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REVIEW

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The exchange of *Musa* spp. fibre in composite fabrication: a systematic review

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Abstract

Background: The areas of application of natural fibres have gained popularity in recent times due to their attractive advantages when compared with other materials of engineering. These advantages include lightness, cost-effectiveness, and ease of processing, ecological friendliness, and durability. Previously, farmers only harvest *Musa* spp. fruits for their food values and packaging purposes.

Main body of the abstract: Several research works have been undertaken which accentuate the applications of the assumed waste portions of *Musa* spp. (banana and plantain) specifically *Musa* spp. fibre as a reinforcement material in composite manufacture. As a material for reinforcement in composites, the characterization, treatment, and fabrication techniques; elemental, chemical, and mechanical properties of *Musa* spp. fibre have been analysed. The mechanical properties of banana fibre reinforcement in polyester, epoxy, cement, and plastics composites were evaluated with those of other biodegradable fibres to explicate their relationships.

Short conclusion: This review aims to explore the current state of knowledge on the interaction of *Musa* spp. fibre in composite manufacture, to aid intending researchers with ample knowledge on the choice of material in bio-based composite design.

Keywords: *Musa* spp., Fibre, Composite, Polymer, Characterization

Background

Musa spp. (banana and plantain) are one of the oldest crops grown by farmers the world over. Banana in Arabic means 'finger'. It belongs to the family of crops known as Musaceae and exists in about 300 species with only 20 varieties consumed as food. About 70 million metric tons of *Musa* spp. is produced annually in the temperate regions of the world (Muller and Krobjilowski 2003; Joshi et al. 2004; Umair 2006). As a result of identified ecological reasons, the application of natural material in the manufacturing and industrial sector has gained prominence (Xu et al. 2015; Monteiro et al. 2014). Two key strategies on which natural fibres composite (NFC) production is based are preventing the depletion of forest resources and ensuring good economic returns (Sathiyamurthy et al. 2013). Because of its enhanced modulus and lightweight, compared to other traditional engineering materials like wood, metal, and steel, natural fibre-reinforced polymer composites have been greatly studied by several researchers (Adekomaya and Adama 2017; Singha et al. 2010).

'Due to their unique strength properties, availability, lightweight, easy separation, improved energy recovery, high resilience, non-corrosive design, low density, low cost, renewability, and biodegradability, composites strengthened using natural fibres have advantages over conventional reinforcement materials such as glass and carbon fibre' (Mahaboob 2011; Arpitha and Yogesha 2017). Composites are structural materials mixed at a macroscopic level consisting of two or more constituents (not soluble in each other) (Arpitha and Yogesha

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2017). In the continuous phase or matrix or resin (thermosets and thermoplastics), composites consist of the reinforcing or discontinuous phase (metal, ceramic, or fibre) embedded (Aminudin et al. 2011). For example, naturally occurring lignin and wood composites contain cellulose fibre (Arun et al. 2016). Fibre-reinforced composites are made up of fibres as a matrix and polymer as reinforcement.

Most of the shortcomings in the properties of plastics in manufacturing are improved upon by the introduction of natural fibres into waste plastics (polymer) (Li et al. 2007). It has been discovered that the application of natural fibre to composites decreases their overall weight by 10% with ease of processing improved significantly by 80% also, the cost of components is lowered by 5% in comparison with fibreglass-reinforced components (Sakthivei and Ramesh 2013). Most engineering components adopted in the production of vehicles, aircraft, domestic appliances, and packaging industries are protected from environmental attack and corrosion, using waterproof, relatively good strength, and corrosion-resistant materials (Mohammed et al. 2015). Because of their lightweight and high strength, polymeric composites play a very important role in such applications (Sathiyamurthy et al. 2013). There has been a major change between natural and synthetic (manmade) materials in the past couple of years. We have seen it in the growth of fresh foods and the market for eco-friendly vehicles for almost any product imaginable with natural materials. Natural fibre's global market size was estimated at $4.46 billion as of 2016 and have been forecasted to have a compound annual growth rate of 11.8% from 2016 to 2024 (https: et al., 10.1155, 2015, 243947. xxxx).

