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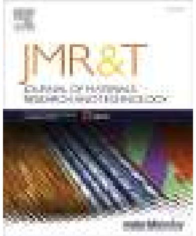

Review Article

Sugar palm (*Arenga pinnata*) fibers: new emerging natural fibre and its relevant properties, treatments and potential applications

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ABSTRACT

The key factors influencing the widespread acceptance of natural fibres as green materials are due to the quick depletion of petroleum resources and the growing awareness of environmental issues associated to the usage of conventional plastics. Due to their eco-friendly and sustainable, natural fibres have garnered the interest of scientists. Sugar palm (*Arenga pinnata*) tree is cultivated in tropical regions and is thought to hold promise as a source of natural fibres. The potential use of fibres derived from the sugar palm in a number of applications has been studied especially as composites materials. Investigations into these fibres on it potential uses have been conducted. Treatments of fibres is one of the important elements to increase the useability of this fibre. However, there is a problem regarding the inconsistent data reported by previous authors on experimental methods and the values of mechanical and physical properties. Therefore, it is now vital to organise data that would be helpful in the design of this fibre so that researchers may make wise choices regarding future study and application. Present review focuses on recent works related to properties of sugar palm fibers, fibers modification and their fabrication as green composites. The review also unveils the potential of sugar palm fibers and polymer for advanced industrial applications such as automotive, defense, packaging, and others. Many manufacturing sectors are focusing on using natural resources, particularly fiber-rich plants, for the production of polymer composites as a result of environmental protection, the use of renewable resources, and product biodegradability. This tendency has

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led to the substitution of plant fibers for synthetic fibers as reinforcement in polymer mixtures. Natural fibers are now prioritized in the composite industry due to economics and their superior properties, which have persuaded many industrial sectors to use synthetic fibers to reinforce plastics.

1. Introduction

Over the past years, synthetic fibres have been widely used in the valuable commercial products especially the composites sector. However, the unfavourable impact of synthetic fibres towards the environment and human health have led to an increase in the use of natural fibres as an alternative [1,2]. Moreover, natural fibres can lead to the production tons of agro-industrial wastes or also known as lignocellulosic biomass. This lignocellulosic biomass can be converted into several bioproducts such as bio composite, biofuels, bio sugars, bio adsorbent and more.

Natural fibres have several interesting properties such as accessibility, affordability, processability, renewability, recyclability, and biodegradability have attracted a number of material scientists [3,4]. Additionally, natural fibres showed a number of other benefits over synthetic fibres, including comparable specific tensile qualities, less health risks, acceptable insulating properties, low density, and less energy usage during processing [5,6].

According to Mukhtar et al. [7] the most common and adopted natural fibres used are flax, kenaf, hemp, jute, coir, sisal, and abaca. Meanwhile, sugar palm fibre (SPF) has been known for decades in the rural communities for its multipurpose traditional uses to make a range of meals and beverages. The SPF are utilised in a variety of traditional applications, including ropes, brooms, and roofs, among others. These fibres are utilised in their natural state, without any chemical treatments, in their traditional applications.

It has recently been exploited as a source of renewable energy in the form of bioethanol produced through the fermentation of sugar palm sap. Although the sugar palm can yield a variety of products, the three most notable are palm sugar, fruits, and fibres. Interestingly, the SPF currently gaining acceptance especially as a reinforcement in composites.

However, the major issue that limits their utilization is the complex structure as represented in Fig. 1 [8]. This is mainly due to the presence of cellulose, hemicelluloses and lignin, making a complex assembly of polymers naturally recalcitrant to any conversion [9,10]. Treatment helps to fractionate biomass prior to further processes, making it simpler to handle in the process [11]. The treatment method used is entirely dependent on the targeted application. Numerous treatment methods are mainly developed to effectively separate these interconnected components in order to get the most advantages from the natural fibres biomass's constituents. Fig. 1 also depicts the common approaches of treatments which come under the four categories of physical, chemical, physiochemical, and biological treatment [4].

Therefore, this review focuses on the emerging use of SPF in several applications. A details discussion on its properties were highlighted. Aside from that, this paper also discusses on the several treatments that usually been applied to the SPF. The application of SPF in composites were also tackled.

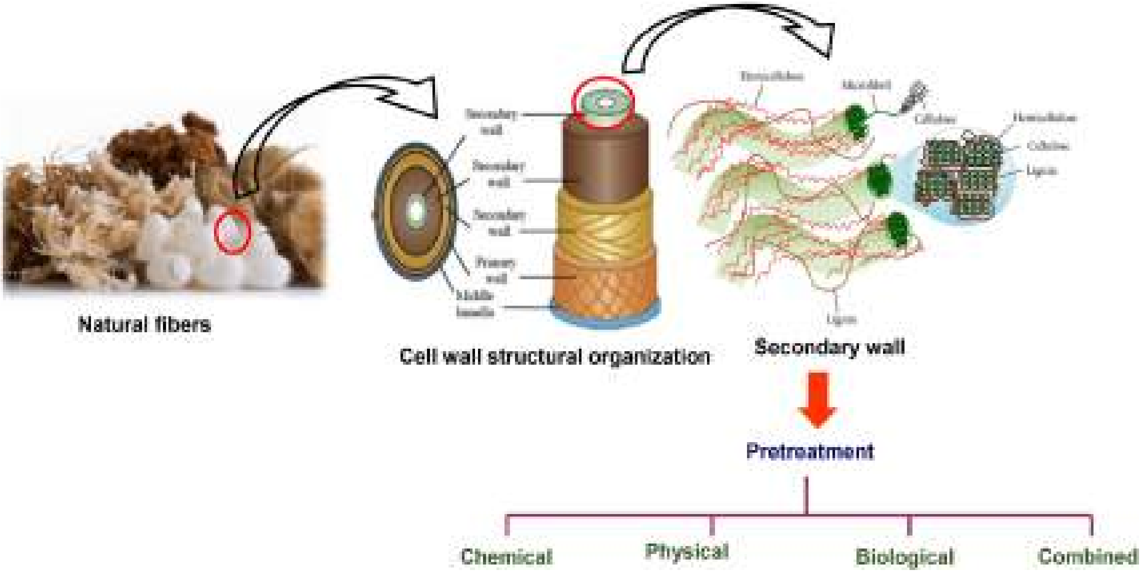

Fig. 1 – Overview of natural fibers pretreatment. Reproduced from ref. [10].

2. Natural fibres

Natural fibres are divided into three categories: plant, animal, and mineral fibres [12]. Natural plant fibres, on the other hand, are the most commonly utilised reinforcement material in composites [13,14]. Natural plant fibres are classified according to the type of plant or plant portion from which they were collected. Natural fibres are now widely used as reinforcement for a variety of applications, including composite manufacturing [15–18]. Cellulose, hemicellulose, and lignin are the primary components of natural fibre obtained from plants. In comparison to coir fibre, SPF offers greater durability, tensile strength, and moisture and heat resistance [19].

Natural fibres have some advantages over manufactured synthetic fibres like glass [20]. Table 1 shows the advantages and disadvantages of natural fibres. Natural fibres' merits frequently surpass their drawbacks. Natural fibres are low density and ease availability. It also degrades quickly and allows for easy machining with minimal tool wear. Although it has low thermal stability, compatibility, and environmental resistance, natural fibres can replace glass fibre and other synthetic fibres in outdoor applications if these particular technological issues offered by natural fibres can be handled.

Due to its superior formability, abundance, renewable, cost-effectiveness, and eco-friendliness, natural fiber composites are currently receiving a lot of study and development attention. This paper provides an overview of natural fiber composites and how they are used in a variety of industrial and engineering uses. Numerous papers about the uses of natural fiber reinforced polymer composites were included in this review. Detailing the possible uses of natural fibers, their composite materials, mechanical and physical properties, and some of their engineering applications is helpful [20].

2.1. Classification of natural fibres

Generally, natural fibres can be categorized into 2 categories such as organic fibre (plant and animal fibres) and non-organic fibre (mineral fibre), as displayed in Fig. 2. Animal fibres are made up of protein, while plant fibres are made of cellulose, hemicellulose and lignin. Meanwhile, plant fibres such as oil palm, sugarcane, kenaf, jute, pineapple, roselle, rice husk, sugar palm, and coconut husk provide the majority of natural fibres [21,22]. Non-wood fibres can be classified into several categories such as bast fibres (e.g. jute, flax, hemp, ramie, and kenaf), leaf fibres (e.g. abaca, sisal, and pineapple), seed fibres (e.g. cotton, coir, and kapok), core fibre (e.g. kenaf, hemp, and jute), grass and reed fibres (e.g. wheat, corn, and rice), grass and reed (e.g. woods and roots).

Table 1 – Advantages and disadvantages of natural fibres.

Advantages	Disadvantages
Lightweight	Low thermal stability
Biodegradability	Lack of interfacial adhesion
Ease of machinability	Quality variation
Non toxic	poor resistance to environment
Availability and low cost	poor compatibility with polymer matrix
Non-abrasive	
Less dependency on non-renewable energy	
Low pollution emission	
Energy recovery	

The SPF is a form of natural fibre derived from various parts of the sugar palm tree [23]. The SPF recovered from the tree is ready to use and can be used as reinforcement in polymer composites. SPF, being a relatively new natural fibre when compared to other natural fibres, can be found in a variety of areas, according to the classification of natural fibres. The reason for this is that the sugar palm tree's fibre might come from the bunch, fronds, or trunk [24].

