very best impact strength was achieved at a four-hundredth weight fraction of kenaf fibre. Datta and Kopczyńska [39] performed a proportionate solution with 0.5 wt.% $KMnO_4$ to switch the kenaf fibre for making kenaf/polyurethane composites.

5.1. Jute Fibre-Reinforced Biocomposites. Jute fibres are appropriate for utilizing as reinforcement in the manufacture of biocomposites. Gassan and Bledzki [40] treating the fibres with silane to improve the flexural strength, tensile, and stiffness of jute-epoxy composites. The bleaching delignification offers a bigger surface bond between the polyester and the jute fibre that results in the excellent composition of composites with mechanical properties. Plackett et al. [41] prepared a film stacking technique and found a noteworthy enrichment in the tensile properties with the PLA/jute composites. Gowda et al. [42] tested with an experimental set on the mechanical behaviour of the jute/polyester composites. Liu et al. [43] examined on biodegradability of poly(butylene succinate)/jute fibre biocomposites since the hydrophilic behaviour of jute fibre is weakened by surface modification, and the compatibility with hydrophobic poly(-butylene succinate) is therefore advanced.

Mohanty et al. [44] investigated the jute fibre high-density composites with polyethylene for the mechanical behaviour as well as dynamic mechanical properties and stated that the mechanical characteristics increased consistently with the fibre loading up to 30%, and beyond it, a

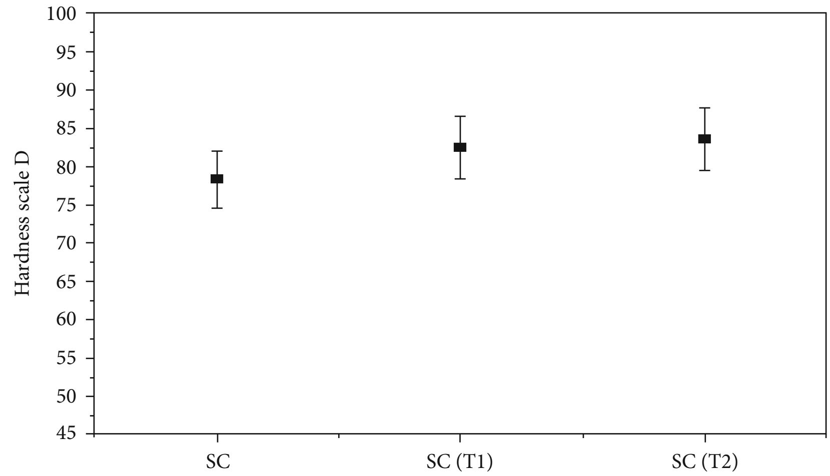

Figure 6: Hardness values of pure and modified sisal composite [11].

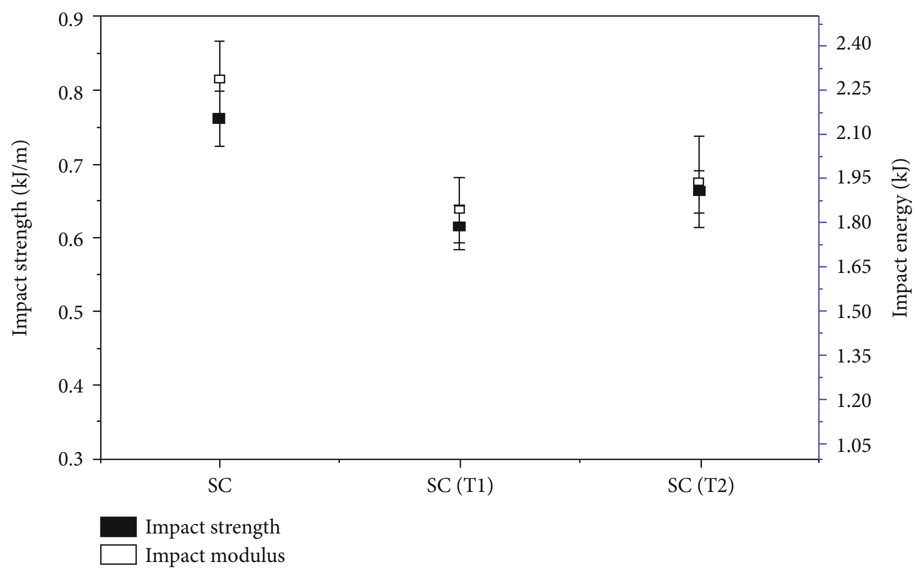

Figure 7: Impact strength of pure and modified sisal composites [11].

notable decline in the mechanical characteristics was evidenced. The best mechanical strength was reported at composites prepared to utilize 1% MAPE concentration and 30% fibre loading. Recent work on the performance of biocomposites is shown in Table 5.

According to Ray et al. [55], jute/vinyl ester composite was manufactured to investigate the mercerization impact on the thermal and dynamic mechanical analysis treated with the jute fibres with utilizing 5% NaOH for 4 and 8 h in numerous fibre loading. As the fibre loading increases, the storage modulus also boosted attributable to higher stress transfer at the interface. Ray et al. [56] treated jute fibres utilizing 5% alkali at 30°C for varying time interval to develop biocomposite combined with vinyl ester and found. The composites arranged with 4 h treated fibres at 35% fibre stacking offered optimum outcomes. Seki et al. [57] investigated the silane treatments and consequence of alkali on the treated jute-polyester composites and flexural properties of treated jute-epoxy by comparative evaluation. The silane treatment provided superior the modulus and strength properties compared to the alkali treatment in each case of the jute polyester composites and the jute-epoxy composites.

5.2. Hemp Fibre-Reinforced Biocomposites. Hemp fibres are one of the bast fibres which are obtained from the plant named Cannabis sativa. Pickering et al. [46] modified hemp fibres for enhancing their appropriateness utilization of composite reinforcement materials to examine treatments of the fibre and the MAPP content of Young's modulus and tensile strength of the fibre hemp composites reinforced with polypropylene. Sawpan and Pickering [58] developed composites with hemp fibre/PLA by the silane and alkali-treated short fibre utilizing the content of fibre (0–40 wt.%) and evidenced that mechanical properties like impact strength, Young's modulus, and strength tensile of the short hemp fibre composites reinforced with PLA enhanced after both treatments owing to increased matrix crystallinity and

Table 5: Recent work on performance of Bio Composites.