For automotive applications, the lightweight and superimproved mechanical properties of NFC materials made them an excellent choice. 'In North America, light vehicles are one of the most important markets for plastics and polymer composites and had evolved dramatically over the last five decades. There are more than 1000 plastic components in the typical light vehicle, which make up about 8.6% of the overall weight and about 50% of the vehicle's volume' (GVR 2018). This helped to make vehicles lighter, increased passenger safety, and also improved fuel efficiency, and reduced emissions of greenhouse gases. Fibre materials' susceptibility to moisture and poor bonding with polymer matrices, however, appear to hamper the growth prospects of NFCs. The application of NFCs to car interiors in the automotive industry has been limited by the swelling reaction when exposed to humidity (Swift et al. 2015). Among the different synthetic materials that had been investigated for automotive use as an alternative to iron and steel, plastics have a large share. The studies of filled plastic composites have stimulated tremendous interest in meeting the scarcity of plastic materials over the last decade (Lightsey 1983). From everyday papers to complex structures, computer parts, etc., plastics are used for almost all (Rai and Jai Singh 1986), as a result of lightweight, low water absorption, elevated stiffness, and strength. Synthetic fibres such as nylon, rayon, aramid, glass, and carbon are widely used as plastic reinforcements. There is currently a need to look for their alternate, which is nothing but normal, due to unpredictable conditions of scarcity and the cost of petroleum and its by-products. Vegetable/plant fibres have proved to be an alternative fibre to their synthetic counterpart in recent years.

Natural fibres are less expensive, biodegradable, and do not present a health risk. The natural fibres are readily accessible and abundant in nature. They serve as a viable alternative in polymer reinforcement because of their low cost and renewability compared to synthetic fibres which are expensive and non-renewable. A multitude of natural fibres including wood sawdust, Borassus fruit, kenaf, okra, bamboo, betel nut, cannabis, abaca, coconut, rice husks, walnut, sisal, Arenga pinnata, roselle, cotton stalk, wheat straw, pineapple leaves, jute, and many others, have been studied as composite fillers (Rao and K. and MohanaRao et al. 2007). In West Africa, *Musa* spp. is extensively cultivated. Nigeria is among the principal producers of *Musa* spp. (Venkateshwaran and Elayaperumal 2010; Mukhopadhyay et al. 2008). In general, the plant is cut after harvesting the fruit, leaving the lower part of the plant for the fresh stalk to emerge from Pothan et al. (2007). Growers harvest only *Musa* spp. fruit for food and fruit wrapping leaves. The other parts of the plant are regarded as waste and a source of natural fibres used in composites for reinforcement (Becker et al. 2013). Banana wastes include rotting berries, peels, a bunch of empty fruit, leaves, rhizome, and pseudostem (Ihueze and Okafor 2014). When properly pretreated and prepared, fruit bunches, pseudo-stems (Abdullah et al. 2014; Imoisili et al. 2017; Srinivasan et al. 2014), and peels (Brindha et al. 2017; Naidu et al. 2013) are very good sources of fibres for the development of reinforced composites and other applications such as pyrolysis feedstock, textiles, and paper manufacture and in the preparation of adsorbent (Srinivasan et al. 2014).

As a result of their excellent mechanical properties, ease of processing, and comparatively low cost, polymer composite reinforced with fibre materials is adapted in various manufacturing processes (Yusuf et al. 2019; Santhosh et al. 2014). A plethora of research work on *Musa* spp. fibres as fillers in composites manufacture have been performed over the years. The goal of this study is to discuss the existing state of awareness of the interplay of *Musa* spp. fibre in composite manufacturing to assist

planning researchers with comprehensive knowledge of bio-based composite design and choice of material.

Main text

Musa spp. *fibre* extraction

The extraction of fibre from the body tissue of *Musa* spp. is known as retting (Amir et al. 2017). Retting can be accomplished through Biological, chemical, physical and mechanical processes. Biological retting can be achieved artificially or naturally with the use of microorganisms or enzymes. Chemical agents, for example, Sodium hydroxide, surfactants, are applied in chemical retting. Steam explosion and ultrasound retting are categorized under physical retting. The production of green fibres is achieved through mechanical means and it is referred to as mechanical retting (Mohanty et al. 2005).

Musa spp. fibre treatment

There are disadvantages associated with using cellulosic fibres in composites as reinforcement materials. These include the incompatibility of hydrophobic polymer matrices with hydrophilic fibres (poor interfacial adhesion), aggregate-form propensity during manufacturing, and low moisture resistance. These properties play important roles in determining the physical, mechanical, structural, and thermal properties of the composites (Sisti et al. 2018). Researchers have shown that chemical modifications of fibres like acetylation, acrylation, and treatment with alkali, polystyrene, styrene–maleic, and anhydride increased the composite's tensile properties by growing the dispersion of the fibres in the composites, reducing the hydrophobicity of the fibre, and improving the compatibility of fibre/matrix through mechanical anchoring, physical, and chemical bonding (Poletto and Zattera 2015; Haneefa et al. 2008).

