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Characterization on chemical and mechanical properties of silane treated fish tail palm fibres

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ABSTRACT

A novel cellulosic fibre was extracted from the peduncle portion of the fish tail palm tree and the extracted fish tail palm fibre was treated with different concentrations (1%, 5%, and 9%) of silane solution. The characteristic analysis on chemical, functional, mechanical and surface property of the extracted fish tail palm fibres were investigated through chemical composition analysis, Fourier Transform InfraRed spectroscopy (FT-IR), single fibre tensile test, and Scanning Electron Microscopy (SEM). Chemical analysis results indicate that silane treatment improved the cellulose content of the fish tail palm fibre. The highest cellulose content of 72.51% was observed in the 9% silane treated fish tail palm fibre. Also, it improved crystallinity index value of 62.5% for 5% silane treated fibre, which is confirmed through the X-ray diffraction analysis. FT-IR result indicates the removal of hemicellulose at characteristic wavelength of 1745 cm^{-1} for 5% silane treated fish tail palm fibre. Tensile property of the silane treated fish tail palm fibre (1, 5, and 9%) shows an increased tensile strength of 7.3%, 12%, and 6.6% as compared to raw fish tail palm fibre. Moreover, this type of novel natural fibres can reduce the cost while offering competent performance during the polymer-based product development.

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1. Introduction

In recent days, eco-friendly products are attracted by various researchers and environmentalists. Environmental sustainability and energy problems to humankind is the reason for moving towards the eco-friendly products [1,2]. Due to COVID-19 pandemic situation, there is a need of sanitation mask for everyone, leading to more demand of cotton and other synthetic fibres. This motivates mask and other sanitation wear makers to consider alternative fibres. Cellulosic fibres have good antimicrobial property when compared to synthetic fibres. Compared with available synthetic fibres, the hemp and bamboo fibres have antimicrobial property by its nature [3]. Some researchers have attempted to make surgical clothing such as bio mask, by this kind of natural cellulosic fibres [4–6].

Production of mask and other surgical sanitary ware by using synthetic fibres leads to various environmental pollutions [7]. Due to its non-bio degradability and difficult-to-decompose nature, it creates long term negative impact on environment [8]. Glass and carbon fibre are the most used synthetic fibres in the production of various polymer products [9]. Problem during usage and disposal of this type of synthetic

fibres, leads to various environmental issues. Besides, it leads to several health problems such as skin disease, allergy and cancer etc. [10,11]. Remedy for the replacement of synthetic fibre will be usage of natural fibre without losing its basic qualities such as low cost, good compatibility with resin and good mechanical properties.

European Union has passed the legislation to use bio fibres as reinforcement during automobile component manufacturing [12]. The main reason for using natural fibre as reinforcement is that the energy consumed for the fibre production is less compared with synthetic fibre. The cost associated with the production of natural fibre is less, possibly due to the fact that natural fibres are mostly by-products from the industrial crops. These natural fibres do not satisfy the future needs of industrial production requirements, but is comparable with the current market requirement [13].

Researchers have attempted various natural fibres such as kenaf [14], flax [15], hemp, sisal, and jute [16] for the production of polymer composites. These reports addressed that, it is possible to use natural fibre as reinforcements in polymer composite and can be used for the various end applications such as furniture's, door panels, shelves and automotive dashboards [17,18].

In recent days, researchers have explored enormous number of new natural fibres from the available natural resources, such as *Dichrostachys cinerea* fibre [19], areca palm leaf stalk fibre [20], *Lygeum spartum* L. fibre [21], Saharan aloe vera cactus leaves fibre [22], and *Agave americana* L. fibre [23]. Fish tail palm tree is a medicinal plant which is also used for decoration purpose in gardens. The seeds and fruits of the tree contain

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antibacterial property [24]. Peduncle portion of the plant is rich in fibre and cellulose content. Commercially it is used in the production of ropes for tying the domestic animals. This rope does not harm the animals when compared with the other synthetic fibres. Further exploration of this fibre on the advanced materials and engineering applications is underway.