Fibre	Matrix	Fabrication method	Results	Ref
Sisal	Rubber	—	Treatment and fibre orientation in longitudinal direction offers better properties	[20]
Sisal	Polypropylene	Melt mixing method	A maximum property of composite was noted after modifications	[45]
Sisal	Polyester	Resin transfer moulding	Adhesion bonding was improved after treatment of fibre using different chemicals	[24]
Kenaf	Polyester	Manual method	Insignificant increment of tensile strength has been observed if the numbers of layers are increased	[21]
Kenaf	Polyester	Pultrusion technique	As water uptake percentage increases, the compressive properties started to decline	[28]
Kenaf	High-density polythene	Injection moulding	The interfacial properties and mechanical performance of the kenaf HDPE composite boosted by adding MA-HDPE composites owing to the enhanced interfacial adhesion between fibre and resin	[29]
Kenaf	Poly(furfuryl alcohol)	Compression moulding	The noteworthy enhancement performance was noted in the developed composites	[32]
Jute	PLA	Film-stacking procedure	The tensile properties of composites were considerably superior to those of neat polylactide	[36]
Jute	Poly(butylene succinate)	Flat sulfide machine	Compatibility with hydrophobic PBS is thus improved by surface modification	[38]
Jute	High-density polyethylene	Melt mixing	Composites prepared at 30% fibre loading and 1% MAPE concentration showed optimum mechanical strength	[39]
Hemp	Polylactic acid	Manual method	The percentage crystallinity of PLA in composites was found to be higher than that for neat PLA and increased with alkali treatment of fibres	[46]
Hemp	Unsaturated polyester	Hand lay-up	Moisture uptake percentage increased as the fibre volume fraction increased owing to the high cellulose content	[47]
Coir	Natural rubber	Two-roll laboratory mill	Damping factor increases with fibre incorporation, which indicates lower heat dissipation in the gum	[48]
Coir	Tannin-phenolic	—	The performance of the composites showed an improvement due to the incorporation of coir fibres in the tannin-phenolic matrices	[49]
Banana	Natural rubber	Compression moulding	The composites made from 15 mm length banana fibres offer the superior tensile strength and good tear strength	[50]
Banana	Polyester	Compression moulding	Surface treatment enhances the storage modulus of banana/polyester composites	[51]
Bamboo	Polypropylene	Hot-press method	Tensile strength and Young's modulus of the improved composites increased about 15 and 30%	[52]
Bamboo	Epoxy	Manual method	The mechanical properties were enhanced compared to pure epoxy	[53]
Flax	Polypropylene	Film-stacking method	Stiffness of the flax-based composite is comparable to E-glass-based composites	[54]

good fibre/matrix adhesion on the increment of fibre content. Kabir et al. [47] used treatments like silane, alkali, and acetylation on surfaces of hemp fibre then reinforced into polyester to enhance the properties of fibre matrix adhesion. An optimum result was obtained utilizing 8% NaOH in comparison to other treated and nontreated variety owing to the growth of hydrophobicity by the elimination of cellulosic elements after treatment.

Fibre strength, as well as fibre-matrix adhesion, was greatly improved after the alkali treatment reported by Sedan et al. [48]. Yan et al. [59] used noil hemp fibre and scutched hemp fibre as reinforcement to fabricate polypropylene-based composites. The introduction of MAPP greatly improved the fibre-PP adhesion results in a notable significance in flexural, impact strength, and tensile strength in both composites. Islam et al. [49] produced polylactic acid-based composites by combining short and long hemp fibre using a compression moulding process to improve bonding with PLA after alkali treatment of fibre. The crystallinity percentage was seen as higher than that for neat PLA with increased alkali treatment of fibres of PLA in composites. Yuanjian and Isaac [60] investigated the mechanical properties of hemp/polyester. Dhakal et al. [61] observed significant effect on the mechanical behaviour of water absorption was evidenced on the various fibre volume fractions prepared by hemp/polyester composites. Performing the water absorption tests directed in the submerging specimens of deionised water bath with 25°C and 100°C for various time lengths reveals that fibre volume fraction with increased moisture uptake also increases because of cellulose content and bigger voids.

5.3. Coir Fibre-Reinforced Biocomposites. Coir fibre is one of the fruit fibres. It has high weather resistance owing to a greater quantity of lignin. Coir fibres absorb water to a minor level in comparison with all the other natural fibres attributable to their lesser content of cellulose. Geethamma et al. [62] evaluated the mechanical dynamic behaviour after chemical treatment of its reinforced composites and natural rubber with the short coir fibres and found that great internal bonding will scatter lesser energy in addition to bad internal bonding towards the composite material. Yan et al. [63] used coir fibres as reinforcement into epoxy and cementitious to examine the effect of the fibre treatment on the mechanical and the microstructure properties on the experimental preparation of composites. Treating the alkali with 5 wt.% NaOH solution induces a clearer and scattered surface of the coir fibre in par with the untreated surface of the fibre. The impact strength analysis with the Izod test of the composites showed improvement in part to the matrix incorporation of the coir fibres in tannin-phenolic [64]. Jayabal et al. [65] investigated the influence of alkali concentration and the coir fibre alkali treatment time evidenced a consistent influence in the physicomechanical properties of the composites with coir polyester. Zyaoul Haque et al. [66] prepared the hybrid coir/glass fibre composites with reinforced epoxy by a manual method to evaluate the concurrence of fibre loading and mechanical properties like tensile strength, flexural strength, and the hardness of composites. Haque et al. [50] manufactured coir/polypropylene composites by a hot compression method.