Coupling agents helped in improving the interfacial adhesion between matrices and fibres, however, most researchers preferred using chemical treatments in resolving these disadvantages (Li et al. 2007; Zin et al. 2018; Lyn 2018; Cai et al. 2015). Physically, techniques such as calendar, heat treatment, electric discharge (corona method), and mercerization, were used in treatment fibre. These methods change the fibres surface and structural properties with a significant impact on polymer adhesion, but they do not influence the fibre's chemical constituents (Fiore et al. 2016). Mercerization, or alkaline therapy, is a widely used physical process. It is a chemical procedure in which natural fibres are immersed in a relatively concentrated aqueous solution with a solid base to achieve adequate swelling by removing hemicelluloses, lignin, waxy materials, and impurities from the fibre cell wall surface. As suggested by ASTM-D1965, mercerization is a concept method of subjecting vegetable fibres to an interaction with a reasonably concentrated strong base aqueous solution to produce great swelling without interfering with the fine structure, dimension, morphology, and mechanical properties of the fibre (Adekunle 2015). In improving the resistance to water absorption and disrupt the network structure of hydrogen bond, mercerization is typically used to eliminate or change the surface OH groups of fibres made of cellulose, thereby raising the roughness of the fibre's surface (Osoka and Onukwuli 2015). The strength of the fibre and absorbency resulting from the swelling of its cell walls are improved by the alkali solution (Kim 2015).

Alkaline fibre treatment depolymerizes cellulose and improves the fibre's surface roughness, which in turn allows the fibre–matrix interface to acquire greater hydrogen bond extension. The application of natural fibre alkali treatment also increases the tensile strength, fibre wetting through fibrillation, adhesion to the fibre–matrix caused by the elimination of artificial and natural impurities, and oils that cover the outer surface of the fibre's cell wall and depolymerizes the architecture of the original fibre to reveal short-length crystallites [41, 39, 47]. The alkali concentration, fibre soaking temperature, and fibre soaking length are the parameters or factors used in mercerization. Okafor et al. (Komal et al. 2019) treated plantain fibres for 4 h with a 5% aqueous NaOH.

Osoka and Onukwuli (Adekunle 2015) treated fibres recovered from the empty fruit bunch of plantain for 30–150 min with 2 to 10 wt % aqueous NaOH. Orekoet al. (Okafor et al. 2012) treated plantain fibres by soaking them for 60 min in 5% aqueous NaOH. Chemically, fibre treatment requires the use of chemical compounds to make two naturally incompatible materials compatible and thus strengthen their mechanical characteristics (Oreko et al. 2018). These fibres are treated in different ways, including enzymatic and alkaline treatment; acetylation, and benzoylation (Xu et al. 2015; Debnath et al. 2019). The widely used binding agents include silane and maleic anhydride as in maleic anhydride-grafted polypropylene (MAPP), and the commonly used maleic anhydride coupling agents.

Maleic anhydride interacts with the OH groups on the fibre surface, replacing the groups of MAPP (Li et al. 2007). This leads to fibre coating with long hydrophobic polymer chains, enhancing hydrophobic matrix compatibility by forming carbon–carbon bonds that enhanced the fibre wettability and interfacial adhesion (Zin et al. 2018; Pannu et al. 2018). Isocyanates, triazine, peroxide, and permanganate (Li et al. 2007; Fiore et al. 2016) are other chemical reagents for natural fibres' treatment.

Musa spp. composite fabrication

Manual technique

To build *Musa* spp. composites, the manufacturer lays the fibres in the resin according to the application's reinforcement needs. This has been accomplished by hand historically and it is referred to as the technique of hand lay-up. The most popular method of composite preparation is hand lay-up technique (Brígida et al. 2010), and it is still the most popular for banana composites because it is cheap and does not require much technical expertise. However, concerted efforts are now being made towards the application of automated methods in fibre placement to ensure quality and repeatability (Kulkarni et al. 2019).