Currently, concrete mixture is made by using natural fibre as reinforcement. During curing of these types of concretes, the hydration of cement occurs rapidly due to presence of free hydroxyl present in the natural fibre [25]. This free hydroxyl group can be reduced by proper surface modification process. Compared with synthetic fibres, natural fibres are hydrophilic in nature with relatively lower cellulose content. During composite materials production, the hydrophobic behaviour of natural fibre has lowered the compatibility between the fibre and the hydrophilic polymeric resin [26]. To improve the compatibility of resin with fibre, various chemical surface treatment (alkaline, silane, acetalization and peroxide treatment) processes were employed on the natural fibres [27]. It is necessary to study the surface modification on natural fibre before using in polymer composite production. During chemical treatments, the removal of impurities such as pectin and wax from the surface of the natural fibre normally improves the adhesion strength between fibre and polymer matrix. The main drawback of natural fibre is its highly polar and hydrophilic in nature; to impose hydrophobicity in natural fibre, the silane treatment is preferred over other chemical treatment. Though alkaline treatment of natural fibres increases the interfacial bonding with matrix, the harsh chemical reactivity reduces crystalline cellulose into amorphous material [28]. Silane treatment is the most important surface treatment, which improves the interfacial adhesion of natural fibre with polymeric resin. Apart from the removal of strength reducing substance, the silane treatment also bridges the natural fibre with the polymeric resin with a chemical bond [29]. The surface modification using silane treatment has the advantage of increasing strength and hydrophobicity of natural fibre. Silane treatment forms a silanol (Si-OH) group on the natural fibre surface. This group acts as an interface agent between the silane treated fibre and polymer matrix [30]. The nature of reaction between silane solution and organic materials (natural fibres) is entirely different as compared to inorganic materials (glass fibre) reaction. The reaction of silane group with cellulose macromolecules produces only pre hydrolysed silanes on the cellulose surface [31]. The exploration of the high strength and crystalline natural fibre as an alternative for the cotton fibre and as a reinforcement agent in polymer composites is continuously taking place. It urges extraction of a new fish tail palm fibres for advanced industrial applications.

In this study, deals with extraction of fish tail palm fibre from peduncle portion of the fish tail palm tree. These fibres were treated with different concentrations 1%, 5%, and 9% of silane solution. Functional modification due to chemical treatment and crystallinity index of the extracted fish tail palm fibres were characterized by using Fourier Transform InfraRed spectroscopy (FT-IR) and X-Ray Diffraction analysis (XRD). Moreover, the surface modification and elemental composition was found out by using Scanning Electron Microscope (SEM) and Energy dispersive spectroscopy. Finally, the mechanical strength of the fish tail palm fibre was analysed using a single fibre tensile test.

2. Materials and methods

2.1. Fibre preparation

Fish tail palm stems are obtained from the fish tail palm tree, Chennai, India. Fig. 1 (a-c) shows the fish tail palm fibre tree, extracted long fibre, and chopped short fibres. The bast is extracted from the stem portion of the fish tail palm tree. Initially the stem portions are cleaned from dirt, flowers, and fruits. Then, the stems were immersed in water for 6 h to loosen the bast portion. After immersing, the stem portion was hammered by a wood mallet with a little force applied on the stem portion.

During hammering, each fibre strand was separated individually. The hammered fish tail palm bast material was around a length of 4 m. This fibre was chopped into 150 mm length for the reference sample and it is used for the characterization purpose.

2.2. Surface treatment of extracted fibre

Among the various surface treatment processes, chemical method of surface treatment is more advantageous to improve the mechanical properties of the produced fibres. The effect of surface treatment on novel fish tail palm fibre was compared with the untreated fibres. Silane treatments with different compositions were done on the extracted fibres.

The straightforward surface treatment for fibre extraction process is silane treatment. The objective of silane treatment is to remove the surface impurities and strength reducing substance from the fibres. For doing silane treatment on natural fibres, silane coupling agent (vinyltri ethoxy silane) was purchased from Thermo fisher Scientific, Delhi, India. The silane solution was prepared by hydrolysing the silane solution of 5 ml in ethanol and water mixture with 80: 20 ratio. To maintain the pH of the solution between 4.5 and 5, acetic acid solution was added in the mixture, by adding acetic anhydride in the mixture solution. Then the fibres were immersed in the prepared solution for 15 min and dried in room temperature for 30 min.

Dried fibres were washed 5–6 times with ethanol to remove the excess chemicals on the surface of the fibre. Cleaned fibres were dried in oven at 105° C for 12 h. The cleaned fibres were designated as raw fibre - RFT, silane treated fibre of 1% as SFT1%, silane treated fibre of 5% as SFT5%, and silane treated fibre of 9% as SFT9%.

2.3. Chemical composition analysis

As per the National Renewable Energy Laboratory standard, the chemical composition of the extracted fish tail palm fibres was measured. The test was conducted to measure the amount of cellulose, hemicelluloses, and lignin present in the extracted fish tail palm fibre.

Initially the fish tail palm fibres of untreated and silane functionalized were analysed using Soxhlet method [32], to find out the water and ethanol extractives. In Soxhlet apparatus, 3 g of fish tail palm fibres were placed for 6 h for water extraction and 16 h for ethanol extraction. Based on the sum of both extractions, the extractive percentage was calculated.