The impact of filler on the mechanical behaviour of coir/polyester composites was investigated by Suardana et al. [67] evidenced the mechanical properties of the composites prepared were boosted on using the red mud waste. Karthikeyan and Balamurugan [68] evidenced the effectiveness of the treatment on fibre length and alkali on the behaviour impact of coir/epoxy composites. Girisha et al. [51] evidenced a sisal/coconut coir epoxy composite was fabricated for examining its influence on the water absorption behaviour of biocomposites. An extensive fall in the mechanical properties happens by contacting of moisture due to the degradation in the interface of the fibre-matrix and found an immense drop off with tensile strength in case of the aged specimens compared to dry samples as aged specimens absorbed water molecules. In this way, the decline in hydrogen bonding happens between the cellulose molecules of the fibre. Subsequently, adhesion bonding between the fibre and the resin was reduced leading to diminished strength. Rout et al. [69] manufactured coir/polyester amide biocomposites to investigate the impact of surface alteration of fibres such as alkali treated, cyanoethylated, bleached, and vinyl grafted. It was evidenced that surface alterations come about in progressed properties of the composites. Among the treated fibres, cyanoethylated coir-polyester amide composite offered with improved tensile strength. The impact of filler on the mechanical behaviour of coir/polyester composites was investigated by Suardana et al. [67] who evidenced the mechanical properties of the composites prepared were boosted on using the red mud waste. Karthikeyan and Balamurugan [68] evidenced the effectiveness of the treatment on fibre length and alkali on the behaviour impact of coir/epoxy composites. Girisha et al. [51] evidenced a sisal/coconut coir epoxy composite was fabricated for examining its influence of the water absorption behaviour of biocomposites. An extensive fall in the mechanical properties happens by contacting of moisture due to the degradation in the interface of the fibre-matrix and found an immense drop off with tensile strength in case of the aged specimens compared to dry samples as aged specimens absorbed water molecules. In this way, the decline in hydrogen bonding happens between the cellulose molecules of the fibre. Subsequently, adhesion bonding between the fibre and the resin was reduced leading to diminished strength. Rout et al. [69] manufactured coir/polyester amide biocomposites to investigate the impact of surface alteration of fibres such as alkali treated, cyanoethylated, bleached, and vinyl grafted. It was evidenced that surface alterations come about in progressed properties of the composites. Among the treated fibres, cyanoethylated coir-polyester amide composite offered improved tensile strength.

5.4. Banana Fibre-Reinforced Biocomposites. At present, banana fibres are misused with the outcome of banana cultivation. The pseudostem of the banana plant provides this strongest natural fibre in bulk quantity. Raghavendra et al. [52] developed the short banana fibre/natural rubber composites to determine the impact of various lengths of fibre content. The optimum results of tensile and tear strength were achieved at the composites produced using 15 mm length banana fibres. Srinivasan et al. [53] fabricated the hybrid composite utilizing flax/banana/glass fibre epoxy composite by manual method, and the hybrid composite offered higher strength compared to the individual fibre composites is noted. Amir et al. [70] added maleic anhydride-grafted polypropylene as a coupling agent for the composites in enhancement to the bonding with the polypropylene with the banana fibre. Banana/polypropylene composites offered the greatest flexural strength and tensile strength by 294% and 72% in comparison to pristine PP. Pothan and Thomas [71] examined the interactive role of fibre/matrix of improved banana composites with fibre/polyester based on dynamic mechanical properties. It tends to be inferred that composites with improved modulus with low damping perfect for the utilization as it is the substitute for building material shall be produced from polyester resins and banana fibre. Sapuan et al. [54] examined the influence of the mechanical properties of the woven banana/epoxy composites to compare to the glass fibre composites.

5.5. Bamboo Fibre-Reinforced Biocomposites. The major affecting factors in the final mechanical properties of bamboo reinforced polymer including length of the fibre, the orientation of fibre, and treatment of fibre have been studied. Optimum chemical concentration, mainly alkali treatment, should be carried out to enhance the interfacial behaviour of the biocomposites. Okubo et al. [72] fabricated the bamboo/polypropylene composites and found a consistent increase of about 15% and 30% in the mechanical properties like modulus and tensile strength of composites in respect to owing the reduction of the number of voids and good impregnation. Banga et al. [73] used bamboo fibres at various weight proportions (20, 30, and 40) to incorporate into epoxy resin to examine the mechanical and physical properties. Mohanty and Nayak [74] manufactured bamboo fibre-reinforced biocomposites to study mechanical behaviour. The bamboo fibre-reinforced composites HDPE were prepared to employ with melt blending technique followed by the injection moulding and found that the flexural and tensile properties had improved on increasing the fibre loadings from 10% to 30%, beyond the deterioration with the composites in its mechanical strength which tends to be inferred that bamboo strands can successfully reinforce with HDPE matrix.

5.6. Flax Fibre-Reinforced Biocomposites. One of the common broadly utilized biofibres is flax (Linum usitatissimum). Pothan and Thomas [71] modified the flax fibres for the increase in the properties of unidirectional flax fibre-reinforced composites. The flax fibres/polypropylene composites were developed by Sapuan et al. [54]. TGA investigation of flax/composite was carried out by Okubo et al. [72] and nominal reduction in thermal stability on alkali treatment probably owing its exclusion of cementing fibres substances. Heijenrath and Peijs [75] fabricated the flax fibres and polypropylene by utilizing a film-stacking process. Munoz and García-Manrique [76] investigated the effects of water absorption behaviour influence the mechanical behaviour of flax/bioepoxy composites. Baiardo et al. [77] manufactured and studied on flax fibre-polyester composites. To fabricate low-density polyethylene-based composites, benzoylation treatment was applied on flax fibre [30].