Automated techniques

Automated processes for fibre placement fall into two categories: Tape laying and winding of filaments. The tape-laying method required the use of equipment that controlled fibre positioning over resins of narrow fibre tapes. The 'sharpness' of the turns needed to position the fibres in the specified direction is determined by the width of the tape. This means that larger tapes were used for incremental turns whereas narrow tapes were used for the sharp turns that are associated with more complex shapes. The smaller units of fibre are used for filament winding. The fibre yarns are woven in given directions in the shape of the part over a rotating mandrel in this system. Successive layers are added until the appropriate thickness is achieved.

While filament winding was initially restricted to simple and direct paths, with the use of robots, the method is now able to produce complex shapes. A second manipulation of the outcome of tape laying or filament winding must be achieved when thermosets are used as polymer resins. In an autoclave or oven, this is normally done by heating the completed structure (Kulkarni et al. 2019). The benefit of online consolidation is provided by thermoplastic systems to remove the high energy and capital costs associated with the curing phase. For manufacturing composites, extrusion is the most common continuous process (Kulkarni et al. 2019).

On the extrusion line at one end, fibres and the resin are pushed through a heated die or shaping tool and then cooled and pulled out at the end. This process can be applied to both thermoplastic and thermoset polymers. RTM (Resin transfer moulding) is a type of composite processing that offers a high flexibility potential, but is limited to low viscosity thermosetting polymers (easily flowing). In the process, a braided, woven, or knitted fibre is placed in a mould, which is further closed and injected with resin (Santhosh et al. 2014; Adeniyi et al. 2019). Following curing, the object is removed by opening the mould. The fibres are generated in a wide range of designs, and for better mechanical properties, many can be joined together in varying orientations. Together with extrusion and RTM, researchers have used injection moulding and compression moulding, which showed that both methods are better suited for thermoplastics than for thermosets (Brígida et al. 2010).

Characterization of *Musa* spp. fibre

X-Ray fluorescence of *Musa* spp. fibre

Using X-ray fluorescence (XRF) (e.g. Nitron 3000), raw plantain fibres are analysed for elemental and oxide compositions. After initialization, the system is turned on and allowed to stabilize for 5 min. The tool commonly used was the Cu–Zn system, which, due to its strength, usually detects a large number of elements and sesquioxides. While the ray point was placed over it, the sample was placed on the sample holder and the ray button was pressed to observe log data. The data are obtained in triplicates and the average is immediately taken (Alavudeen et al. 2015).

The elemental composition of raw plantain fibres is provided in Table 1 (Adeniyi et al. 2020). The data revealed that the five highest inorganic constituents of plantain fibre in the descending order were indium, silicon, potassium, calcium, and aluminium. These elements and others present in smaller amounts are underpinned by the use of harvested plantain fibres in various engineering applications. For instance, indium and silicon are useful in the manufacture of electronic devices such as transistors, insulators, rectifiers, and chips, given that

Table 1 *Musa* spp. fibre elemental compositions (Alavudeen et al. 2015; Adeniyi et al. 2020)

Element name	Element symbol	Percentage composition (%)
Indium	In	35.01
Potassium	K	25.05
Silicon	Si	13.87
Calcium	Ca	7.76
Aluminium	Al	4.00
Chlorine	Cl	3.74
Sulphur	S	2.06
Iron	Fe	1.04
Titanium	Ti	0.19
Copper	Cu	0.18
Manganese	Mn	0.09
Arsenic	As	0.009
Lead	Pb	0.008
Barium	Ba	0.004

they are present in the quantities extracted. For the production of thin conductive transparent films for photovoltaic use, indium oxide can also be doped with tin oxide on its own. The comparable use of bio-extracted silicon and indium has been verified by previous works (Ju´ stiz-Smith et al. 2008; Vu et al. 2010). Plantain fibre can also be reprocessed due to the potassium and silicon content of the fibre for use in fertilizer production (Zhang et al. 2015). Potassium for industrial and health applications such as blood pressure control can also be derived from plantain fibre (Mohiuddin et al. 2014). In the manufacture of yarn, thread, high-quality textiles, and auto-body works, plantain fibres can also be used as a composite material (Becker et al. 2013; Okafor et al. 2012; Ramesh et al. 2014).