From the extractives of fish tail palm fibres, 330 mg was taken to carry out the acid hydrolysis process. The acid hydrolysis was done by adding 3 ml of sulphuric acid for 1 h at room temperature. After that, the sulphuric acid was diluted by adding 84 ml of deionised water and kept in furnace for 121 °C for 1 h. The insoluble residues coming out from the acid hydrolysis process was filtered out and taken for acid insoluble lignin determination. The lignin content of fish tail palm fibre is comprised of both acid soluble and insoluble lignin. The acid insoluble lignin was determined by drying the filtrate coming out from the acid hydrolysis process at 105 °C and weighing it (as initial weight). After that, the dried filtrate was again dried in muffle furnace at 575 °C.

Based on the weight difference, the acid insoluble lignin percentage was measured. The acid soluble lignin percentage was found out by using UV-Vis spectrophotometer. The sum of both soluble and insoluble lignin details the lignin percentage of fish tail palm fibre. The hydrolysate from the acid hydrolysis process was used for determining the acid soluble lignin percentage. The formed hydrolysate was characterized in liquid chromatography equipment to find out the cellulose and hemicellulose content of the extracted fibres.

2.4. Scanning electron microscopy (SEM) analysis

Morphological study of the extracted fibres was carried out in scanning electron microscope (JEOL JSM840A, Japan). The effect of chemical



Fig. 1. Fish tail palm fibre processing (a) fish tail palm tree, (b) extracted fish tail palm fibre, and (c) chopped fish tail palm fibre.

reaction on fibre surface and fibre diameter was observed using SEM. Energy dispersive spectroscopy reveals the elemental composition of the fibres before and after chemical treatment. This elemental composition reveals the oxygen to carbon ratio of the untreated and chemical treated fibres.

2.5. Fourier-transform infrared spectroscopy (FTIR) analysis

FTIR analysis was conducted to observe the functional modifications and changes in the functional groups such as cellulose, hemicellulose and lignin in the extracted natural fibres. Initially the fish tail palm fibres of untreated and various composition of silane treated fish tail palm fibre samples of 5 g was milled into powder by using a pestle and mortar. The powder samples were made into pellet by using potassium bromide solution.

The experiment was conducted in a Bruker Alpha FTIR Spectrometer with an ATR (Attenuated Total Reflectance) attachment. The spectra were observed in the transmittance mode of range 5000 to 400 cm^{-1} region with a spatial resolution of 2 cm^{-1} .

2.6. X-ray diffraction analysis

X-Ray diffraction analysis was used to study the crystal structure and crystallinity index of the extracted and chemical treated fibres. The experiment was conducted in Bruker D8 equipment, Karlsruhe, Germany, with various experimental conditions of diffraction angle 4°–60° with Cu-K α irradiation, scanning speed of 0.02/s, current of 40 mA and voltage of 40 mV.

Segal empirical method was employed to find out the crystallinity index of the extracted fibres [33]. Higher crystallinity index denotes the fibres are strong and cellulose was oriented in better manner. Crystallinity index (CI) was calculated based upon the following Eq. (1),

$$\text{Crystallinity Index (CI)} = \frac{I_{Cr} - I_{am}}{I_{Cr}} * 100\% \quad (1)$$

where I_{cr} , and I_{am} represents crystalline intensity and amorphous intensity at an angle (2 θ). The peak intensities nearer to 22° are considered as crystalline material and peak intensities closer to 18° are considered as amorphous material in extracted fibres.

2.7. Single fibre tensile test

Single fibre tensile test was carried out as per ASTM D3822–07 standard. The test was conducted in a universal testing machine (INSTRON 5500R) with a displacement rate of 0.5 mm/min at room temperature. An average of 20 samples was tested to neglect the experimental errors

during testing process. Average tensile strength of single fish tail palm fibre was determined by the Eq. (2) mentioned below,

$$f_{fpt} = \frac{4F_{avg}}{\pi d_{avg}^2} \quad (2)$$

where f_{fpt} is the tensile strength calculated for the fish tail palm fibres, F_{avg} is the average tensile force of fish tail palm fibre during single fibre tensile testing, and d_{avg} is the average diameter of the fish tail fibre measured.