2.2. Availability of SPF

The native range of sugar palm trees are in forested areas (Fig. 3) but never far for settled areas, in ravines, along streams, on slopes and areas under semi-cultivation. Sugar palm trees are seldom found in primary forests but are usually found in secondary forest near human settlements. It grows well in hot and humid climates from sea level to 1400 m elevations. Countries where the sugar palm is native are Bangladesh, Brunei, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand and Vietnam. It is one of the most diverse multipurpose tree species in culture [25]. Sugar palm trees can be found in abundance along rivers and bushes in rural parts of Malaysia [26]. For example, the sugar palm can be seen in many places as it generally grows wild. Kebun Rimau Sdn. Bhd. has planted roughly 809 ha of sugar palm plantation in Tawau (Sabah, West Malaysia), and 50 ha of sugar palm tree plantation in Benta and Pahang [26]. However, compared to other palm species like oil palm and coconut, this species has a significantly smaller plantation area.

3. Introduction to characteristic of SPF

SPF can be analysed based of few characteristics that is crucial to be taken into consideration when considering the usage of SPF in the industry. Some of the properties are physical, chemical composition, mechanical and morphological properties of SPF. As for the physical properties, it should include some information regarding the exterior measurement (diameters, length, height) and resistance or reaction towards water. Chemical composition on the other hand discusses the composition of SPF for different part of the tree. The mechanical properties discuss about the tensile strength of SPF at different parts of the trees as well as comparison with other types of fibers. The morphology properties discuss the surface topography of SPF based of the SEM analysis.

3.1. Physical properties

Sugar palm is a tall and massive palm with a single unbranched stem that can reach a height of 20 m and a diameter of 65 cm. Long black fibres and the roots of torn leaves cover the trunk. The trunk can also be used to store starch. At the

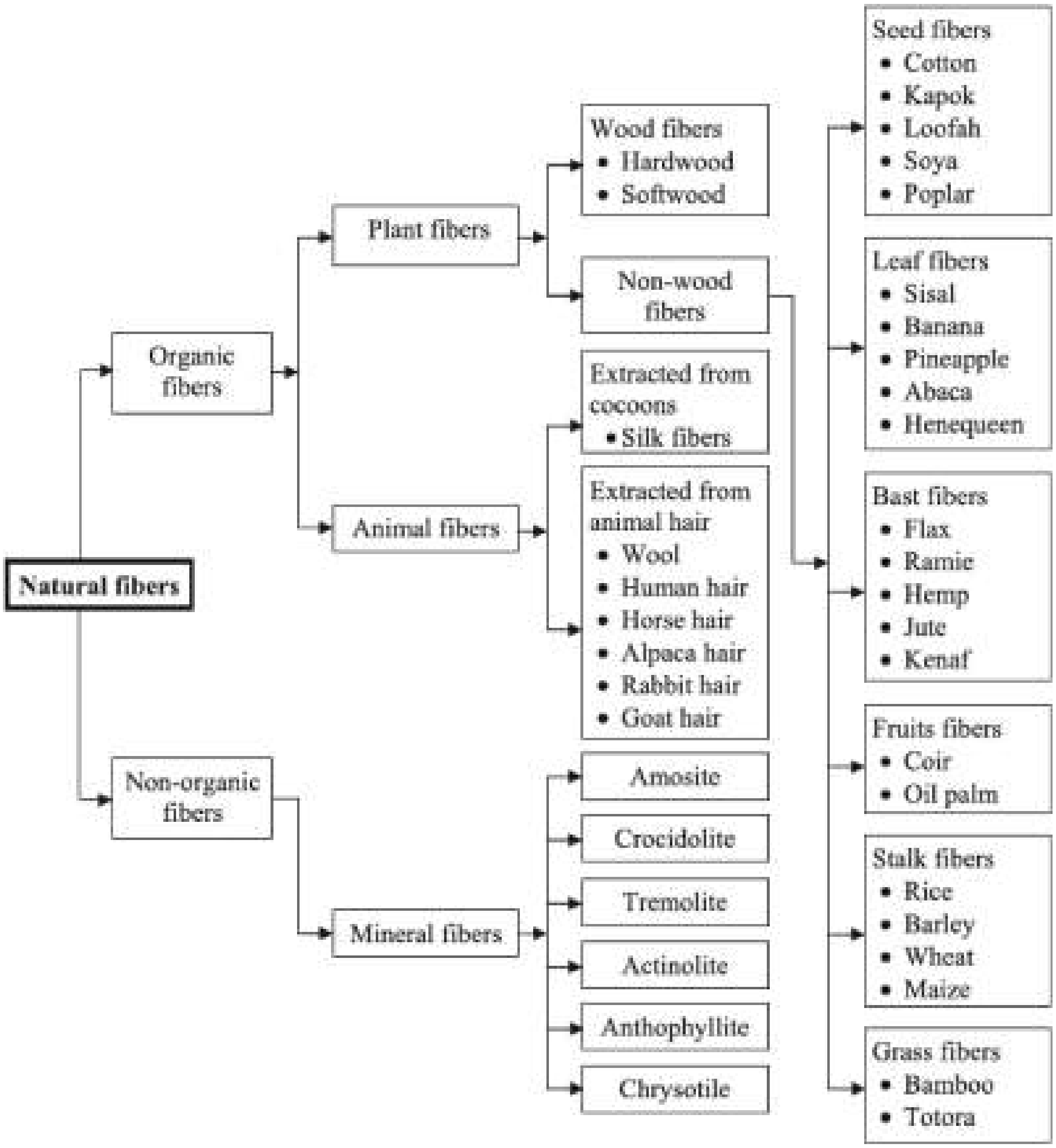

Fig. 2 – Classification of natural fibres.

Fig. 3 – Some of the geographical location of sugar palm [27].

start of flowering, the starch is normally converted to sugars for the manufacture of seeds or tapped palm juice [28]. When the tree is not producing sugar or fruits, however, the starch can be harvested and used for other reasons [29,30].

The SPF is highly robust, resistant to sea water, and easy to process because they are accessible naturally in the form of woven fibre. SPF can be extracted from 4 different parts such as SPF (ijuk), frond, bunch, and trunk (Fig. 4). Ijuk is a black/brown SPF with a variety of physical and mechanical qualities that have been documented in the literature [31]. Different methods showed different density and diameter. This is due to the recognised quality variations of natural fibres as well as the measurement equipment/procedure used. The diameter ranged from 300 to 500 m, according to Razak et al. [31].

SPF, like other natural fibres, is hydrophilic, and its smooth surface impacts its compatibility with the hydrophobic polymer matrix. Based on the literature review, it was discovered that changing the surface of the fibre with different chemicals can improve the computability between the fibre and the matrix in the composite application. The effects of the treatments on the microstructure of the fibre were usually assessed using scanning electron microscopy pictures published in the literature [32].

The sugar palm tree is widely distributed in Malaysia along the rural areas of Bruas-Parit (Perak), Raub (Pahang), Jasin (Melaka), and Kuala Pilah, according to a report from the Forest Research Institute Malaysia (FRIM) (Negeri Sembilan). About 809 ha of sugar palm trees are grown there [22].

3.2. *Chemical composition*

Chemical compositions varies significantly between plants and various parts of the same plant, as displayed in Table 2. SPF chemical composition varies depending on the type and nature of the fibre [33]. Cellulose and hemicellulose are the primary components of all cell walls [34]. The qualities of each composition influence the properties of each fibre. The chemical compositions of plants and various parts of the same plant differ greatly. Waxes make up the majority of SPFs, with cellulose (-cellulose), lignin, pectin, and hemicellulose acting as a compatibilizer between lignin and cellulose [35]. The highest percentage of cellulose is found in the frond, while ijuk fibre includes over 90% of the total fibres found in the sugar palm tree. In addition, the chemical contents of the fibres vary depending on the height of the sugar palm tree. Table 3 list the compositions of SPFs based of different height of tree. Sugar palm trees' cellulose, hemicellulose, and lignin content increased as their height climbed, according to Ishak et al. [36]. However, when the tree grew older, their contents decreased, which was associated to the fibre maturity stage.

3.3. *Mechanical properties*

The mechanical properties of natural fibre and synthetic fibres are display in Table 4. From the table, it can observed that tensile strength of natural fibre are 3 times lowered compared to synthetic fibre of E-glass and S-glass. However in term of tensile modulus, flax, hemp and pineapple fibres are comparable to synthetic fibres. Table 4 lists some of the most important characteristics of SPF, such as the mechanical properties of different portions of SPF. When compared to synthetic fibres such as glass fibres, SPF provide the composites with strength and stiffness while also avoiding fibre fractures [55]. Sahari et al. [56] investigated the tensile characteristics of SPF in the frond, bunch, ijuk, and trunk of a sugar palm tree. They discovered that frond fibre has the highest tensile strength and modulus, followed by bunch, ijuk, and trunk.

Fig. 4 – Sugar palm tree [19].

Table 2 – Chemical composition of agro-waste fibres and forest by-products from different plant and different part.