Greater moisture resistance and tensile strength characteristics were determined by the cause of excellent interlocking between matrices and the fibres [78, 79]. Wang et al. [80] carried a like process to boost the interfacial adhesion with polyethylene in flax fibre. Alix et al. [81] applied styrene treatments and silane in the flax fibres and found a slight increase in the moisture resistance of its polyester resin composites. Tayfun [82] decreased the water uptake capacity of the composite flax fibre polyurethane by applying treatments like alkali, permanganate, peroxide, and silanization on flax fibres. Fiore et al. [83] assessed with sodium bicarbonate treatment impact on the mechanical performance of flax/epoxy composite and noted enhancement in fibre-matrix bonding with improvement in the execution of flax composites. Om Prakash et al. [84] manufactured the fibre-reinforced hybrid polyester composites with banana and snake grass in random orientation and random lay-up and found that the 40% increase in the flexural strength with a mild drop in the flexural modulus of the composite influencing the shear and normal stresses.

5.7. Wool Fibre-Reinforced Biocomposites. Wool is another choice to be utilized as reinforcement for the preparation of biocomposite. The textile industry has a predominant and very essential use of wool fibres acquired from mammals. Conzatti et al. [85] developed short wool fibres/polypropylene consisting 60 wt.% of well-dispersed wool fibres by melt blending. The addition of a maleinized polypropylene compatibilizer was examined to enhance fibre/matrix adhesion and also enhance the fire retardancy on growing thermal stability. Kim et al. [86] fabricated composite sheets based on short wool fibres and polypropylene through the extrusion process. The wool fibre addition enhances the composites tensile properties, and further enhancement shall be done by adding up MAPP owing to enhanced interfacial adhesion between wool and polypropylene whereas wool fibres addition in polypropylene enhances the material fire retardancy by escalating the char residue and thermal stability [87]. The use of wool biocomposites gets highlight because wool exerts, in contrast to various animal fibres, fairly better thermal properties; lower the rates of fire spread and heat discharge and conjointly lower the heat of combustion [88].

5.8. Feather Basis Reinforced Biocomposites. Feather fibre is an appropriate fibre as reinforcement in order to develop the biocomposite as it offers good specific strength, recyclable and renewable in nature, so the application for developing biodegradable materials has developed continuously.

Okoro et al. [89] explored the mechanical behaviour of the high-density polyethylene-based composites reinforced with feather fibres. Fibres were mercerized with 0.1 M KOH solution and evidenced that chemical moderation with KOH improves the percentage index on the crystallinity of feather fibres prepared by the composite samples possessing the better mechanical properties. Amieva et al. [90] prepared recycled polypropylene-reinforced composites with a quill extrusion process from chicken feathers. Choudary et al. [91] developed feather fibre/polyester composites using a manual process. The tensile strength of composite has enhanced in comparison to the virgin polyester by the inclusion of reinforcement feather fibres with polyester matrix. Jayamani et al. [92] combined chicken feather fibres with polyester to produce composites by modifying its percentage weight fraction of fibres (2-10 wt.%). Potassium hydroxide was used as an alkali treatment for varying the structure in which raising the surface roughness of fibres leads to good adhesion.

Rao et al. [93] fabricated randomly oriented short feather fibre epoxy composites by manual methods to examine the erosion response of the composite. Srivatsav et al. [94] reinforced chicken feather with epoxy composite to evaluate the composite thermal characteristics. Alagarsamy et al. [95] evidenced with experiments on the mechanical behaviour of the coconut coir/chicken feather/polyester composite hybrid. The composite specimen was fabricated with various weight percentages of chicken feather and coconut coir blended with polyester utilizing the manual method and noted that the coconut coir fibre enhanced the tensile and impact strength of composites and quantity of chicken feather was responsible for flexural strength of composites.

6. Application of Biocomposites

Natural fibres for the case with banana, ramie, hemp, flax, kenaf, and jute have a higher specific quality; low density is utilized with few mechanical applications. As per investigators, the bast fibres have extraordinary mechanical properties making them a substitute to glass fibres in polymer composites as reinforcing components and making them appropriate for different applications. The bast fibre composites are environmentally inviting, utilized in automobiles, military applications, construction building, and packaging businesses.

Green advertising, new mandates on recycling, social impact, and change of intellectual qualities have driven the customer towards environmentally friendly products. Thus, natural fibre-based composites can play a significant role in futuristic engineering product especially in the automobile sector. The natural fibres can be extricated from animals, plants and minerals. Plant-based natural fibres such as hemicellulose lignin and cellulose can be derived from bast, fruit, seed, wood, leaf, grass/reed, and stalk which are widely used in the manufacturing of automobile parts. This is predominantly because of the short development time frame, renewability, and wider availability. Moreover, benefits like low density, low cost, availability, low energy consumption, and acceptable modulus-weight ratio during manufacturing make it an effective material for automotive applications.

As per Composites World March 2016 article, there has been a significant development with natural fibre composites that helped the automotive industry to lead the path with its selection of natural fibres for various auxiliary parts of the vehicle which, in turn, improved the market share in the automotive industries. Biocomposite will be demonstrated to be a "New Frontier in Automobile Sector" in the forthcoming times.

7. Concluding Remarks

Biocomposites can be the future generation materials for all structural applications in various industries such as the automobile industry and infrastructure and also in customer applications. Wide exposure of the natural fibre-reinforced composites to moisture comes about within the degradation of the fibre-matrix interface which clarifies a significant drop in mechanical properties. This paper gives a review of the presentation of biocomposites given by various analysts. The survey with accumulated data on the properties of biocomposites was attempted on the utilization of the commercial application. In any case, their drawbacks, for example, poor interfacial bond with the matrix and the natural fibres, poor fire resistance, moisture absorption, durability, and the low impact strength, have at any rate incompletely kept them from being viewed as a solid option for conventional composites.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

This study was performed as a part of the Employment of Jimma Institute of Technology, Jimma, Ethiopia.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] K. Begum and M. Islam, "Natural fibre as a substitute to synthetic fibre in polymer composites: a review," *Research Journal of Engineering Sciences*, vol. 2, no. 3, pp. 46–53, 2013.