3. Results and discussion

3.1. Chemical composition analysis of fish tail palm fibre

Chemical composition analysis determines the elements such as cellulose, hemicellulose, lignin, and other extractives present in the natural fibres. Cellulose content is the backbone for the fibre selection, since the cellulose content dictates the strength, stability, stiffness and resistance to hydrolysis for the natural fibres [34]. Fig. 2 shows the various chemical components present in untreated and different compositions silane treated fish tail palm fibres. The experimental results show that chemical treatment increases the cellulose content in the fish tail palm fibre. Silane treatment on fish tail palm fibre breaks out the hemicellulose

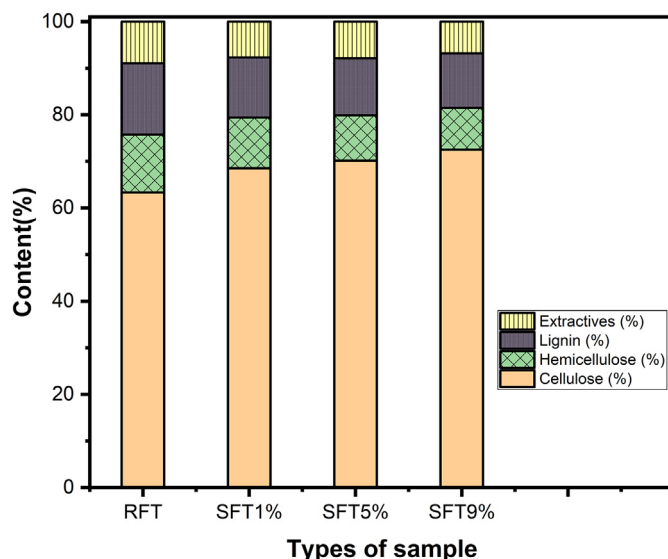


Fig. 2. Chemical composition analysis of various silane treated fish tail palm fibre.

Table 1
Chemical composition analysis of fish tail palm fibre with existing natural fibre.

Types of fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractives (%)	Reference
Kenaf	53.14	14.3	8.18	0.8	[14]
Sisal	60–78	10–14.2	8–14	2	[37]
Bamboo	26–43	30	1–31	–	[37]
Jute	72	13	13	0.5	[38]
Hemp	74	18	4	2.3	[38]
Ferula cummins	53.3	8.5	1.4	–	[39]
Flax	81	14	3	1.7	[40]
<i>Ficus religiosa</i>	55.58	13.86	10.13	5.58	[41]
Agave	68.42	4.85	4.85	0.26	[42]
Fish tail palm fibre	72.51	8.97	11.75	6.77	Current work

and lignin content, and thereby it improves the cellulose content in fibre.

During chemical treatment, the hemicellulose and lignin are removed due to their amorphous nature and are easily attacked by the chemical reagents. In case of cellulose, it is harder due to its crystalline phase and is difficult to digest in chemical solution [35]. The highest cellulose content of 72.51% was observed in the 9% of silane treated fish tail palm fibres and as an effect of silane treatment, there is an increase of cellulose content by 8 to 14.5%. Therefore, the silane treatment has high impact on removing the strength reducing substances such as hemicellulose and lignin from fibre surface and leads to higher strength than the untreated fish tail palm fibre.

To find the saturation limit of cellulose present in the extracted fish tail palm fibre, again the fibre was treated with a 13% silane solution. It is observed from the experimental result that, the 13% silane treated fibre shows a decrease in cellulose content. The cellulose content decreased up to 69.5%. Liu et al. reported that a reduction of cellulose content due to a high concentration of chemical treatment leads to a drastic decrement in the tensile strength of cellulosic fibres [36]. These findings directly indicate that after 9%, silane treatment is expected to decrease the mechanical properties of extracted fish tail palm fibre. Hence, the experimentation was done up to 9% of silane treated fibre. Apart from this, the comparative analysis of fish tail palm fibre with other commercially available fibres is shown in Table 1.

The extracted fish tail palm fibre exhibits relatively higher cellulose content as compared to other fibres such as kenaf (53.14%), *Ficus religiosa* (55.58%), and bamboo (26–43%). The cellulose percentage is comparable with sisal, hemp, and jute fibres. Higher cellulose content in the fish tail palm fibre ensures high strength and modulus of

elasticity. Moreover, a high volume of hemicellulose has adverse effect on strength of fibre [38]. Though flax fibre showed higher cellulose amount, it is better to compare with hemicellulose content, which is high, limiting it in strength requirements. When compared to flax fibre, fish tail palm fibre has less cellulose content and less hemicellulose content. The higher hemicellulose content limits the strength of flax fibre. The fish tail palm fibre showing lesser hemicellulose substance increases its applicability in various applications.

3.2. FTIR analysis

Fig. 3 shows the FTIR spectra of the untreated and various percentage of silane treated fish tail palm tree fibre. The peak position and the modifications in the functional groups are tabulated in Table 2.