Fourier transform infrared spectroscopy (FTIR) of plantain fibres

The study of fibres functional group using FTIR is an important indicator of the possibility of the integration of fibres with polymer matrices. To qualitatively classify the constituents of the fibre, FTIR Spectroscopy was carried out on the treated and untreated plantain fibre samples. The strength of light absorbed or released by the fibre at a given wavelength corresponding to a given functional group in the fibre is obtained by FTIR spectroscopy. The FTIR spectra for samples of plantain fibres, NT, 2 T, 4 T, and 6 T are shown in Fig. 1. The characterization spectra of untreated and treated plantain fibres as derived from Fig. 1 are summarized in Table 2 (Alavudeen et al. 2015).

For the raw fibre, the broadband at 3344 cm^{-1} corresponds to cellulose vibrational stretching of hydrogen bonded-OH (Xu et al. 2015). This stretching is correlated with the involvement of OH in cellulose, lignin, hemicellulose, and a carboxylic acid, according to Monteiro et al. (Monteiro et al. 2014). The absorption observed at 2917.15 and 2850.66 cm^{-1} corresponds to the alkyl cellulose group's asymmetric and symmetric stretching vibrations, which are typical of any natural fibre. The absorption band value of 1739.13 cm^{-1} and about 1650.66 cm^{-1} can be resulting from the stretching of hemicellulose and probably fatty acids from lignin of the carbonyl (C=0) ester and carboxyl groups (Ortega et al. 2016; Bakri and Jayamani 2016).

The absorption at 1425.86 cm^{-1} corresponds to aromatic ring vibrations, while the small peaks between 1372.03 and 1242.22 cm^{-1} describe the C–H bending bond structure of the cellulose, hemicellulose, and lignin functional group, while the peak at 1039.58 cm^{-1} corresponds to cellulose, hemicellulose, and minor lignin material C–O-symmetric stretching vibration (Ortega et al. 2016; Sefadi and Luyt 2012). The β-glucoside linkages between the sugar units in cellulose and hemicellulose are due to the small absorption band at 878.10 cm^{-1} (Xu et al. 2015).

After treatment of the fibres, the strength of the peak about 3344 cm^{-1} earlier noted for the raw fibre increased

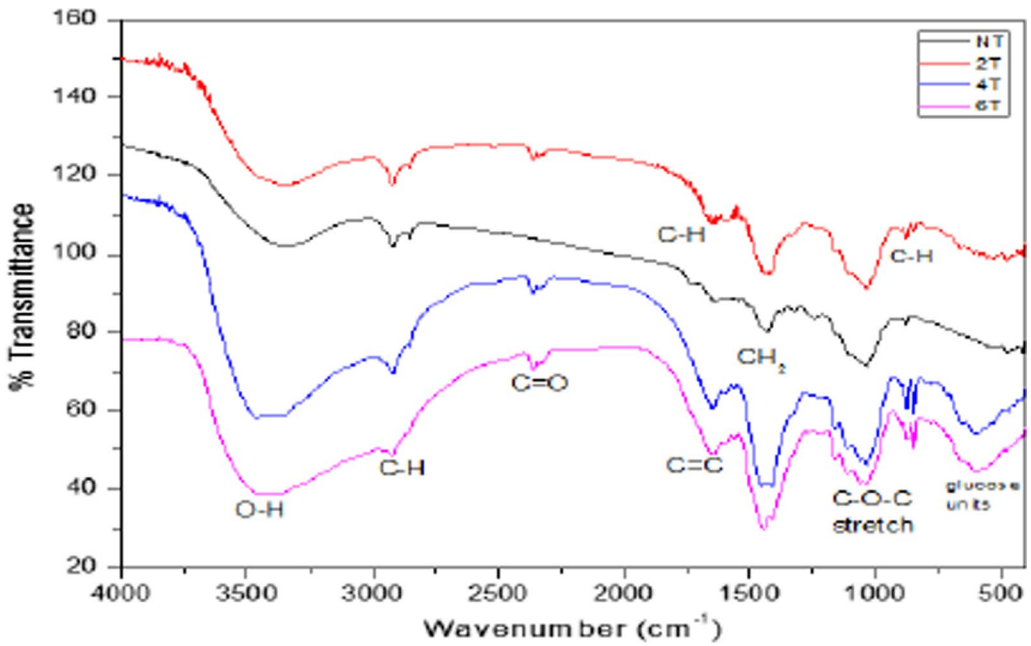

Fig. 1 IR spectra of treated and non-treated plantain fibres (Alavudeen et al. 2015)

Table 2 IR spectral analysis of treated and untreated plantain fibre (Alavudeen et al. 2015)