[2] K. N. Keya, N. A. Kona, F. A. Koly, K. M. Maraz, M. N. Islam, and R. A. Khan, "Natural fiber reinforced polymer composites: history, types, advantages and applications," *Materials Engineering Research*, vol. 1, no. 2, pp. 69–87, 2019.

[3] D. Jagadeesh, K. Kanny, and K. Prashantha, "A review on research and development of green composites from plant protein-based polymers," *Polymer Composites*, vol. 38, no. 8, pp. 1504–1518, 2017.

[4] P. Sahu and M. K. Gupta, "A review on the properties of natural fibres and its biocomposites effect of alkali treatment," *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 234, no. 1, pp. 198–217, 2020.

[5] P. Sahu and M. K. Gupta, "Lowering in water absorption capacity and mechanical degradation of sisal composites by effect of eco-friendly treatment and coating," *Polymer Composites*, vol. 1, no. 1, pp. 1–14, 2019.

[6] L. Mohammed, M. N. Ansari, G. Pua, M. Jawaid, and M. S. Islam, "A review on natural fibre reinforced polymer composite and its applications," *International Journal of Polymer Science*, vol. 2015, Article ID 243947, 2015.

[7] Y. G. Thyavihalli Girijappa, S. Mavinkere Rangappa, J. Parameswaranpillai, and S. Siengchin, "Natural fibers as sustainable and renewable resource for development of eco-friendly composites: a comprehensive review," *Frontiers in Materials*, vol. 6, 2019.

[8] M. R. Sanjay, G. R. Arpitha, L. L. Naik, K. Gopalakrishna, and B. Yogesha, "Applications of natural fibers and its composites: an overview," *Natural Resources*, vol. 7, no. 3, pp. 108–114, 2016.

[9] P. Sahu and M. K. Gupta, "Dynamic mechanical properties of a biocomposite reinforced with sodiumbicarbonate-treated sisal fibers at different frequencies," *Mechanics of Composite Materials*, vol. 57, no. 1, pp. 81–90, 2021.

[10] P. Sahu and M. K. Gupta, "Water absorption behavior of cellulosic fibres polymer composites: a review on its effects and remedies," *Journal of Industrial Textiles*, no. article 152808372097442, 2020.

[11] P. Sahu and M. K. Gupta, "Eco-friendly treatment and coating for improving the performance of sisal composites," *Polymer Testing*, vol. 93, no. 93, 2021.

[12] S. K. Swain, A. J. Pattanayak, and A. P. Sahoo, "Functional biopolymer composites," in *Functional Biopolymers*, pp. 159–182, Springer, Cham, 2018.

[13] P. Peças, H. Carvalho, H. Salman et al., "Natural fibre composites and their applications: a review," *Journal of Composites Science*, vol. 2, no. 4, p. 66, 2018.

[14] B. Aaliya, K. V. Sunooj, and M. Lackner, "Biopolymer composites: a review," *International Journal of Biobased Plastics*, vol. 3, no. 1, pp. 40–84, 2021.

[15] B. C. Mitra, "Environment friendly composite materials: biocomposites and green composites. Natural fibre composites

and their applications: a review," *Journal of Composites Science*, vol. 2, no. 4, 2018.

[16] P. Sahu and M. K. Gupta, "Sisal (Agave Sisalana) fibre and its polymer-based composites: a review on current developments," *Journal of Reinforced Plastics and Composites*, vol. 36, no. 24, pp. 1759–1780, 2017.

[17] G. Koronis, A. Silva, and M. Fontul, "Green composites: a review of adequate materials for automotive applications," *Composites Part B: Engineering*, vol. 44, no. 1, pp. 120–127, 2013.

[18] M. J. John and R. D. Anandjiwala, "Recent developments in chemical modification and characterization of natural fiber-reinforced composites," *Polymer Composites*, vol. 29, no. 2, pp. 187–207, 2008.

[19] I. M. De Rosa, C. Santulli, and F. Sarasini, "Mechanical and thermal characterization of epoxy composites reinforced with random and quasi-unidirectional untreated Phormium tenax leaf fibers," *Materials & Design*, vol. 31, no. 5, pp. 2397–2405, 2010.

[20] M. A. Al-Maadeed and S. Labidi, "Recycled polymers in natural fibre-reinforced polymer composites," in *Natural Fibre Composites*, pp. 103–114, Woodhead Publishing Limited, 2014.

[21] B. Asaithambi, G. Ganesan, and S. A. Kumar, "Bio-composites: development and mechanical characterization of banana/sisal fibre reinforced poly lactic acid (PLA) hybrid composites," *Fibres and Polymers*, vol. 15, no. 4, pp. 847–854, 2014.

[22] L. Yan, N. Chouw, and K. Jayaraman, "Flax fibre and its composites - a review," *Composites Part B: Engineering*, vol. 56, pp. 296–317, 2014.

[23] K. Joseph, R. D. Tolêdo Filho, B. James, S. Thomas, and L. H. . Carvalho, "A review on sisal FIBER reinforced polymer composites," *Revista Brasileira de Engenharia Agrı'cola e Ambiental*, vol. 3, no. 3, pp. 367–379, 1999.

[24] M. R. Sanjay, P. Madhu, M. Jawaid, P. Senthamaraikannan, S. Senthil, and S. Pradeep, "Characterization and properties of natural fiber polymer composites: a comprehensive review," *Journal of Cleaner Production*, vol. 172, pp. 566–581, 2018.

[25] S. Varghese, B. Kuriakose, S. Thomas, and A. T. Koshy, "Mechanical and viscoelastic properties of short fiber reinforced natural rubber composites: effects of interfacial adhesion, fiber loading, and orientation," *Journal of Adhesion Science and Technology*, vol. 8, no. 3, pp. 235–248, 1994.

[26] P. V. Joseph, K. Joseph, and S. Thomas, "Short sisal fiber reinforced polypropylene composites: the role of interface modification on ultimate properties," *Composite Interfaces*, vol. 9, no. 2, pp. 171–205, 2002.