The peak position in the range of 300–3600 cm^{-1} related to O—H stretching of H-bonded alcohol, water and phenols group [43]. Moreover, a strong and intense peak is observed in this range of all the raw and surface treated fish tail palm fibre. The strong peak at 2924 cm^{-1} in raw fibre, 2928 cm^{-1} in SFT1% fibre, 2927 cm^{-1} in SFT5% fibre and 2924 cm^{-1} in SFT9% fibre corresponds to C—H stretching vibration of CH and CH₂ in cellulose and hemicelluloses [44]. The presence of sharp and intense peak in the raw fish tail palm fibre, present in 1745 cm^{-1} corresponds to =CO stretching vibration of carboxylic acid and ester groups of hemicellulose. The intensity was reduced as seen in the various compositions of silane treated fish tail palm fibres [14]. This results in reduction of hemicellulose content in the surface treated fish tail palm fibres. Similarly, the presence of peak at (1347–1286 cm^{-1}) and (1286–1184 cm^{-1}) corresponds to aromatic C—O bending and stretching of acetyl group. This absence of peak at 1242 cm^{-1} in chemical treated fish tail palm fibres results in absence of hemicellulose and lignin in the extracted fish tail palm fibre [45].

The presence of peak at 1460 and 1376 cm^{-1} , is attributed to CH₂ and CH bending present in cellulose. Silane treatment does not affect the peak in this range, indicating that there is no damage in the cellulose content during surface treatment [46]. The intrinsic peak present in the range 912–1140 cm^{-1} signifies that C—O stretching vibration, which belongs to polysaccharide in cellulose [15]. The weak peak is observed at 1080 cm^{-1} after treating the fibre with silane solution (5% and 9%). This may be due to the asymmetric stretching of Si—O—Si bond in amino propyl tri ethoxy silane [47]. This is the result of condensation reaction of hydrolysed silane and hydroxyl groups of raw fibre cellulose [48]. The most intense bands observed in the spectrum are 1192, 1078, 910, 817, and 780 cm^{-1} due to the stretching of C—O, Si—O, and Si—C bonds [49]. The intensity of the hemicellulose peak at

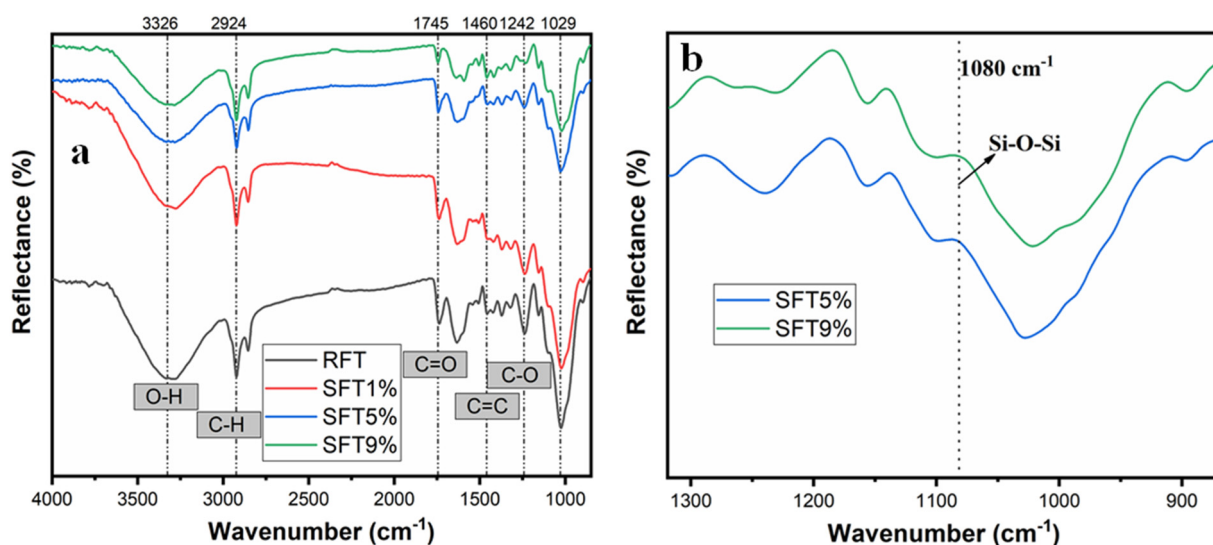


Fig. 3. FT-IR spectra of untreated, silane treated with different composition of 1%, 5%, and 9% of fish tail palm fibre.

Table 2
FT-IR spectra data of the extracted and chemical treated fish tail palm fibre.