Functional group	NT (cm^{-1})	2 T (cm^{-1})	4 T (cm^{-1})	6 T (cm^{-1})	Possible assignments
O–H stretching (H-bonded)	3344.59	3354.09	3464.91 3347.76	3452.24	Cellulose, hemicellulose, and lignin
C–H stretching (aromatic)	2917.15 2850.66	2923.48 2850.66	2920.32	2923.48	Cellulose, lignin, carboxylic acids
C = C stretching (ester, aromatic ring, ketone)	1739.31 1650.66	1656.99	1659.89	1739.81 1650.66	Lignin, hemicellulose
C–H bending (deformations)	1425.86	1425.86	1451.19 1406.86	1444.85 1410.03	Cellulose, lignin
C–O	1242.22 1039.58	1033.25	1036.41	1232.72 1033.25	Lignin, hemicellulose
C–O–C stretch			1106.07	1159.89 1112.40	Cellulose
Glucose units	878.10	881.27 249.60	878.10 852.77	871.77 846.44	β-glycosidic linkages between the monosaccharides

to around 3354 cm^{-1}, this increase may be due to the OH group's breakdown of lignin and part hydrogen bond (Reddy et al. 2013). This hydrogen-bonded (−OH) vibration characteristic peak indicates the presence of intermolecular hydrogen bonding that appears to change in improved treated fibres to higher absorbance value (Reddy et al. 2013). From the data presented, it can be observed that only 2% of the treated fibres had higher absorbance compared to NT fibres, which means that 2 T fibres are stronger than untreated fibres, whereas 4 T and 6 T fibres have decreased intensity.

If the amount of the alkali increases, the OH band becomes wider and this implies the presence of a high cellulose concentration. Also, the band 1739.31 cm^{-1} which is absent in the treated fibres due to the CH_3COO- and COOH functional group of hemicellulose found in the raw fibre spectra. The absence of this characteristic vibrational stretching indicates that the hemicellulose material has been substantially eliminated by alkaline therapy (Sefadi and Luyt 2012). Fibres are further demonstrated in literature in the functional group study for further fibre treatment as shown in FTIR spectra [41, 5, 62, 64]. The results of the FTIR study showed that NaOH treatment resulted in the gradual elimination of hemicellulose and lignin, which act as fibre binding components. As demonstrated by the widening of the OH band, the therapy was also successful in exposing lignin. Free hydroxyl groups that can react with polymer groups in composite production are shown by large concentrations of cellulose on fibre surfaces (Alavudeen et al. 2015).

Chemical composition of *Musa* spp. fibre

As stated by Adeniyi*et al.* (Kulkarni et al. 2019) and Geethama et al. (Ihueze et al. 2015), Table 3 presents the characteristic chemical composition of the banana and plantain.

Table 3 Chemical composition of extracted *Musa* spp. fibres (Kulkarni et al. 2019; Ihueze et al. 2015)

Chemical constituent	Banana fibre (%)	Plantain fibre (%)
Cellulose	64	56.83
Hemicellulose/ Holocellulose	19	68.68
Lignin	5	19.13
Moisture	10–11	–
Acetone extractives	–	1.27
Water soluble	–	10.75
Ash	–	2.37

Physicomechanical properties of natural *Musa* spp. fibre

Fibre samples subjected to standardized characterization tests such as ash and charcoal contents, water absorption, moisture content, tensile strength, elemental analysis, and chemical analysis, and the presence of metal elements as tabulated (Tables 1, 2, 3, 4). Also, ions in natural fibres and the different chemical properties of cellulosic fibres had been similarly reported (Rai and Jai Singh 1986; Rao and K. and MohanaRao et al. 2007; Alavudeen et al. 2015; Adeniyi et al. 2020).

Also, the bananas cross-sectional area was examined by Murali and Mohan (Reddy and Yang 2003) using optical laser beam equipment, demonstrating that the banana fibre's cross-sectional area taken for the study is 0.3596mm^2. At various degrees of orientation of the fibre cross section, the cross section measurements of the fibres are determined. This investigation projected that the cross sections of the fibre were roughly circular. The

Table 4 Physicomechanical properties of isolated *Musa* spp. fibres (Rao and K. and MohanaRao et al. 2007; Alavudeen et al. 2015)