[27] P. V. Joseph, G. Mathew, K. Joseph, G. Groeninck, and S. Thomas, "Dynamic mechanical properties of short sisal fibre reinforced polypropylene composites," *Composites Part A: Applied Science and Manufacturing*, vol. 34, no. 3, pp. 275–290, 2003.

[28] P. A. Sreekumar, S. P. Thomas, J. . Saiter, K. Joseph, G. Unnikrishnan, and S. Thomas, "Effect of fiber surface modification on the mechanical and water absorption characteristics of sisal/polyester composites fabricated by resin transfer molding," *Composites Part A: Applied Science and Manufacturing*, vol. 40, no. 11, pp. 1777–1784, 2009.

[29] A. Paul, K. Joseph, and S. Thomas, "Effect of surface treatments on the electrical properties of low-density polyethylene composites reinforced with short sisal fibers," *Composites Science and Technology*, vol. 57, no. 1, pp. 67–79, 1997.

[30] J. Datta and P. Kopczyńska, "Effect of kenaf fibre modification on morphology and mechanical properties of thermoplastic polyurethane materials," *Industrial Crops and Products*, vol. 74, pp. 566–576, 2015.

[31] T. Nishino, K. Hirao, M. Kotera, K. Nakamae, and H. Inagaki, "Kenaf reinforced biodegradable composite," *Composites Science and Technology*, vol. 63, no. 9, pp. 1281–1286, 2003.

[32] A. E. Ismail, C. A. Aziz, and M. Aswadi, "Tensile strength of woven yarn kenaf fiber reinforced polyester composites," *Journal of Mechanical Engineering and Sciences*, vol. 9, pp. 1695–1704, 2015.

[33] N. Nosbi, H. M. Akil, Z. M. Ishak, and A. A. Bakar, "Degradation of compressive properties of pultruded kenaf fiber reinforced composites after immersion in various solutions," *Materials & Design*, vol. 31, no. 10, pp. 4960–4964, 2010.

[34] F. M. Salleh, A. Hassan, R. Yahya, A. Lafia-Araga, A. D. Azzahari, and M. D. Z. M. Nazir, "Improvement in the mechanical performance and interfacial behavior of kenaf fiber reinforced high density polyethylene composites by the addition of maleic anhydride grafted high density polyethylene," *Journal of Polymer Research*, vol. 21, no. 5, p. 439, 2014.

[35] H. Anuar and A. Zuraida, "Improvement in mechanical properties of reinforced thermoplastic elastomer composite with kenaf bast fibre," *Composites Part B: Engineering*, vol. 42, no. 3, pp. 462–465, 2011.

[36] A. M. Fairuz, S. M. Sapuan, E. S. Zainudin, and C. N. Jaafar, "Effect of filler loading on mechanical properties of pultruded kenaf fibre reinforced vinyl ester composites," *Journal of Mechanical Engineering and Sciences*, vol. 10, no. 1, pp. 1931–1942, 2016.

[37] H. Deka, M. Misra, and A. Mohanty, "Renewable resource based "all green composites" from kenaf biofiber and poly(furfuryl alcohol) bioresin," *Industrial Crops and Products*, vol. 41, pp. 94–101, 2013.

[38] S. A. Mutasher, A. Poh, A. M. Than, and J. Law, "The effect of alkali treatment mechanical properties of kenaf fiber epoxy composite," *Key Engineering Materials*, vol. 471-472, pp. 191–196, 2011.

[39] J. Datta and P. Kopczynska, "XRD peak profile analysis of SiC reinforced Al2O3 ceramic composite synthesized by electrical resistance heating and microwave sintering: a comparison," *Advances in Materials Science and Engineering*, vol. 21, Article ID 8341924, 2021.

[40] J. Gassan and A. Bledzki, "Effect of cyclic moisture absorption desorption on the mechanical properties of silanized jute-epoxy composites," *Polymer Composites*, vol. 20, no. 4, pp. 604–611, 1999.

[41] D. Plackett, T. Løgstrup Andersen, W. Batsberg Pedersen, and L. Nielsen, "Biodegradable composites based on L-polylactide and jute fibres," *Composites Science and Technology*, vol. 63, no. 9, pp. 1287–1296, 2003.

[42] T. Munikenche Gowda, A. C. Naidu, and R. Chhaya, "Some mechanical properties of untreated jute fabric-reinforced polyester composites," *Composites Part A: Applied Science and Manufacturing*, vol. 30, no. 3, pp. 277–284, 1999.

[43] L. Liu, J. Yu, L. Cheng, and X. Yang, "Biodegradability of poly(-butylene succinate) (PBS) composite reinforced with jute fibre," *Polymer Degradation and Stability*, vol. 94, no. 1, pp. 90–94, 2009.

[44] S. Mohanty, S. K. Verma, and S. K. Nayak, "Dynamic mechanical and thermal properties of MAPE treated jute/HDPE

composites," *Composites Science and Technology*, vol. 66, no. 3-4, pp. 538–547, 2006.

[45] T. Väisänen, O. Das, and L. Tomppo, "A review on new bio-based constituents for natural fiber-polymer composites," *Journal of Cleaner Production*, vol. 149, no. 149, pp. 582–596, 2017.

[46] K. L. Pickering, M. A. Efendy, and T. M. le, "A review of recent developments in natural fibre composites and their mechanical performance," *Composites Part A: Applied Science and Manufacturing*, vol. 83, pp. 98–112, 2016.

[47] M. M. Kabir, H. Wang, T. Aravinthan, F. Cardona, and K. T. Lau, "Effects of natural fibre surface on composite properties: a review," in *Proceedings of the 1st international postgraduate conference on engineering, designing and developing the built environment for sustainable wellbeing (EDDBE2011)*, pp. 94–99, Queensland University of Technology, 2011.

[48] D. Sedan, C. Pagnoux, A. Smith, and T. Chotard, "Mechanical properties of hemp fibre reinforced cement: influence of the fibre/matrix interaction," *Journal of the European Ceramic Society*, vol. 28, no. 1, pp. 183–192, 2008.