Fibres	Holocellulose (wt%)		Lignin (wt%)	Ash (wt%)	Extractives (wt%)	Crystallinity (%)	Ref.
	Cellulose (wt%)	Hemicellulose (wt%)					
SPF (ijuk)	43.88	7.24	33.24	1.01	2.73	55.8	[37]
Sugar palm frond	66.49	14.73	18.89	3.05	2.46	–	[2]
Sugar palm bunch	61.76	10.02	23.48	3.38	2.24	–	[2]
Sugar palm trunk	40.56	21.46	46.44	2.38	6.30	–	[2]
Wheat straw fibre	43.2 ± 0.15	34.1 ± 1.2	22.0 ± 3.1	–	–	57.5	[38]
Soy hull fibre	56.4 ± 0.92	12.5 ± 0.72	18.0 ± 2.5	–	–	59.8	[38]
Arecanut husk fibre	34.18	20.83	31.60	2.34	–	37	[39]
Helicteres isora plant	71 ± 2.6	3.1 ± 0.5	21 ± 0.9	–	–	38	[40]
Pineapple leaf fibre	81.27 ± 2.45	12.31 ± 1.35	3.46 ± 0.58	–	–	35.97	[41]
Ramie fibre	69.83	9.63	3.98	–	–	55.48	[42]
Oil palm mesocarp fibre (OPMF)	28.2 ± 0.8	32.7 ± 4.8	32.4 ± 4.0	–	6.5 ± 0.1	34.3	[43]
Oil palm empty fruit bunch (OPEFB)	37.1 ± 4.4	39.9 ± 0.75	18.6 ± 1.3	–	3.1 ± 3.4	45.0	[43]
Oil palm frond (OPF)	45.0 ± 0.6	32.0 ± 1.4	16.9 ± 0.4	–	2.3 ± 1.0	54.5	[43]
Oil palm empty fruit bunch (OPEFB) fibre	40 ±2	23 ±2	21 ± 1	–	2.0 ± 0.2	40	[44]
Rubber wood	45 ±3	20 ±2	29 ± 2	–	2.5 ± 0.5	46	[44]
Curauna fibre	70.2 ± 0.7	18.3 ± 0.8	9.3 ± 0.9	–	–	64	[45]
Banana fibre	7.5	74.9	7.9	0.01	9.6	15.0	[46]
Sugarcane bagasse	43.6	27.7	27.7	–	–	76	[47]
Kenaf bast	63.5 ± 0.5	17.6 ±1.4	12.7 ± 1.5	2.2 ± 0.8	4.0 ±1.0	48.2	[48]
Phoenix dactylifera palm leaflet	33.5	26.0	27.0	6.5	–	50	[49]
Phoenix dactylifera palm rachis	44.0	28.0	14.0	2.5	–	55	[49]
Kenaf core powder	80.26	23.58	–	–	–	48.1	[50]
Water hyacinth fibre	42.8	20.6	4.1	–	–	59.56	[51]
Wheat straw	43.2 ± 0.15	34.1 ± 1.2	22.0 ± 3.1	–	–	57.5	[52]
Sugar beet fibre	44.95 ± 0.09	25.40 ± 2.06	11.23 ± 1.66	17.67 ± 1.54	–	35.67	[53]
Mengkuang leaves	37.3 ± 0.6	34.4 ± 0.2	24 ± 0.8		2.5 ± 0.02	55.1	[54]

3.4. *Morphological properties*

The surface morphology of oil palm and coir fibre may be seen in great detail in the scanning electron microscopy (SEM) image of SPF [57]. Along the fibre's length, parallel lines can be seen, and the surface of the fibre shows visible pore-like patches that are almost uniformly spaced. Fig. 5a makes it very evident that the SPF's exterior surface is covered in wax, contaminants, and some nodes. As shown in Fig. 5, the surface topography of the rod-like SPFs was rough, and the spots that emerged were equally spaced holes [57,58]. Tyloses are the visible spots that cover the pit on the cell wall and are found on the surface of the fibres. The pore patches are thought to be tyloses, similar to how coir's parallel lines are thought to be microfibrils [26]. The SPF surface's porous features greatly aid in the mechanical interlocking of matrix resin during composite production [59]. However, the pores also allow for facile capillary action-mediated water infiltration into the fibre, especially when exposed to an aquatic environment [60].

3.5. *Thermal stability*

Natural fiber-reinforced composites' thermal characteristics are a significant barrier to their use. The main characteristics of the composite alter as a result of the degradation of the fiber components like cellulose, hemicellulose, and lignin at higher temperatures. Since many years ago, researchers have been examining the suitability of natural fibers with polymers and high temperature stability.

Just as the hemicellulose has finished degrading, the cellulose began to break down. Compared to amorphous hemicellulose, cellulose contains more crystalline strands that take a lot of energy to break down. It was discovered that the

Table 3 – The chemical compositions of SPFs obtained from different heights of tree [24].

Composition	Height (m)							
	1	2	3	5	7	9	11	13
Cellulose (%)	37.3	49.4	55.3	56.6	56.8	55.8	54.4	53.4
Hemicellulose (%)	4.7	6.1	7.4	7.7	7.9	7.9	7.9	7.5
Lignin (%)	17.9	18.9	20.9	20.5	23.6	23	24.3	24.9
Moisture (%)	5.36	8.64	7.92	8.37	8.19	7.72	8.12	8.7
Extractive (%)	2.49	2.02	1.71	1.41	1.35	1.48	1.21	0.85
Ash (%)	30.9	14	5.8	4.2	2.1	4.1	4	4.3

Table 4 – Natural and synthetic fibre mechanical properties [2,56].

Fibre	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)
Sugar palm (frond)	421.4	10.4	9.8
Sugar palm bunch	365.1	8.6	12.5
Sugar palm trunk	198.3	3.1	29.7
SPF (Ijuk)	276.6	5.9	22.3
Abaca	980	–	–
Bagasse	20–290	19.7–27.1	1.1
Banana	355	33.8	5.3
Coie	220	6	15–25
Cotton	400	12	3–10
Flax	800–1500	60–80	1.2–1.6
Hemp	550–900	70	1.6
Henequen	430–580	–	3–4.7
Jute	400–800	10–30	1.8
Kenaf (bast)	295	–	2.7–6.9
Oil palm (Empty fruit bunch)	248	3.2	2.5
Pineapple	170–1627	82	1–3
Ramie	500	44	2
Sisal	600–700	38	2–3
Sugar palm (frond)	421.4	10.4	9.8
E-glass	2000–3500	70	2.5
S-glass	4570	86	2.8

temperature range between which cellulose degraded was 309 and 650 C. The peaks at 348.16 C (untreated) correlates to 45.03 weight loss. The fiber in this instance is also discovered to degrade over a broader temperature range, from 174.9 to 645.5 C, which may have included the degradation of hemicellulose and lignin. This pattern might result from the existence of Si on the SPF's outer layer.

4. Treatments of SPF

As discussed above, treatment of natural fibres is really important in order to overcome several conversion limitations. Natural fibre reinforcements have some drawbacks, such as poor fibre-matrix bonding qualities and a tendency for natural fibres to absorb a lot of water [61]. Natural fibre-based composites' mechanical and thermal properties can be affected by these treatments. To fulfil the desired criteria, these qualities can be increased by applying various fibre treatments or adding additives to the polymer.

4.1. *Alkali treatment*

Mercerization, also known as alkali treatment, is the process of exposing natural fibre to a fairly concentrated strong base solution (aqueous NaOH or KOH solution) (Fig. 6), which depends on the type and concentration of solution, temperature and time of treatment, as well as material tension to produce great swelling with subsequent changes in the fine structure, morphology, dimensions, and mechanical properties; ASTM:D1695-07 [62]. After being treated with alkaline, the SPF surface became clean, as depicted in Fig. 6c.

Alkali treatment resulted in chemical modifications and surface enhancements (Fig. 6b). According to the TGA and FTIR tests, it eliminated some of the fibre's hemicellulose and lignin [63]. Alkali treatment is a useful approach for improving fibre-matrix bonding. As a result, the composite's behaviour could be improved [24,64]. Natural fibres' hydrophilic qualities lower the bonding strength between fibres and matrices, as well as their mechanical properties [4]. The alkaline solution reacts with the fibre's hydroxyl groups, making it more hydrophilic and resulting in positive fibre-matrix interaction [24].

Alkaline therapy also causes fibre fibrillation, or the splitting of fibre bundles into fibres [65]. As a result, the effective surface area of the fibres in contact with the matrix expands. According to reports, alkaline treatment with NaOH has four impacts on the fibre: (1) it expands the potential reaction sites by exposing the cellulose fibre's surface (2) It improves mechanical reinforcement by increasing surface roughness; (3) It increases the percentage crystallinity index of alkali-treated fibres and improves mechanical behaviour; (4) It decreases spiral angle, bringing it closer to the fibre axis, and it improves molecular orientation [66].

Natural fibers treated with alkali show more of their cellulose substance on the surface, while lignin and hemicellulose are removed along with impurities like wax and oils [49]. The crystalline characteristics are also impacted by alkali treatment, which transforms cellulose I into cellulose II [57].

4.2. *Silane treatment*

The silane treatment was able to separate the lignin and hemicellulose of the SPF. The silane treatment boosted the degree of crosslinking and increased the active bonding surface area of SPF (Fig. 7), which will be advantageous in its capacity as a reinforcement [67]. In compared to alkaline treatment, this treatment may lower the quantity of cellulose hydroxyl groups in SPF to a greater extent, according to the study.

In the silane treatment, a methanol–water solution containing 2% silane was created, as reported in a recent work on the silane treatment of SPFs [68]. Using acetic acid to maintain a pH of 3.5, the solution was agitated continuously for 10 min. The SPF were then immersed in the solution and agitated for 3 h.