Reference	Density (kg/m^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Crystallinity	Tenacity (MPa)
Adeniyi et al. 2019)	–	470–550	12	4–6	–	–
Geethama et al. 1995)	1350	550 ± 6.7	–	5–6	–	–
Idicula et al. 2005)	1350	550 ± 6.8	–	3–4	–	–
Imoisili et al. 2017)	1344	489.54	8.05	3.27	–	–
Idicula et al. 2010)	–	355 ± 20	–	–	–	–
Jannah et al. 2009)	–	500	–	7	–	–
Joseph et al. 2002)		161.8 ± 11.8	8.5 ± 0.9	–	–	–
Merlini et al. 2011)	1300	750	–	2–4	–	–
Mukhopadhyay et al. 2008)	1300	8.5 ± 0.9	–	1.8–3.5	–	–
Xu et al. 2015)	–	210 ± 20	26.86 ± 11.84	0.8 ± 0.3	–	–
Haneefa et al. 2008)	–	212	–	–		
Becker et al. 2013)	–	–	–	1.0–3.5	45	2.4–3.7
Paul et al. 2007)	–	–	8–20	1.0–3.5	–	529–759

magnitude of laser beam diffraction was also found to be dependent on the curvature of the cross section and the variety of the fibre. The test, therefore, gives relative fibre shapes rather than the real area of the cross section.

The optical microscopy study by Kulkarni et al. (Geethama et al. 1998) has revealed the banana fibre cell structure. It has four cell types, namely phloem, sclerenchyma, xylem, and parenchyma, which made up the banana fibre. Besides, in this analysis, they discovered the variations of mechanical properties with the fibre diameter (Rao and K. and MohanaRao et al. 2007). Using banana fibre combined with epoxy resin and hardener, Al-Qureshi (Kulkarni et al. 1982) designed and tested a truck 'Manaca' model. However, some rare and necessary fibreglass/banana chopped fibre/epoxy hybrid composite panels were laminated. It has gone through several years of research for road quality and has shown excellent results in conclusion. The percentage moisture content and density of individual fibres are shown in Table 2 (Alavudeen et al. 2015).

Geethama et al. (1998) measured the tenacity and elastic modulus of banana fibre in the range of 529–759 MPa and 8–20 GPa, respectively, with a percentage elongation of banana fibre breakage varying from 1.0 to 3.5 (Alavudeen et al. 2015).

Musa spp. composites characterization

According to the ASTMD 3039 (Standard Test Method), universal testing machine (UTM) was used for the analysis of composites' Tensile Properties (Al-Qureshi 1999). The samples selected were tested to study the morphological and functional responses of the composite, prepared entirely at room temperature during cold processing, with the highest levels of factor combinations. To qualitatively classify the constituents of the fibre using a Thermo-Scientific Nicolet iS5-iD1 unit, Fourier transform infrared (FTIR) spectroscopy is carried out on the treated and untreated composite samples (with the highest degree of factor combination). Using a scanning electron microscope (SEMPhenomProX) with a microscope acceleration voltage set to 15 kV, the surface properties of composites are also carried out (Alavudeen et al. 2015).

Tensile characteristics of *Musa* spp. composites

Figure 2 shows the tensile strength, as applied to the identification of the samples, where the treated fibres are represented with samples 1 to 30. In brief, composites produced with treated and untreated plantain fibres were considered and subjected to fibre-length effects and fibre concentration at different levels of their combinations. It was verified, on a general basis, that composites in samples 1 to 9 have a tensile strength higher than composites in samples 10 to 30. This may be explained by the adhesive effect of the handled polystyrene matrix as previously described by Abdulkareem et al. (ASTM et al. 2017; Abdulkareem and Adeniyi 2017). Figure 2 displays the graphical presentation of the tensile strength obtained from the study of composite samples. The graph showed a high tensile strength yielded by samples 6, 9, and 5 in descending order, with a maximum tensile strength of 401 MPa for sample 5 (Alavudeen et al. 2015).