Wavelength range (cm ⁻¹)	Possible assignment	Types of fibre				Source
		RFT	SFT1%	SFT5%	SFT9%	
3600–3000	O-H stretching H-bonded alcohol, water, phenols	3326	3322	3318	3314	Cellulose, hemicellulose, lignin
2500–3000	C-H stretching vibration in cellulose and hemicellulose	2924	2928	2927	2924	Cellulose, hemicellulose
2000–1693	=CO stretching vibration of carboxylic acid and ester groups of hemicellulose	1745	1754	1743	1744	Hemicellulose
1693–1607	absorbed water	1639	1643	1641	1637	Water
1607–1486	aromatic C=C stretching in lignin	1588	1584	1586	1582	Lignin
1486–1395	CH ₂ bending	1460	1464	1460	1461	Cellulose
1395–1347	C-H bending	1376	1382	1372	1370	Cellulose
1347–1286	aromatic C–O bending	1313	1315	1313	1318	Lignin
1286–1184	-CO stretching of acetyl group	1242	–	–	–	Lignin
1140–912	C-O stretching vibration in cellulose	1029	1032	1029	1021	Cellulose, hemicellulose, lignin
912–840	β-Glucosidic linkage in cellulose	897	901	893	893	Cellulose

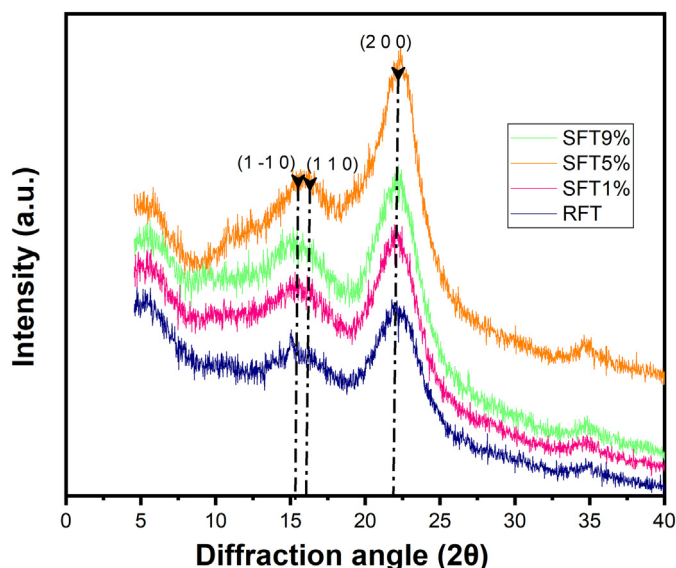
Table 3
EDX analysis of fish tail palm fibre.

Types of sample	Carbon (C) (%)	Oxygen (O) (%)	Remaining elements (%)	O/C ratio
RFT	57.01	39.71	3.28	0.70
SFT1%	54.44	41.22	4.34	0.76
SFT5%	52.28	43.71	4.01	0.84
SFT9%	51.44	45.22	0.334	0.87

1373 cm⁻¹ is decreased because of masking, since silane treatment creates silane band at 1355 cm⁻¹ [50]. It is visible that, the chemical treatment does not attack the cellulose content of the natural fibre.

3.3. EDX analysis

Table 3 shows the oxygen and carbon percentage of untreated and various silane treated fish tail palm fibre. The reason for the EDX analysis is to find out the oxygen to carbon ratio, present in natural fibre. Higher carbon content indicates that there is a higher volume of lignin present in the fibre. It is seen that various percentage of silane treatment on fish tail palm fibre reduces the carbon content. Table shows that the highest oxygen to carbon ratio of 0.87 was observed in 9% silane treated fish tail palm fibre. Silane treatment of 9% shows effective removal of lignin from the fibre surface, which results in increase in the cellulose

**Fig. 4.** XRD analysis spectra of fish tail palm fibres.

content of the fish tail palm fibre. Similar effect on improved cellulose content was observed on luffa fibre by treating with silane solution [51].

3.4. XRD analysis

XRD pattern of raw and silane treated fish tail palm fibre are shown in Fig. 4. From the figure, the major peaks are present at 2θ angle of 15.63°, 16.52° and 22.04°, with corresponding lattice peaks of (1–10), (110) and (200). These peaks are associated with cellulose I crystallites. The experimental result shows that, there is no structural change from cellulose I to cellulose II, during surface treatments of various composition of silane treatment.

Table 4 shows the crystallinity index of the untreated and various percentage (1, 5, and 9%) of silane chemical treated on fish tail palm fibre, and it is calculated based on the Eq. (1). As compared with the raw fish tail palm fibre (51.2%), the silane treatment of 1%, 5%, and 9% shows higher crystallinity index of 58.3%, 62.5%, and 60.1%. It is because of the effective removal of amorphous portion such as hemicellulose, lignin, pectin, and impurities from the fibre surface, which improves better packaging of cellulose content in the fibre. This result is supported by the FT-IR analysis report which is shown in Fig. 3. Similar results were also observed by various researchers [52,53].