Zahari et al. [69] treated the SPF with silane and looked at how it affected the mechanical and water absorption capabilities of SPF reinforced composites [69]. The solution was made with a 98 percent concentration of Vinyltrimethoxy silane that was diluted in distilled water with a ratio of 0.003l chemical to 0.997l distilled water. After soaking for 15 min, the fibres were dried for 2 h. The fracture locations of treated fibre reinforced composites had narrower gaps [32]. Because the silane chemical was able to separate the lignin and hemicellulose segment of the SPF fibres, SPF fibers treated with 2% silane have improved physical and mechanical qualities. As an alkaline treatment, silane coupling agents may lessen the quantity of cellulose hydroxyl groups at the SPF–TPU matrix interface. Water causes silane to decompose into silanol and

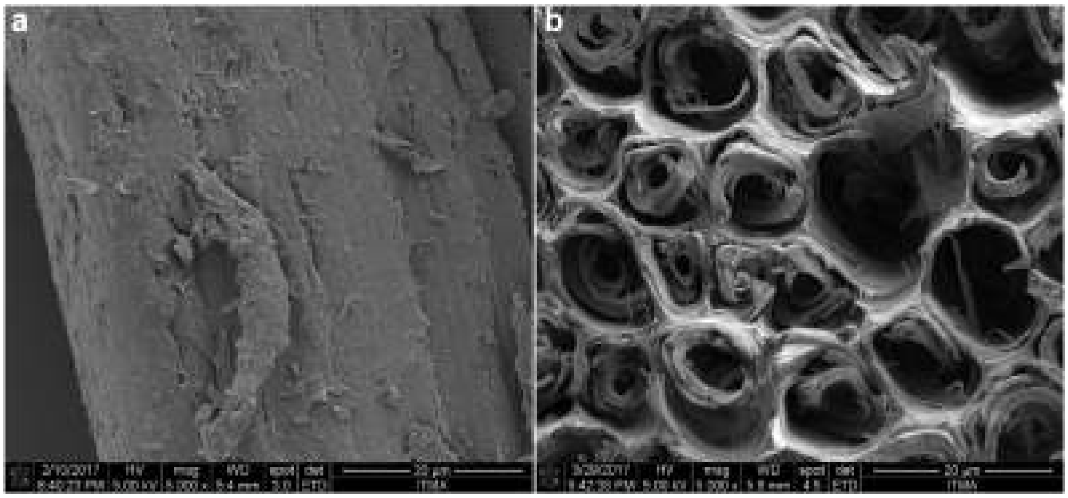

Fig. 5 – Image of a) parallel-section, and b) cross-section of single SPFs using SEM [57].

alcohol. Silanols are formed when an alkoxy group is hydrolyzable in the presence of moisture [70]. The OH groups of the cellulose in natural fibres then undergo a reaction with the silanol to create stable covalent connections with the cell walls, which are chemisorbed onto the fibre surface [71].

Silane treatment increases the fibre surface area and raises the degree of cross-linking in the interface region, enabling a stronger interaction between the fibre and matrix [72]. As a result of the covalent interaction between the TPU matrix and the SPF, the hydrocarbon chains offered by the silane treatment prevent the swelling of the SPF [73].

4.3. *Seawater treatment*

SPFs are commonly utilised in applications that require long-term exposure to seawater [2]. Seawater, which is biologically available, inexpensive, and abundant, was used to treat the fiber [74]. This highlighted the seawater treatment's potential utility. Following that, a study was carried out to see how seawater treatment affected the SPF [74]. Prior to conducting the tests, the fibres were soaked in seawater for 30 days. The authors concluded that removing the outer layer of hemicellulose and pectin from the SPFs improved the surface properties and improved the fibre's reinforcing power after a 30-day seawater immersion. This assists in the removal of the outer layer of hemicellulose and pectin. Although this layer protects the fibre from the weather and heat, it is only tenuously attached to the second layer, which is made up of lignin and crystal celluloses [74]. These components' removal is comparable to alkaline treatment in that it causes fibrillations. The SPF surface became clean after sea water treatment, as shown in Fig. 8. Similar Several studies have been conducted on surface modification and its impact on composite behaviour [32,75,76].

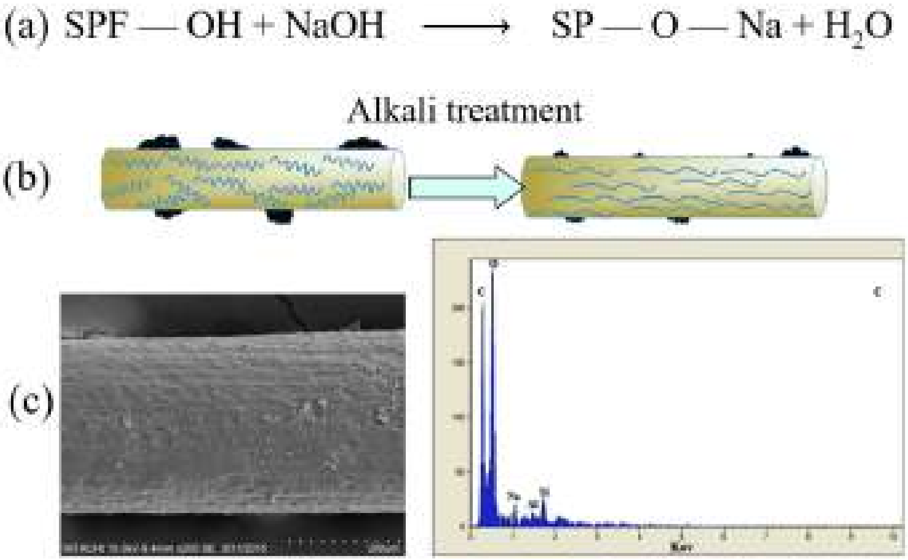

Fig. 6 – a) The reaction between the NF and the NaOH, b) Image of natural fibre undergoing alkali treatment, and c) SEM and EDX images of the alkali treated SPF [62].

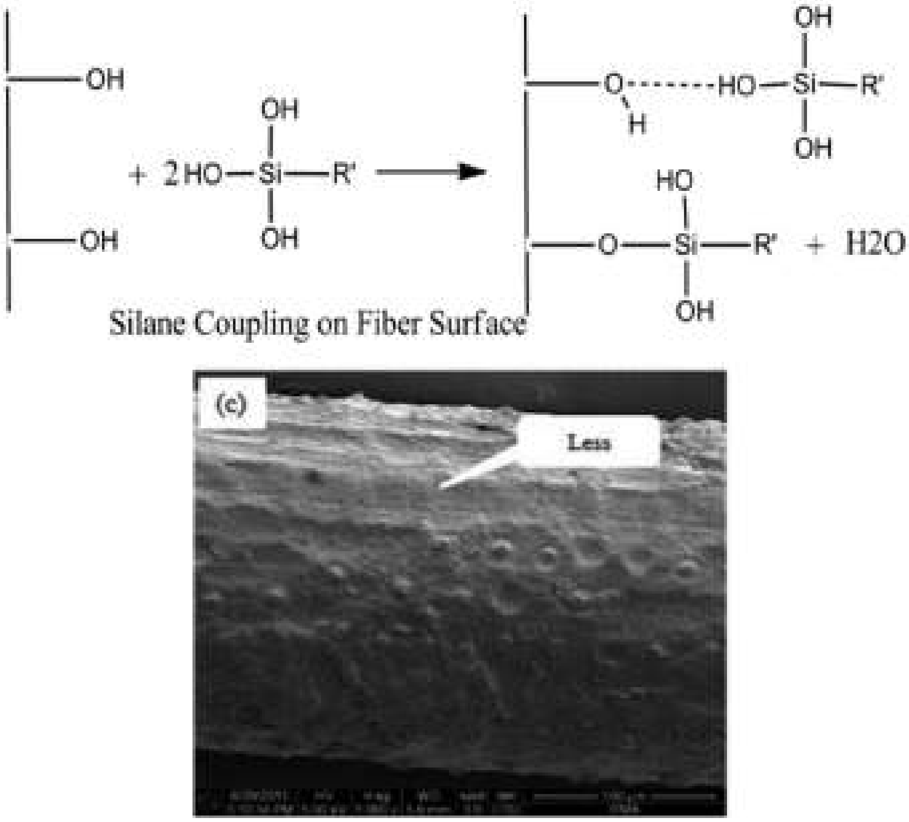

Fig. 7 – **Natural fiber reaction during silane treatment [32].**

4.4. *Benzoylation treatment*

Benzoylation treatment is performed using benzoyl chloride (Fig. 9). The procedure begins with a preparation that includes cleaning and drying steps over a number of days, followed by the usage of 18% NaOH solution on the fiber for 30 min. The treated fiber was then thoroughly stirred with 50 ml of benzoyl chloride for 15 min while suspended in a 10% NaOH solution. The fiber was then taken out and cleaned with distilled water [77]. A study using benzoyl chloride-treated SPF-reinforced epoxy biocomposites has revealed the mechanisms that improve the interfacial adhesion of sugar palm-epoxy biocomposites [78]. In conclusion, chemical lignocellulosic fiber treatment significantly improves the tensile strength and modulus of biocomposites made of sugar palm and epoxy fibers [78].

4.5. *Ionic liquid treatment*

At room temperature, ionic liquids (ILs) are a family of chemical configurations that contain both an anion and a cation. It is possible to change the ions' physical state and chemical characteristics, and numerous combinations have been developed and studied. There are several different kinds of cations, including guanidinium, quaternary ammonium, pyridinium, pyrrolidinium, piperidinium, morpholinium, and methylimidazolium (MIM). In addition to halogens (Br, Cl), bis (trifluoromethyl)sulfonylamide (NTf2), tetrafluororoborate (BF4), hexafluorophosphate (PF6), dicyanamide (DCA), acesulfame (ACS), and saccharin (SAC), they can also be found in mixes with these substances. As reaction media, thermal fluids, lubricants, plasticizers, dispersants, and surfactants as well as antibacterial, anticorrosion, and electropolishing agents, ionic liquids have been employed in a variety of applications. As reaction media, thermal fluids, lubricants, plasticizers, dispersants, and surfactants as well as antibacterial, anticorrosion, and electropolishing agents, ionic liquids have been employed in a variety of applications [80].

A research had been done on a ramie fibre with the usage of ILs which was studied by [81]. Several treatment techniques were developed to enhance the surface quality and rigidity of ramie fibre or other similar fibre-based fabrics in order to increase the wearability of textiles. Recently, some studies have claimed that applying chemical or enzymatic treatments to ramie (or other bast fibre) fabrics significantly improved the softness of the fabrics [82]. However, compared to ILs treatment, the strength of the cloth significantly diminished following chemical/enzymatic treatment, and extensive time and specialized microbiology procedures were needed [83].