[49] M. S. Islam, K. L. Pickering, and N. J. Foreman, "Influence of alkali treatment on the interfacial and physico-mechanical properties of industrial hemp fibre reinforced polylactic acid composites," *Composites Part A: Applied Science and Manufacturing*, vol. 41, no. 5, pp. 596–603, 2010.

[50] M. M. Haque, M. E. Ali, M. Hasan, M. N. Islam, and H. Kim, "Chemical treatment of coir fiber reinforced polypropylene composites," *Industrial & Engineering Chemistry Research*, vol. 51, no. 10, pp. 3958–3965, 2012.

[51] C. Girisha, G. Sanjeevamurthy, and G. R. Srinivas, "Sisal/coconut coir natural fibres-epoxy composites: water absorption and mechanical properties," *International Journal of Innovative Technology*, vol. 2, pp. 166–170, 2012.

[52] S. Raghavendra, P. B. Shetty, and P. G. Mukunda, "Mechanical properties of short banana fibre reinforced natural rubber composites," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, pp. 1652–1656, 2013.

[53] V. S. Srinivasan, S. R. Boopathy, D. Sangeetha, and B. V. Ramnath, "Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite," *Materials & Design*, vol. 60, pp. 620–627, 2014.

[54] S. M. Sapuan, A. Leenie, M. Harimi, and Y. K. Beng, "Mechanical properties of woven banana fibre reinforced epoxy composites," *Materials & Design*, vol. 27, no. 8, pp. 689–693, 2006.

[55] D. Ray, B. K. Sarkar, A. K. Rana, and N. R. Bose, "Effect of alkali treated jute fibres on composite properties," *Bulletin of Materials Science*, vol. 24, no. 2, pp. 129–135, 2001.

[56] D. Ray, B. K. Sarkar, S. Das, and A. K. Rana, "Dynamic mechanical and thermal analysis of vinylester-resin-matrix composites reinforced with untreated and alkali-treated jute fibres," *Composites Science and Technology*, vol. 62, no. 7-8, pp. 911–917, 2002.

[57] Y. Seki, K. Sever, M. Sarıkanat, I. Sen, and A. Aral, "Jute/polyester composites: the effect of water aging on the inter laminar shear strength (ILSS)," *6th International Advanced Technologies Symposium*, vol. 1, pp. 368–371, 2011.

[58] M. A. Sawpan, K. L. Pickering, and A. Fernyhough, "Flexural properties of hemp fibre reinforced polylactide and unsaturated polyester composites," *Composites Part A: Applied Science and Manufacturing*, vol. 43, no. 3, pp. 519–526, 2012.

[59] Z. L. Yan, H. Wang, K. T. Lau et al., "Reinforcement of polypropylene with hemp fibres," *Composites Part B: Engineering*, vol. 46, pp. 221–226, 2013.

[60] T. Yuanjian and D. H. Isaac, "Impact and fatigue behaviour of hemp fibre composites," *Composites Science and Technology*, vol. 67, no. 15-16, pp. 3300–3307, 2007.

[61] H. N. Dhakal, Z. Y. Zhang, and M. O. Richardson, "Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites," *Composites Science and Technology*, vol. 67, no. 7-8, pp. 1674–1683, 2007.

[62] V. G. Geethamma, G. Kalprasad, and T. Sabu, "Dynamic mechanical behaviour of short coir fibre reinforced natural rubber composite," *Composites Part A: Applied Science and Manufacturing*, vol. 36, no. 11, pp. 1495–1506, 2005.

[63] L. Yan, N. Chouw, L. Huang, and B. Kasal, "Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites," *Construction and Building Materials*, vol. 112, pp. 168–182, 2016.

[64] V. Barbosa Jr., E. C. Ramires, I. A. Razera, and E. Frollini, "Bio-based composites from tannin–phenolic polymers reinforced with coir fibres," *Industrial Crops and Products*, vol. 32, pp. 305–312, 2010.

[65] S. Jayabal, S. Sathiyamurthy, K. T. Loganathan, and S. Kalyanasundaram, "Effect of soaking time and concentration of NaOH solution on mechanical properties of coir–polyester composites," *Bulletin of Materials Science*, vol. 35, no. 4, pp. 567–574, 2012.

[66] M. D. Zyaoul Haque, S. Yadav, S. Kumar, and Sandeep, "Mechanical behaviour of COIR/GLASS fibre reinforced EPOXY based composites," *International Research Journal of Engineering and Technology*, vol. 3, p. 5, 2016.

[67] N. P. Suardana, I. P. Lokantara, and J. K. Lim, "Influence of water absorption on mechanical properties of coconut coir fibre/poly-lactic acid biocomposites," *Materials Physics and Mechanics*, vol. 12, no. 2, pp. 113–125, 2011.

[68] A. Karthikeyan and K. Balamurugan, "Effect of alkali treatment and fibre length on impact behavior of coir fibre reinforced epoxy composites," *Journal of Scientific and Industrial Research*, vol. 9, pp. 627–631, 2012.

[69] J. Rout, M. Misra, S. S. Tripathy, S. K. Nayak, and A. K. Mohanty, "Novel eco-friendly biodegradable coir-polyester amide biocomposites: fabrication and properties evaluation," *Polymer Composites*, vol. 22, no. 6, pp. 770–778, 2001.

[70] N. Amir, K. A. Abidin, and F. B. Shiri, "Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite," *Procedia Engineering*, vol. 184, pp. 573–580, 2017.

[71] L. A. Pothan and S. Thomas, "Effect of hybridization and chemical modification on the water-absorption behavior of banana fiber-reinforced polyester composites," *Journal of Applied Polymer Science*, vol. 91, no. 6, pp. 3856–3865, 2004.

[72] K. Okubo, T. Fujii, and Y. Yamamoto, "Development of bamboo-based polymer composites and their mechanical properties," *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 3, pp. 377–383, 2004.

[73] H. Banga, V. K. Singh, and S. K. Choudhary, "Fabrication and study of mechanical properties of bamboo fibre reinforced bio-composites," *Innovative System Design and Engineering*, vol. 6, no. 1, pp. 84–96, 2015.