3.5. Surface analysis of extracted fibres

Fig. 5 (a-d) shows the micrographs of untreated, and various percentages (1, 5, and 9%) of silane chemical treated fish tail palm fibre. By using ImageJ analysis software associated with the SEM image, the diameter of the fibre was measured. Through this observation, the diameter of the silane treated fibre is lesser in size, when compared with raw fish tail palm fibre. This diameter reduction is due to removal of hemicellulose, lignin from the fibre surface. Additionally, SFT9% fibre results in lowest fibre diameter when compared with all other fibres. Possibly, removal of much lignin results in finest fibres and removal of outer waxy substance from the fibre surface. The results are in line with the previous experimental reports by Yousif et al. [54] on-oil palm fibre, Chin and yousif et al. [55] on kenaf fibre, and Sawpan et al. [45] on-hemp fibre.

Table 4
Crystallinity content of fish tail palm fibre.

Types of sample	Crystallinity index (%)
RFT	51.2
SFT1%	58.3
SFT5%	62.5
SFT9%	60.1

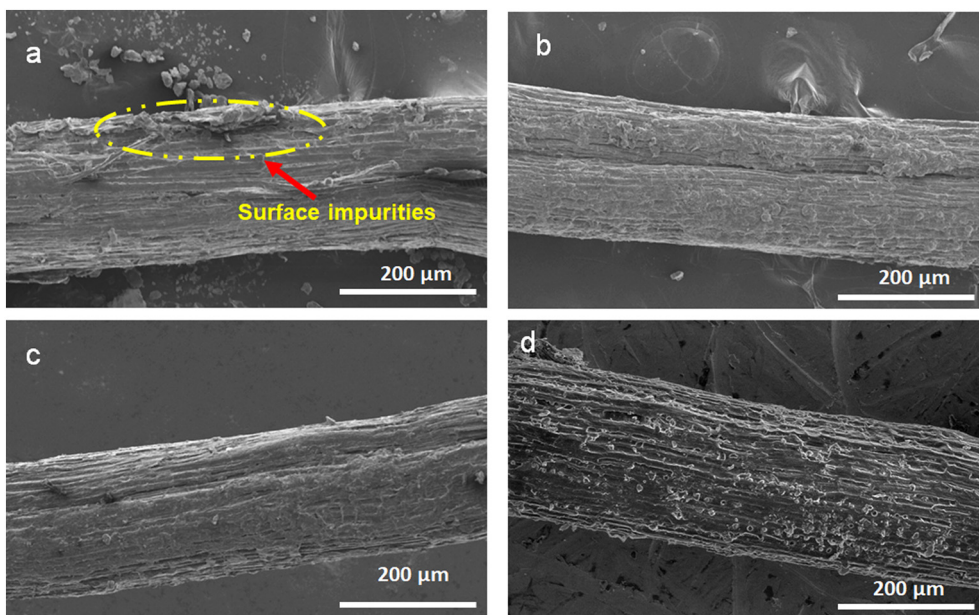


Fig. 5. SEM images of fish tail palm fibre (a) Untreated, (b) SFT1%, (c) SFT5%, and (d) SFT9%.

From Fig. 5 (d), there is a severity in the reaction of silane on the fibre surface for 9% of silane treated fibre, which will cause fibrillation on the fish tail palm fibre. Similar effect on date palm fibre has been reported [56]. Apart from this, all the other silane treated fish tail palm fibres show finest fibre compared with the raw fibres.

3.6. Single fibre tensile test

The tensile strength of the untreated and various percentages (1, 5, and 9%) of silane chemical agent treated fish tail palm fibres is shown in Table 5. Among the untreated and silane treated fish tail palm fibres, 5% of silane treated fibre exhibits higher tensile strength of 476 MPa. This is due to increase in the cellulose content of chemically treated fibres. Similar observation on various surface treatments on corn stalk waste fibres with higher tensile strength than the untreated fibres has been reported [36].

The tensile properties on various percentages (1, 5, and 9%) of silane chemical agent treated fish tail palm fibre shows higher tensile strength of 7.3%, 12%, and 6.6%, when compared to raw fish tail palm fibres. The inherent reason for the increase in the tensile strength is due to removal of strength reducing hemicellulose substance which normally increases the crystallinity content of the fibre. Apart from this, silane treatment of 9% fish tail palm fibres shows lesser tensile strength value when compared with 5% silane treated fibres. This is due to improvement of brittleness with higher percentage of silane treatment. This statement is in line with previously published report [12] by Cai et al. Stress-strain curves of untreated and treated fish tail palm fibre are shown in Fig. 6. It depicts a linear increase of strength with stain, and maximum tensile strength is reached for SFT5%.

Table 5
Tensile strength of untreated and silane treated fish tail palm fibre.