Additionally, lubricating the fibres is yet another successful method for enhancing the softness of ramie fabric. The softness of ramie cloth could be significantly increased by adding polyurethane. However, a negative side effect was a reduction in moisture absorbance, which made the material less comfortable [84]. Finding a way to reduce the fineness/rigidity of ramie fibre while maintaining a reasonable level of strength is therefore imperative. ILs have recently been used to treat ramie fibre for softening purposes because it is an efficient

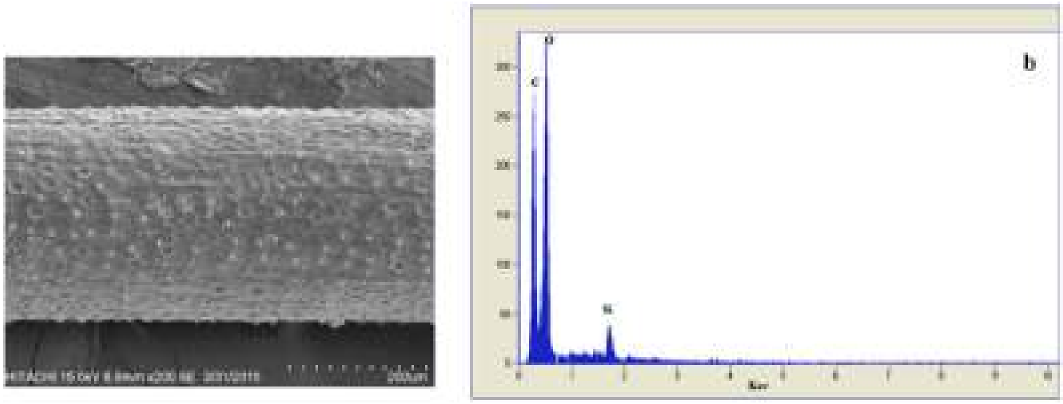

Fig. 8 – SEM and EDX images of the sea water treated SPF [74].

solvent that may dissolve the cellulose [85]. ILs are a “green solvent,” meaning it is environmentally benign and readily recyclable [85]. However, the pure ILs can dissolve cellulose very fast, leading to the modification of the ramie fibre with poor controllability. In this study, ILs mixed with water of different ratios were attempted to treat degummed ramie fibres. The fibre properties including fineness, strength, and other related indexes were also measured to find a better way to soft ramie fibre for the high wearable property.

4.6. *Acid hydrolysis treatment*

Amorphous region can be removed using the well-known technique known as acid hydrolysis. Sumaiyah et al. [86], Fahma et al. [87], and Ilyas et al. [88] published studies where SPF was used to find and isolate nanocrystalline cellulose from sugar palm bunches. Sumaiyah and associates also [86] Nanocellulose crystals (NCCs) were created by hydrolyzing sugar palm bunch (SPB) cellulose with strong sulfuric acid (54%).

The NCCs' TEM image demonstrated their spherical shape and nanosize dimensions, which had a diameter of 15–20 nm. Functional group analysis revealed that sulfuric acid had no impact on the cellulose's functional group; it merely eliminated the chain. The FTIR analysis also reveals the presence of OH groups, alkane CH, OH from water absorption, and CO (glycosidic bond) between glucose units in cellulose. The initial mass loss occurred at a temperature of 173 °C with a residual mass of 11.25%, according to the thermal gravimetric analysis (TGA), whereas the structure and degree of crystallinity of the NCCs of SPB are 97.57%. The NCCs degrade at low temperatures because the cellulose has sulphate groups on it. The larger NCCs also resulted in a greater number of free chain ends, which broke down at a lower temperature and produced more char in this NCCs sample. Based on Ilyas et al. [88] this was explained by the hydrolysis treatment on SPC that eliminated the amorphous area. The picture of the sugar palm nanocellulose solution is shown in Fig. 10d. The hydrolysis process went on for SPNCCs-30 (Fig. 10a), SPNCCs-45 (Fig. 10b), and SPNCCs-60 (Fig. 10c) for 30, 45, and 60 min, respectively. This showed changes in the SPNCCs' sizes, which were decreased by 31 and 42%, respectively, compared to SPNCCs-30. This resulted from the hydrolysis process utilized to remove the amorphous region from the nanofibers' prolonged reaction time with H_2SO4.

Additionally, Table 5 shows the physical properties of SPNCCs-30, SPNCCs-45 and SPNCCs-60. A prolonged hydrolysis period may aggravate the length and diameter of SPNCCs. Therefore, the length and diameter of the nanofibers decrease with increasing hydrolysis reaction durations. Additionally, the AFM phase image (Fig. 10e) showed that the peak nanofibers height was 5.781 nm, which is equivalent to the average nanofibers diameter (10.7 2.34 nm) as obtained from the AFM images [88].

On the other hand, Fahma et al. [87], NCCs were created by acid hydrolysis of SPFs' -cellulose using a sulphuric acid solution (64 wt.%) while vigorously stirring the mixture at 45 °C for 90 min. According to the TEM examination image of NCCs in Fig. 11, the un-neutralized and neutralized NCCs of SPF had diameters of 2.3 0.9 nm and 2.4 0.8 nm, respectively, and their nanosize dimensions were not significantly different. This was caused by the addition of only a modest amount of NaOH,

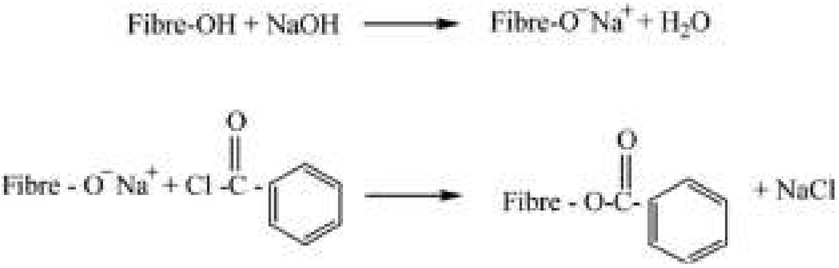

Fig. 9 – Image of natural fiber reaction during benzoylation treatment [79].

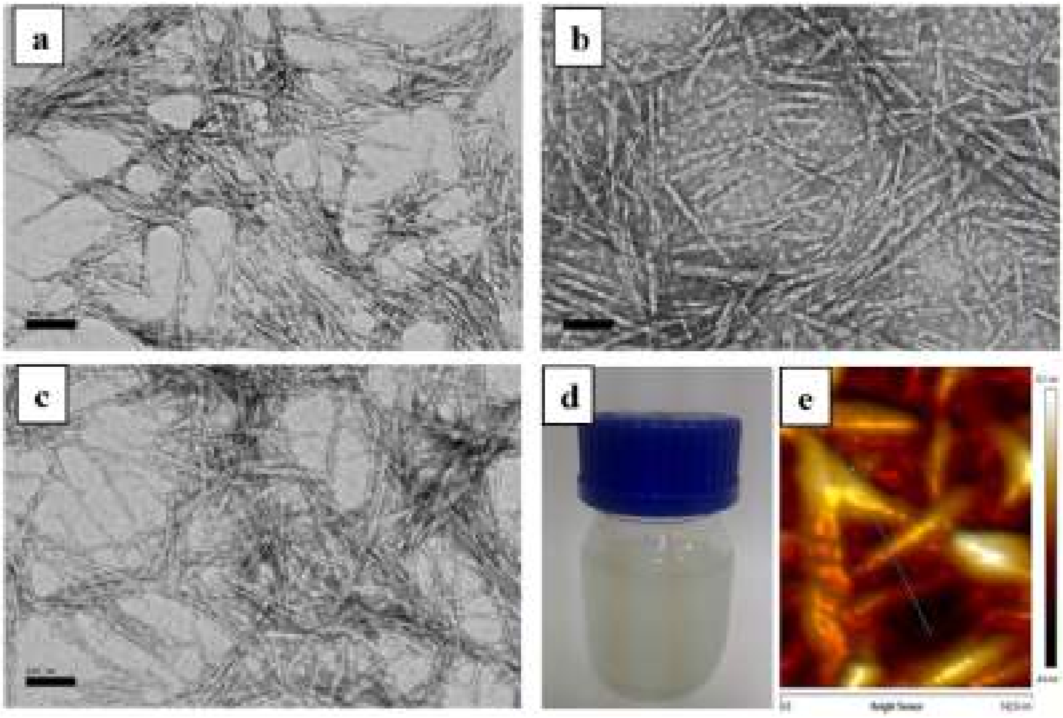

Fig. 10 – TEM micrographs of the (a) SPNCCs-30, (b) SPNCCs-45, (c) SPNCCs-60, (d) Aqueous suspension (2 wt%) of SPNCCs and (e) AFM image of SPNCCs-45 [37,89].

which had no impact on the shape of NCCs. The NCCs are predominantly in the form of individual nanofibrils, which is another indication from the AFM image that the H_2SO4 hydrolysis treatment was successful in producing NCCs.

The crystalline structure of the samples was ascertained using the XRD analysis. The fact that both unneutralized and neutralized NCCs exhibited the same typical cellulose I crystal structure shows that adding NaOH to NCCs until the pH becomes neutral did not alter their structural characteristics. However, for untreated NCC, the degree of crystallinity and crystallite size of cellulose fell from 54.84% to 54.56% and 3.12 nm–2.57 nm, respectively, after sulfuric acid hydrolysis. This is a result of the severe sulphuric acid treatment, which destroyed both crystalline and amorphous areas.