[74] S. Mohanty and S. K. Nayak, “Interfacial, dynamic mechanical, and thermal fiber reinforced behavior of MAPE treated sisal fiber reinforced HDPE composites,” *Journal of Applied Polymer Science*, vol. 102, no. 4, pp. 3306–3315, 2006.

[75] R. Heijenrath and T. Peijs, “Natural-fibre-mat-reinforced thermoplastic composites based on flax fibres and polypropylene,” *Advanced Composites Letters*, vol. 5, no. 3, article 096369359600500, 1996.

[76] E. Munoz and J. A. García-Manrique, “Water absorption behaviour and its effect on the mechanical properties of flax fibre reinforced bioepoxy composites,” *International Journal Of Polymer Science*, vol. 2015, Article ID 390275, 2015.

[77] M. Baiardo, E. Zini, and M. Scandola, “Flax fibre-polyester composites,” *Composites Part A: Applied Science and Manufacturing*, vol. 35, no. 6, pp. 703–710, 2004.

[78] I. Van de Weyenberg, T. C. Truon, B. Vangrimde, and I. Verpoest, “Improving the properties of UD flax fibre reinforced composites by applying an alkaline fibre treatment,” *Composites Part A: Applied Science and Manufacturing*, vol. 37, no. 9, pp. 1368–1376, 2006.

[79] S. K. Garkhail, R. W. Heijenrath, and T. Peijs, “Mechanical properties of natural-fibre-mat-reinforced thermoplastics based on flax fibres and polypropylene,” *Applied Composite Materials*, vol. 7, no. 5/6, pp. 351–372, 2000.

[80] B. Wang, S. Panigrahi, L. Tabil, and W. Crerar, “Pre-treatment of flax fibers for use in rotationally molded biocomposites,” *Journal of Reinforced Plastics and Composites*, vol. 26, no. 5, pp. 447–463, 2007.

[81] S. Alix, L. Lebrun, C. Morvan, and S. Marais, “Study of water behaviour of chemically treated flax fibres-based composites: a way to approach the hydric interface,” *Composites Science and Technology*, vol. 71, no. 6, pp. 893–899, 2011.

[82] U. Tayfun, *Influence of surface treatment of fillers on the mechanical properties of thermoplastic polyurethane composites, [Ph.D. thesis]*, Polymer Science and Technology, METU, 2015.

[83] V. Fiore, T. Scalici, and A. Valenza, “Effect of sodium bicarbonate treatment on mechanical properties of flax-reinforced epoxy composite materials,” *Journal of Composite Materials*, vol. 52, no. 8, pp. 1061–1072, 2018.

[84] S. Om Prakash, T. Mathavaraj Ravikumar, and M. Arulraj, “Experimental study on mechanical properties of randomly oriented natural fibre hybrid composites,” *Iranian (Iranica) Journal of Energy and Environment*, vol. 1, pp. 70–74, 2020.

[85] L. Conzatti, F. Giunco, P. Stagnaro, M. Capobianco, M. Castellano, and E. Marsano, “Polyester-based biocomposites containing wool fibres,” *Composites Part A: Applied Science and Manufacturing*, vol. 43, no. 7, pp. 1113–1119, 2012.

[86] N. K. Kim, D. Bhattacharyya, and R. Lin, “Multi-functional properties of wool fibre composites,” *Advanced Materials Research*, vol. 747, pp. 8–11, 2013.

[87] F. Bertini, M. Canetti, A. Patrucco, and M. Zoccola, “Wool keratin-polypropylene composites: properties and thermal degradation,” *Polymer Degradation and Stability*, vol. 98, no. 5, pp. 980–987, 2013.

[88] S. K. Ramamoorthy, M. Skrifvars, and A. Persson, “A review of natural fibers used in biocomposites: plant, animal and regenerated cellulose fibers,” *Polymer Reviews*, vol. 55, no. 1, pp. 107–162, 2015.

[89] A. M. Okoro, I. O. Oladele, and M. C. Khoathane, “Synthesis and characterization of the mechanical properties of high-density polyethylene-based composites reinforced with animal fibres,” *Leonardo Journal of Sciences*, vol. 29, pp. 99–112, 2016.

[90] E. J. A. EJ, C. Velasco-Santos, A. L. Martínez-Hernández, J. L. Rivera-Armenta, A. M. Mendoza-Martínez, and V. M. Castaño, “Composites from chicken feathers quill and recycled polypropylene,” *Journal of Composite Materials*, vol. 49, no. 3, pp. 275–283, 2015.

[91] R. B. Choudary, A. S. Prasad, and N. R. Bhargava, “Feather fiber reinforced polyester composites,” *Material Science Research of India*, vol. 4, no. 2, pp. 487–492, 2007.

[92] E. Jayamani, S. K. Heng, L. T. Sean, M. K. Bin Bakri, and M. Khusairy, “Mechanical properties of chicken feather reinforced unsaturated polyester composites,” *Key Engineering Materials*, vol. 775, pp. 3–6, 2018.

[93] V. Ananda Rao, A. Satapathy, and S. C. Mishra, “Polymer composites reinforced with short fibres obtained from poultry feathers,” *Proceedings of International and INCCOM-6 Conference Future Trends in Composite Materials and Processing*, vol. 1, pp. 1–12, 2007.

[94] V. Srivatsav, C. Ravishankar, M. Ramakarishna, Y. Jyothi, and T. N. Bhanuparakash, “Mechanical and thermal properties of chicken feather reinforced epoxy composite,” *AIP Conference Proceedings*, vol. 1992, no. 1, pp. 34–40, 2018.

[95] S. V. Alagarsamy, A. V. Sagayaraj, and S. Vignesh, “Investigating the mechanical behaviour of coconut coir—chicken feather reinforced hybrid composite,” *International Journal of Science, Engineering and Technology Research*, vol. 4, pp. 4215–4221, 2015.