Types of sample	Diameter (µm)	Tensile force (N)	Tensile strength (MPa)
RFT	245 ± 14.21	1.92 ± 0.41	407.47 ± 121.11
SFT1%	237 ± 11.47	1.81 ± 0.54	433.15 ± 92.17
SFT5%	230 ± 11.19	2.02 ± 0.45	476.26 ± 114.35
SFT9%	224 ± 12.32	1.72 ± 0.33	434.14 ± 107.64

3.7. Comparative analysis of fish tail palm fibre with the existing natural fibres

The overall results of extracted fish tail palm fibre were compared with newly explored natural fibres, as presented in Table 6. From Table 6, it can be seen that the fish tail palm fibre has higher crystallinity index than the existing natural fibres such as *Cyrtostachys renda*, *Citrullus lanatus*, *Ptychosperma macarthurii*, and *Tridax procumbens*. Therefore, the silane treated fish tail palm fibre has the potential to be used for bio composites and other sustainable value-added products.

4. Conclusion

In the present work, the novel fish tail palm fibre was extracted from the peduncle portion of the fish tail palm tree and they are functionalized by silane coupling agent and characterized for mechanical

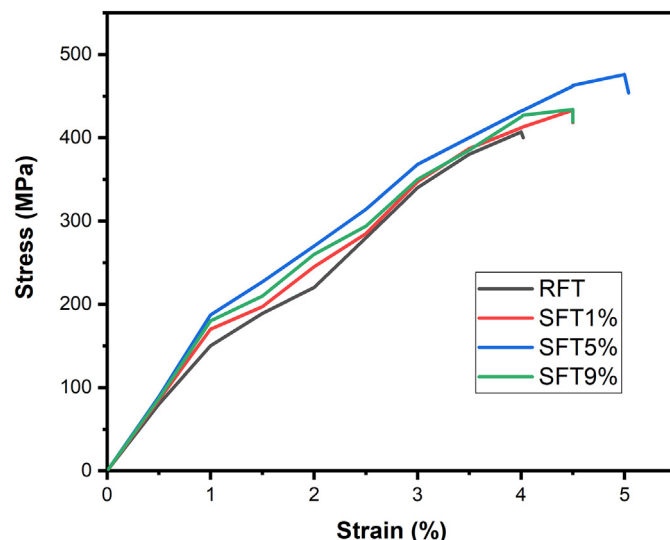


Fig. 6. Stress-strain curve of untreated and treated fibres.

Table 6

Properties of the current and recently explored natural fibres.

Types of fibres	Cellulose (%)	Crystallinity Index (%)	Single fibre tensile strength (MPa)	References
Fish tail palm fibre	72.51	51.2	407.47 ± 121.11	Current work
Ensete stem fibres	56.05	–	513 ± 57.7	[57]
Cyrtostachys renda	45.15	6	–	[58]
<i>Citrullus lanatus</i>	53.7	33.33	38.1 ± 1.56	[59]
<i>Ptychosperma macarthurii</i>	32.83	36.79	–	[60]
<i>Olea europaea</i> L.	39.42	68.5	–	[61]
Red banana peduncle	72.9	62.1	440 ± 13.4	[62]
<i>Albizia amara</i>	64.54	63.78	640 ± 13.4	[63]
<i>Tridax procumbens</i>	32	34.46	25.75 ± 2.45	[64]

properties for use as fibre in resin-based composites. The outcomes of the present work are illustrated below:

1. The chemical composition analysis of silane functionalized 9% fish tail palm fibre shows the maximum cellulose content of 72.51% followed by hemicellulose of 8.97%, pectin of 11.75% and extractives of 6.77%.
2. The FT-IR result depicts the removal of hemicellulose at spectra range of 1745 cm^{-1} for the 5% silane treated fish tail palm fibres. Moreover, the silane treatment does not affect the cellulose content of treated fibres, and has presence of respective peaks (1460, 897 cm^{-1}) in the FT-IR plots.
3. The crystallinity index of the untreated and silane treated fish tail palm fibre was indexed by using XRD analysis. The maximum crystallinity index value of (62.5%) was observed in 5% silane treated fish tail palm fibres.
4. Surface morphology of the silane treated fish tail palm fibres are absence of surface impurities, with lowest fibre diameter.
5. Mechanical property like tensile strength was increased by the influence of silane treatment. The maximum tensile strength of 476.26 MPa was observed for the SFT5% treated sample.
6. When compared with other natural fibres, fish tail palm fibre exhibits better mechanical properties, which makes it suitable for various applications such as polymer and concrete reinforcements.

CRedit authorship contribution statement

P. Sabarinathan: Conceptualization, Investigation, Writing- Review & Editing

K. Rajkumar: Visualization, validation, Supervision, Project administration

V.E. Annamalai: Resources, Supervision, Funding acquisition

K. Vishal: Investigation, Validation

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