Additionally, they noted that the unneutralized NCCs sample underwent two distinct pyrolysis processes, the first of which began to break down the material at a temperature of 150–280 °C and the second of which occurred at a temperature of 300–500 °C, both of which were earlier than what happened to the unneutralized NCCs and cellulose. The first degradation process might be caused by the acid sulphate group attaching to the NCCs, while the second degradation process could be caused by the NCCs themselves if they are not linked to the acid sulphate group. It may be deduced from the fact that the neutralized NCCs only underwent one pyrolysis process at a degradation temperature of 300 °C that the attachment of acid sulphate groups to NCCs resulted in a marked decline in thermal stability. The similarity between the chemical compositions of un-neutralized and neutralized NCCs was further confirmed by the examination of FTIR spectra.

5. Application of SPF in composites

Composite materials are made up of two or more easily distinct elements that are combined to improve the individual element's qualities [81,90]. Newly created materials may be preferred for a variety of reasons, including the fact that they are stronger, lighter, and less expensive than existing materials [91]. Constituents are the individual ingredients that make up composites in general. Most composites have two basic materials: reinforcement and matrix; however, composites can include more than two components, such as fillers, compatibilizers, coupling agents, pigments, lubricants, surfactants, and solvents. Only the most basic textile-based composites, also known as textolites, include two components: a polymer matrix and reinforcement in the form of natural, synthetic, or hybrid fibres or fabrics. The reinforcement is substantially stiffer and stronger than the matrix, which contributes to the superior properties of the composites [92]. In textile-based composites, the polymer matrix's primary roles are to bind reinforcements (fabric, fibres, or nanofibers) and maintain the composite's integrity.

The transition to more environmentally friendly fibers is a measure to save costs and safeguard the environment. The “cradle to cradle” notion of consumer items is substituted with the “cradle to grave” concept through the use of renewable fibers. The life cycle of SPF based composite materials, which represent the “cradle to cradle” idea, is shown in Fig. 12. At the end of their useful lives, these SPF reinforced composites naturally decompose into water and carbon dioxide

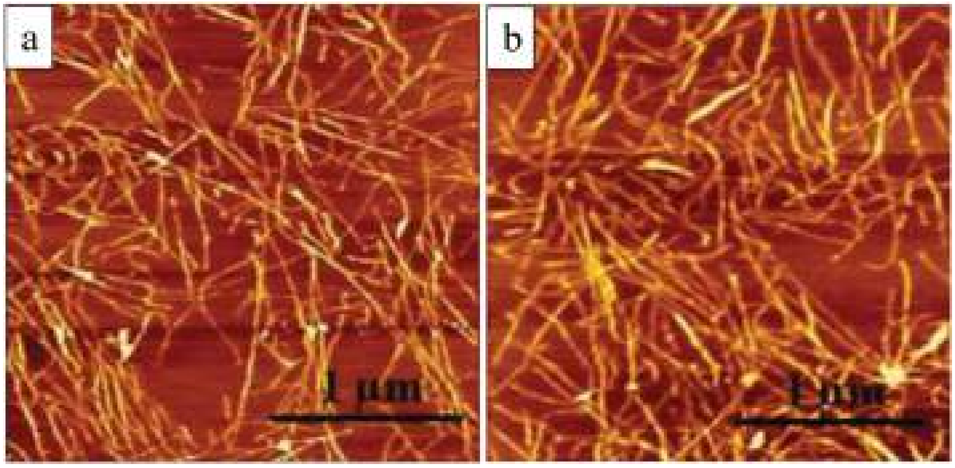

Fig. 11 – AFM images of un-neutralized (a) and neutralized (b) nanocrystalline cellulose of SPF [87].

(CO_2). Their synthetic fiber substitutes are not sustainable and do not decompose, which inevitably results in nefarious solid waste disposal issues [81].

Choosing the right matrix has advantages in terms of cost, performance, and fibre compatibility. The resins are classified as thermoset, thermoplastic, or bio-based polymer [19]. Recent research has focused on natural fibres reinforcing polymer composites, as many studies have indicated that polymeric matrices are the most commonly employed in the industry. The fundamental role of the polymer matrix in fibre reinforced composites, according to [93], is to transfer stress between the fibres while simultaneously protecting the fibres' surface from any mechanical damage. The matrix has been identified as a crucial element in achieving good mechanical properties such as tensile and flexural modulus [94].

The SPF have been studied extensively as a polymer composite reinforcing material. Bachtiar et al. [95] study of the effect of alkaline treatment on the flexural properties of SPF reinforced epoxy composites. The fibres were treated using sodium hydroxide (NaOH) with 0.25 M and 0.5 M concentration solution for 1 h, 4 h and 8 h soaking time. The purpose of treating fibres with alkali was to enhance the interfacial bonding between matrix and fibre surfaces. The maximum flexural strength occurred at 0.25 M NaOH solution with 1 h of soaking time, i. e 96.71 MPa, improving by 24.41% from untreated fibre composite. But, the maximum flexural modulus took place at 0.5 M NaOH solution with 4 h soaking time, i.e. 6948 MPa, improving by 148% from untreated composite.

Rashid et al. [96] prepared SPF composites made phenolic resin. The SPF was subjected to either a 30-day treatment in sea water or a 4-h treatment in a 0.5% alkaline solution. The composite samples were created using a hot press machine, and the composites contained 30% (vol.) SPF in powdered form. On the mechanical (flexural, impact, and compressive), thermal, and morphological properties of the composites, the effects of the fiber treatments were examined. Compared to the untreated composite, the SPF treatments significantly enhanced the composites' mechanical qualities. The flexural and impact strength of the composites were increased the greatest by the alkaline treatment. The compressive strength was improved the most by the sea water treatment, though. Morphological investigations showed that the surface treatments enhanced the connection between the fibers and the matrix. The thermal stability of the composites was only marginally impacted by the alkaline and sea water treatments of the SPF, according to the thermal degradation investigation. As a result, SPF works well as a substitute natural fiber for strengthening bio-composites [96]. Table 6 summarized other studies on SPF reinforced polymer composites.

Table 5 – Physical properties of SPNCCs-30, SPNCCs-45 and SPNCCs-60 [37].

Fibres	Length (nm)	Diameter (nm)
Sugar Palm Cellulose (SPC)	–	11870
SPNCCs-30	175± 37.01	13±1.73
SPNCCs-45	130 ± 30.23	9± 1.96
SPNCCs-60	110± 33.69	7.5±1.35

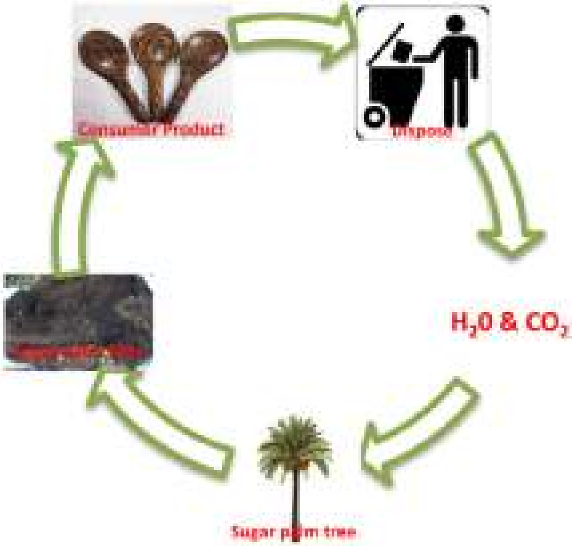

Fig. 12 – The life-cycle of SPF composite materials [81].

Table 6 – SPF reinforced polymer composites.

Matrix	Treatment	Process	Findings	Ref.
Thermo-set	Alkali treament	Hand lay-up	Tensile strength = 41.88 MPa, Tensile modulus = 3780 GPa	[95]
Phenolic	Alkali treatment	Hot press	Tensile strength = 32.5 MPa, Tensile modulus = 0.263 GPa	[97]
Polypropylene	Silane treatment	Mixing brabender	Tensile strength = 23 MPa, Tensile modulus = 1096 GPa	[98]
Polypropylene	Silane treatment	Mixing brabender	Tensile strength = 173.44 MPa, Tensile modulus = 10.07 GPa	[73]
Unsaturated polyester	Alkali treatment	Sheet molding	Thermal degration properties (1st phase = 80 to 130c), (2nd phase = 250c), (3rd phase = 250 to 370c), (4th phase = 360 to 400)	[99]
Epoxy	Thermo-set	Hand lay-up	Tensile strength = 22.7 MPa, Tensile modulus = 3.62 GPa	[79]
Thermoplastic polyurethane	Alkali treatment (6wt% NaOH)	Hot press	Thermal degration properties (1st phase = 146nc), (4th phase = 480 c)	[100]
Unsaturated polyester	seawater	Hand lay-up	Tensile strength = 18.33 MPa, Tensile modulus = 4.374 GPa	[101]
Polyurethane	Combine	Extruding	Tensile strength = 18.42 MPa, Tensile modulus = 1.307 GPa	[102]
Polyurethane	Combine	Mixing brabender	Tensile strength = 142.09 MPa, Tensile modulus = 7.75 GPa	[73]

Besides that, the introduction of hybrid composites, which contain two or more fibres in one matrix, is considered as a way to improve the properties of natural fiber-reinforced polymer composites. Combining one natural fibre with another natural fiber/synthetic fibre in one matrix improves the thermal and mechanical properties of the composite [97]. This has demonstrated that hybrid composites are more reliable in a variety of applications and are also more environmentally friendly. Natural–natural fibres, natural–synthetic fibres, natural fibre with carbonaceous materials, and natural fibre with metal can all be used to hybridise natural fiber-based reinforced polymer composites [98].

Safri et al. [78] determined how adding glass fiber and benzoylating SPF composites affect their dynamic mechanical, impact, and post-impact properties. The hybrid composites were created by hand-laying up various volume fractions of glass fiber and SPF. In comparison to EP/UTSPF composites, EP/30TSPF/70 GF composites had the largest loss and storage modulus, according to the results of dynamic mechanical analysis (DMA). The experimental findings for the low-velocity impact tests indicate that the impact response and impact energy had a very good relationship. The photos from the ultrasonic C-scan reveal that as the impact energy rises, the damaged area expands. The impact damage had a clear relationship with the impact response, according to the compression after impact (CAI) investigations, and the EP/30TSPF/70 GF composite's compressive strength dropped as the impact energy increased. Overall, it can be said that the sugar palm composites' dynamic mechanical, impact, and post-impact properties are improved by the benzoylation process and the addition of glass fiber [78].

Atiqah et al. [99] prepared a SPF based hybrid composites with the objective to determine how different treatments, such as 6% alkaline (TNSP), 2% silane (TSSP), and 6% alkaline-2% silane (TNSSP), affected the physical and thermal properties of composites made of sugar palm, glass, and thermoplastic polyurethane. The combined alkaline-silane treated hybrid composites (TNSSP) had the lowest density, thickness swelling, and water absorption when compared to other composites when considering physical attributes. Compared to untreated SPF-based composites, treated composites were shown to have better thermal stability (UTSP). Overall, the hybrid composites of processed sugar palm, glass, and thermoplastic polyurethane are suited for the production of automobile [99].

The impact of microwave treatment on the tensile characteristics of reinforced thermoplastic polyurethane composites reinforced with treated SPF and 6% NaOH was studied by Mohammed et al. [100]. First, a 6% alkali solution was used to cure the SPFs. The alkali-treated SPF were then subjected to microwave treatment. In the microwave treatment, three different temperatures (i.e., 70, 80, and 90 C) were used. The polyurethane resin and SPFs were combined, and the hot press and extruder equipment were used to create the composites. Following the ASTM D-638 standard, the tensile properties (i.e., tensile strength, tensile modulus, and elongation at break) were investigated. With a microwave temperature of 70 °C and a 6% alkali pre-treatment, the highest tensile strength of 18.42 MPa was recorded. Consequently, the temperature is 70 °C [100].

A study by Mukhtar et al. [101] examined how sodium bicarbonate treatment affects the physical and mechanical characteristics of hybrid and nonhybrid laminate composites made of glass fibre-reinforced polypropylene and sugar palm. The results will be contrasted with the standard alkali therapy. Utilizing a combination of the hot compression procedure and film stacking, laminate composites were created. Prior to manufacturing, sodium bicarbonate and 4 and 10 weight percent of alkali, respectively, were applied to the naturally woven SPF in the mat. All of the laminate composites were tested for tensile strength, flexibility, and impact resistance as well as for water absorption and morphological analysis. Both sodium bicarbonate and alkaline treatments increased the tensile strength of the hybrid and nonhybrid composites. The alkaline-treated SPF composite (L03), which showed the highest value of 61.75 MPa, and the sodium bicarbonate-treated SPF composite (L04), which recorded 58.76 MPa compared to 53.01 MPa for the untreated SPF composite, both showed a rise that was more pronounced (L02). The flexural strength followed the same pattern. Overall, alkaline treatment outperformed sodium bicarbonate treatment in terms of performance [101]. Table 7 summarized several other studies on SPF reinforced hybrid composites.

5.1. *Potential application of SPF based composites in automotive industries*

Polymer materials account for around 100–150 kg of a modern car's overall body weight. The main reasons for the growing demand for biobased polymers and composites in automotive applications are to reduce car weight for better fuel efficiency, car carbon footprint in the form of carbon dioxide emissions, and reliance on non-renewable materials, and also to increase design flexibility for easier assembling/dismantling. Furthermore, government rules that promote environmental protection and consumer preferences also contribute to automakers' increased use of biobased materials. By 2005, the European Commission released guideline 2000/53/EG requiring that 85 percent of vehicle weight be recyclable. This ratio is rise to 95% in year of 2015 [114].

It is reported that 80 million cars were produced worldwide annually in 2021. Automobile manufacturers are being forced by new legislation, such the EU End of Life Vehicles (ELV) regulations, to think about the environmental impact of their production and maybe switch from the usage of synthetic components to agro-based products. Natural fibres are currently used in exterior and interior components in semi- and non-structural applications, meeting performance standards such as elongation, ultimate breaking force, impact strength, flexural properties, flammability, fogging characteristics, acoustic absorption, odour, dimensional stability, suitability for processing dwell time and temperature, crash resistance, and water absorption. Natural fibre composites have already begun to be used in passenger car parts, including as the rear parcel shelf, door trim panels, and seat squabs, by a few well-known manufacturers, such as Volkswagen-Audi, Daimler-Chrysler, and Opel-GM [115]. Table 8 depicts the current utilisation of natural fibre in the vehicle industry by the major automakers [2,98].

Table 7 – SPF reinforced hybrid composites.

Hybrids fibre	Matrix	Process	Mechanical Findings	Ref.
Woven glass	Unsaturated polyester	Compression molding		
Chopped Glass fiber	Unsaturated polyester	Hand lay-up	Flexural strength = 17.5 MPa, Tensile strength = 21.5 MPa, Impact strength = 20.6 kJ/M2	[102]
Glass fiber	Thermoplastic polyurethane	Melt compounding		[103]
Carbon fiber	Epoxy	Hand lay-up		[79]
Glass fiber	Epoxy	Hand lay-up		[78]
Seaweed fiber	Thermoplastic sugar palm starch/agar	Hydraulic thermo-process		[104]
Roselle short fibre	Polyurethane composites	Melt mixing and hot compression	Flexural strength = 10.19 MPa, Tensile strength = 13.6 MPa, Impact strength = 29.4 kJ/M2	[105]
Cornhusk	Cornstarch	Solution casting		[106]
Glass fiber	Unsaturated polyester	Sheet molding		[107]
Cassava fiber	Cassava starch	Casting		[108]
Kenaf fiber	Polypropylene	Compression molding		[109]
Cornstalk fiber	Cornstarch	Solution casting		[110]
Ramie fiber	Epoxy	Compression molding		[111]
Roselle fiber	Vinyl ester	Hand lay-up		[101]
Glass fiber	Polypropylene	Film stacking and hot compression		[112]
seaweed (long fibre	SP starch/agar	Melt mixing and hot compression	Flexural strength = 31.25 MPa, Tensile strength = 17.74 MPa, Impact strength = 6.0 kJ/M2	[113]
Ramie (woven fibre)	Epoxy		Flexural strength = 80.70 MPa, Tensile strength = 52.66 MPa	[110]

Table 8 – List of natural fibers reinforced hybrid composites currently being used in the automotive industry [98,116].

Automobile model	Natural Fiber Utilized	Applications
Audi A2	Flax, Sisal fibers and polyurethane	Door trim panels
BMW 7 Series	Sisal fiber	door trim panels
Chevrolet Impala	Flax fiber and polypropylene	rear shelf compartment
Ford Focus and Fiesta	Kenaf fiber and sun	Interior door panels
Honda Pilot	wood fiber	Floor area parts
Mercedes Benz A,C,E and S-class	flax hemp, sisal, cotton abaca and jute fibers	Underbody panels, seat back rests, engine and transmission cover, and rear panel shelves
Toyota Prius and Raum	Corn biopolymer, starch and kenaf fiber	Intstrument panels, sun visors, ceiling surface, skins and spare tie cover

In general, the primary driving reason why fiber are increasingly been utilized in the automotive industry to replace heavier materials like steels is due to their lightweight. Besides reducing the weight of vehicles, automakers are looking into selecting the most resource efficient plastics (i.e. biobased plastics) for better sus-tainability. This further contributes to the deduction of CO2 emissions and energy usage [109].

5.2. *Potential application of SPF based composites in packaging industries*

Natural fibres including SPF are possible to be utilised in composites for food packaging. Several studies of natural fibres have found that employing a biodegradable polymer matrix has several advantages, including low cost, low density with good characteristics, and non-harmful processing. Because of this, the filler and matrix will have an impact on the biodegradability of the composite for food packaging. Biodegradation processes are influenced by water availability, which encourages microbial assault and matrix hydrolysis. The water absorption of natural fibres provides a harsher support for microbial growth. The rate of biodegradation is affected by temperature, humidity, and the total number of bacteria present, since the process accelerates with the availability of all biodegradation variables [117].

When making food packaging, various elements must be taken into account, including oxygen penetration into the packaging material, which is in direct contact with food [118]. Berthet et al. [119] explored methods to increase water vapour permeability in food packaging and found that composite materials are appropriate for respiring foods like fruits. It has been observed that incorporating wheat straw fibres

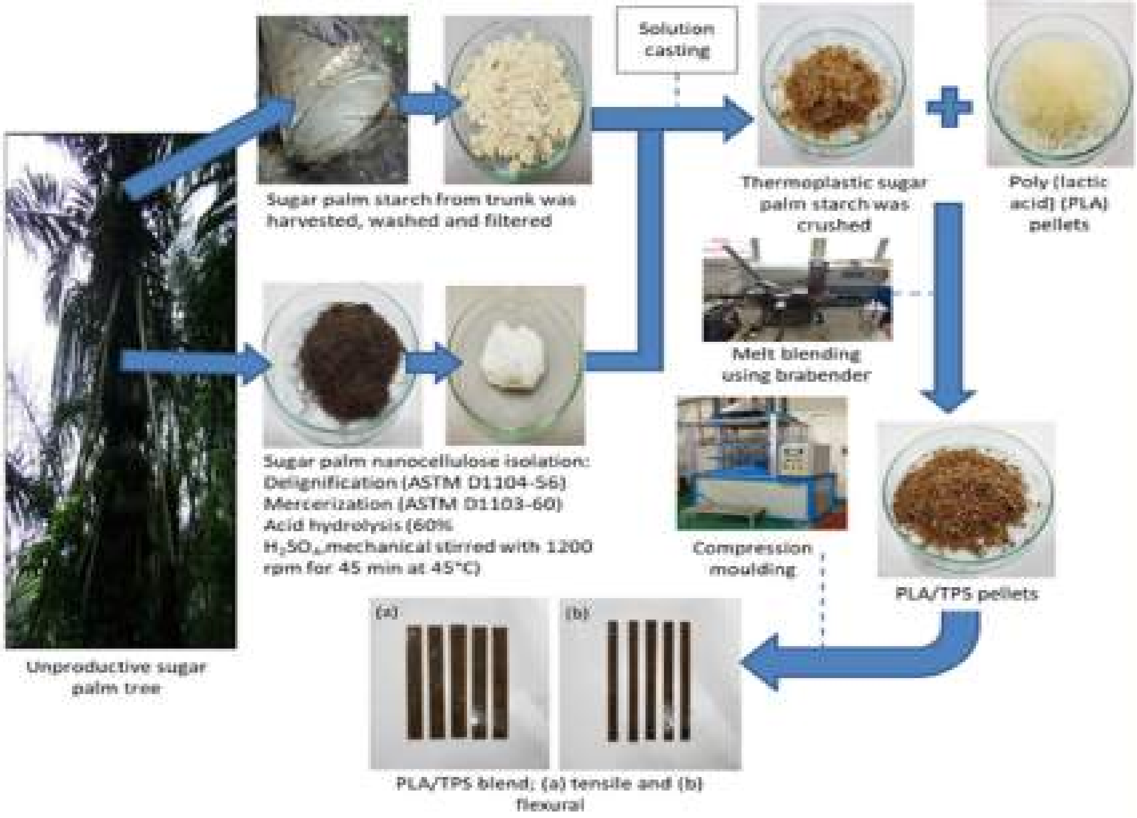

Fig. 13 – Sugar palm nanocrystalline fibre reinforced sugar palm starch/PLA bio nanocomposites.

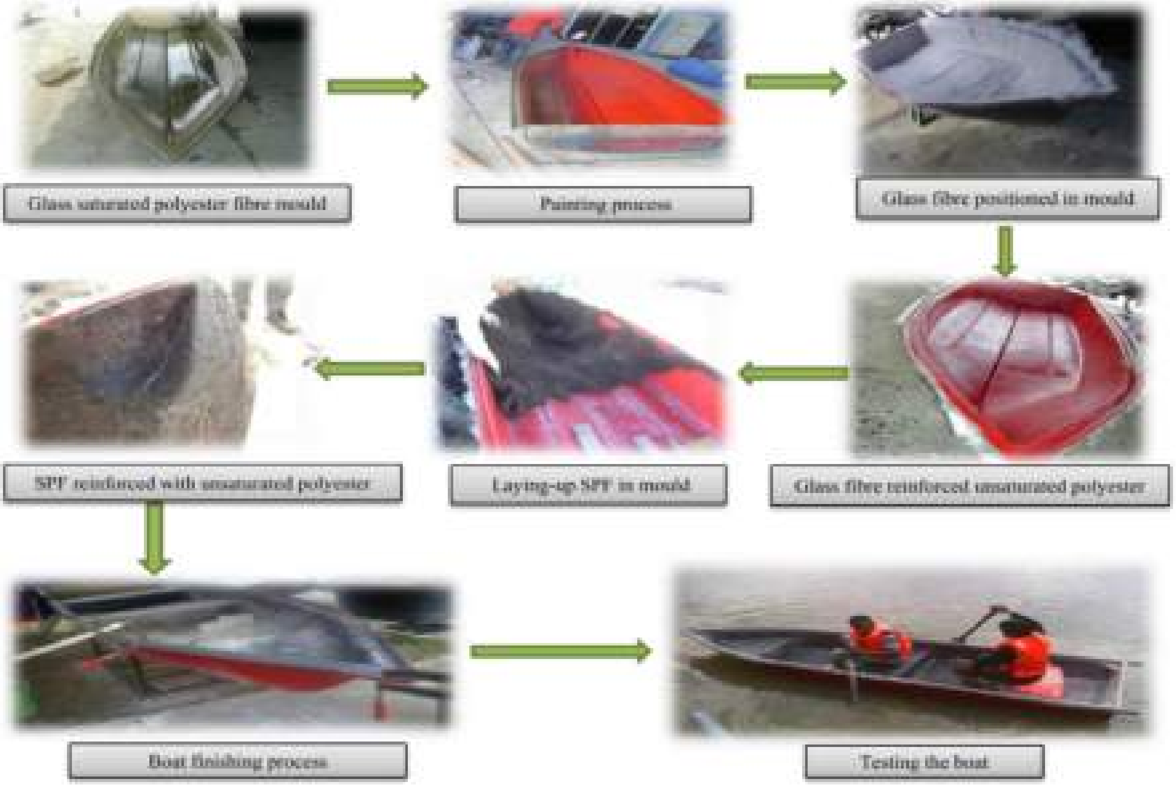

Fig. 14 – Fabrication of SPF boat [2].

increased the rate of water vapours, making the composite suitable for use in food goods. Bioplastics in packaging applications such as starch, cellulose acetate, cellophane, and polylactic acid have recently gotten a lot of attention (PLA).

PLA is frequently combined with other biodegradable polymers to improve qualities suited for packaging products, whereas cellophane can be used to package products like as coffee and cheese. Furthermore, cellulose acetate is rarely utilised in product packaging because to its higher cost than PBAT, PCL, and Polybutylene succinate (PBS). Starch–polymer blends have been proposed as a sustainable packaging option throughout this research. Starch is a green substance made up of amylose and amylopectin that is derived from plants. Amylopectin is a branched polymer that can increase water resistance, processing capabilities, and mechanical qualities. Amylose is a linear polymer while amylopectin is a branched polymer. Furthermore, the starch-based nanocomposite film has demonstrated great strength, as well as the ability to be converted into plastic bags and food packaging while being environmentally benign. Nanofiller has been shown to increase gas, water vapour, and mechanical barrier qualities while also lowering production costs due to reduced material usage [94,120].

Through melt mixing and compression moulding, Nazrin et al. [121] prepared the sugar palm nanocrystalline fibre reinforced SPS/PLA nanocomposite as depicted in Fig. 13. They found that the overall mechanical (tensile and flexural) characteristics of the sugar palm bio nanocomposite declined as the starch loading was increased. A high SPS level resulted in agglomeration, while a low content produced cracks and voids [23,122,123]. Additionally, as the starch loading increased, the sugar palm nanocomposite's thermal stability decreased. Physical characteristics like thickness swelling were related to water absorption and showed an upward trend as starch amount increased.

5.3. *Potential application of SPF based composites in boat making*

As for other applications, Misri et al. [124] used the hand-lay-up approach to make a tiny boat out of a new material that is a mix of SPF and fibre glass-reinforced unsaturated polyester (Fig. 14). The mechanical qualities of these hybrid boats were determined through tensile and impact tests. According to Sanyang et al. [2], SPF have been shown to be extremely durable and resistant to salt water. As a result, they've long been used to construct boat parts and ropes for ship cordages. They're also used to make brooms, brushes, and mats, as well as roofs in rural communities. Because of their exceptional properties, SPF have recently seen increased use as a reinforcement material in polymer composites. SPF has a lower density than commercial E-glass fibre, with SPF having a density of 1.22–1.26 kg/m^3 and commercial E-glass fibre having a density of 2.55 kg/m^3. As a result of this, the weight of a boat made from a sugar palm hybrid with fibre glass fibre composite has been lowered by 50% [124].

Fig. 15 – 12 products from sugar palm tree.

5.4. *Challenges associated with processing and commercializing sugar palm fibers*

The potential use of sugar palm natural fibers in a variety of applications has been the subject of numerous study studies as mentioned in section 5.1–5.3. Sugar palm trees are multipurpose tree. It's because almost every part of the tree (roots, leaves, stems, fibres, fruits, etc.) can be used for a variety of purposes and products (up to at least 60), either for traditional uses like sugar palm food products, kolang kaling (sugar palm fruits), vinegar, fibre products (such as fibre, roof, brush, and broom), or for research purposes like starch and sugar palm fibre, as well as base materials for a variety of structures. Researchers explored several uses of sugar palm products in the form of fibres, foodstuff, and other uses. Sugar palm fibre, starch, roof, rope, brooms, brushes, bottle brushes, vinegar, fruit, liquid sugar, fined sugar, and block sugar are among the 12 goods based on sugar palm that has been successfully commercialized by several researchers as shown in Fig. 15.

The production of sugar palm natural fiber composites is however constrained by a number of variables. High moisture absorption, inferior strength and durability to synthetic fibers, and bad compatibility between the matrix and the fiber are the primary drawbacks of natural fibers [3]. Sugar palm natural fibers tend to take water from the air, which can result in swelling and voids in composite materials. The outcome of this flaw is a decrease in the composites' strength and an increase in their mass. Enhancing the adhesion between the matrix and the fiber surface requires the alteration of natural fibers [10].

6. Conclusion

The SPF have a lot of potential for usage as reinforcement in polymer composites because of its attractive qualities. It is a form of bast fibre with a high cellulose concentration, resulting in the fibre's excellent tensile qualities. Not only is the fibre long-lasting, but it also resists seawater. Furthermore, it is easily processed because it is commonly available in the form of woven fibres. Several successful SPF composite products are now in development. Because many people are unfamiliar with sugar palms and there is little information available about them, further research is needed to uncover their significance and promote their utility for the public benefit. Many considerations need to take place based on the physical, chemical and mechanical of SPF in order to build some improvisation of sugar. this fibre has a lot of potential as a composite reinforcement material. Several successful SPF composite products are now in development. Because many people are unfamiliar with sugar palms and there is little information about them, further research is needed to uncover their significance and encourage their use for the benefit of humanity.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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