This research indicated that untreated plantain fibre had the highest tensile strength when combined with polystyrene resin. As shown in the result tensile strength improved as fibre length and fibre concentration increased. This is distinct from similar works with different polymer matrices (Arun et al. 2016; Abdulkareem and Adeniyi 2017); the treated fibres were believed

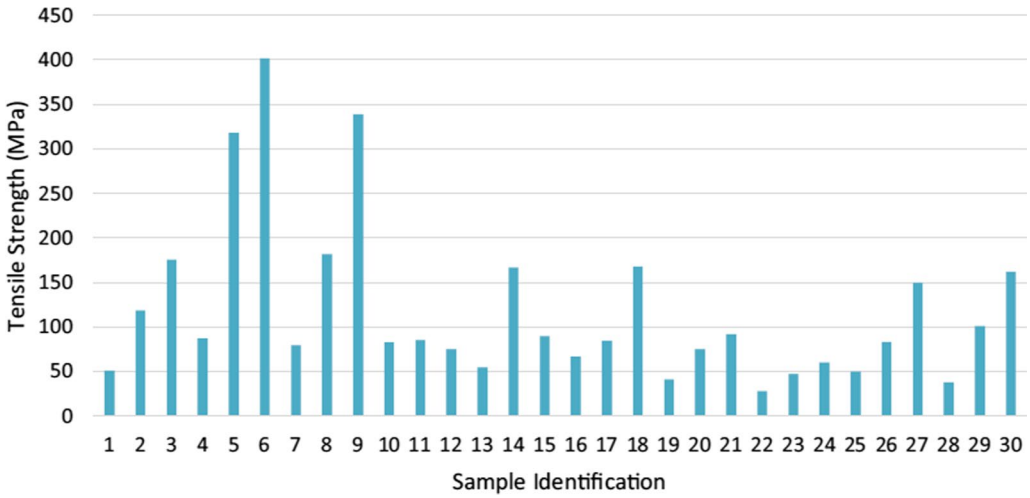

Fig. 2 Tensile strengths response of plantain fibre polystyrene composites (Alavudeen et al. 2015)

to have the highest fibrous composite tensile strength. However, in this research, interfacial adhesion was not an obstacle, previous works in the literature reported that polystyrene contributes to the adhesive matrix Abdulkareem et al., (ASTM et al. 2017; Abdulkareem and Adeniyi 2017), which makes untreated fibre stronger throughout curing. The whole composite processing was also performed at room temperature in cold pressing and there was no polymer melting or hot pressing involved, it was a non-thermal mixing process.

FTIR Characteristics of *Musa* spp. composites

The FTIR spectra for composites of treated and untreated plantain fibres are shown in Fig. 3. The composites with treated and untreated samples were picked from the high-level samples because the fibre length and the fibre concentration did not influence the composition of the final composite (Kulkarni et al. 2019). The possible functional groups found are O–H (hydroxyl), C=C (alkenes), CH_2, C–O, CO–OH (carboxyl), and aromatic carbon groups (Abdulkareem et al. 2020; Herman et al. 2015). A contrast of the fibre composite spectra of not treated and treated showed that the amplitude of the PFRPC peaks of not treated was greater than that of the treated composites. This indicates that the absorbance ratios of the processed fibre composites are greater than those of the untreated fibres. The mean light intensities are both 88.18 and 88.46 for untreated and treated PFRPC composites, which revealed the influence of fibre alteration on the absorption of light. This means that, while composites can have comparable properties, treated fibre composites may be more brittle than untreated fibre composites (Reddy et al. 2013). This indicates that the treated composites have higher fibre–matrix adhesion relative to untreated fibre composites, as already seen in the SEM findings (Alavudeen et al. 2015).

SEM characteristics of *Musa* spp. composites

The internal cracks and internal structure composite samples were observed using SEM micrographs (Mohiuddin et al. 2014). Among the high-level samples of treated and untreated specimens, the composites used were chosen. This was to show the effects of fibre treatment on the polystyrene matrix. The micrograph showed clearly the effect of reinforcement with plantain fibres, the dispersion of fibres, and the effect of the treated fibres (Fig. 4).

Concerning the untreated PFRPC, the surface of the treated PFRPC had a heterogeneous surface with a relatively homogeneous surface. As alkaline treatment of fibres increased their surface roughness was exposed. A rougher surface relative to that of the untreated composite was observed. Li et al. (2007) also found out that proper bonding of microfibrils in untreated PFRPC was found in contrast with that of treated PFRPC whose microfibrils were dispersed and not properly bonded. This phenomenon was attributed to the removal by alkaline treatment of hemicellulose and pectin as binding agents between fibre-forming microfibrils (Li et al. 2007; Ramesh et al. 2014). Figure 4 displays fibre pull-outs, as seen by the white circle, thus creating voids. Higher interfacial bonding was attributed to the presence of hackles (shown by the red circle). Low compatibility with polystyrene of untreated plantain fibre (Song et al. 2018) was observed in SEM micrographs of untreated PFRPC. The treated PFRPC micrograph reveals that the

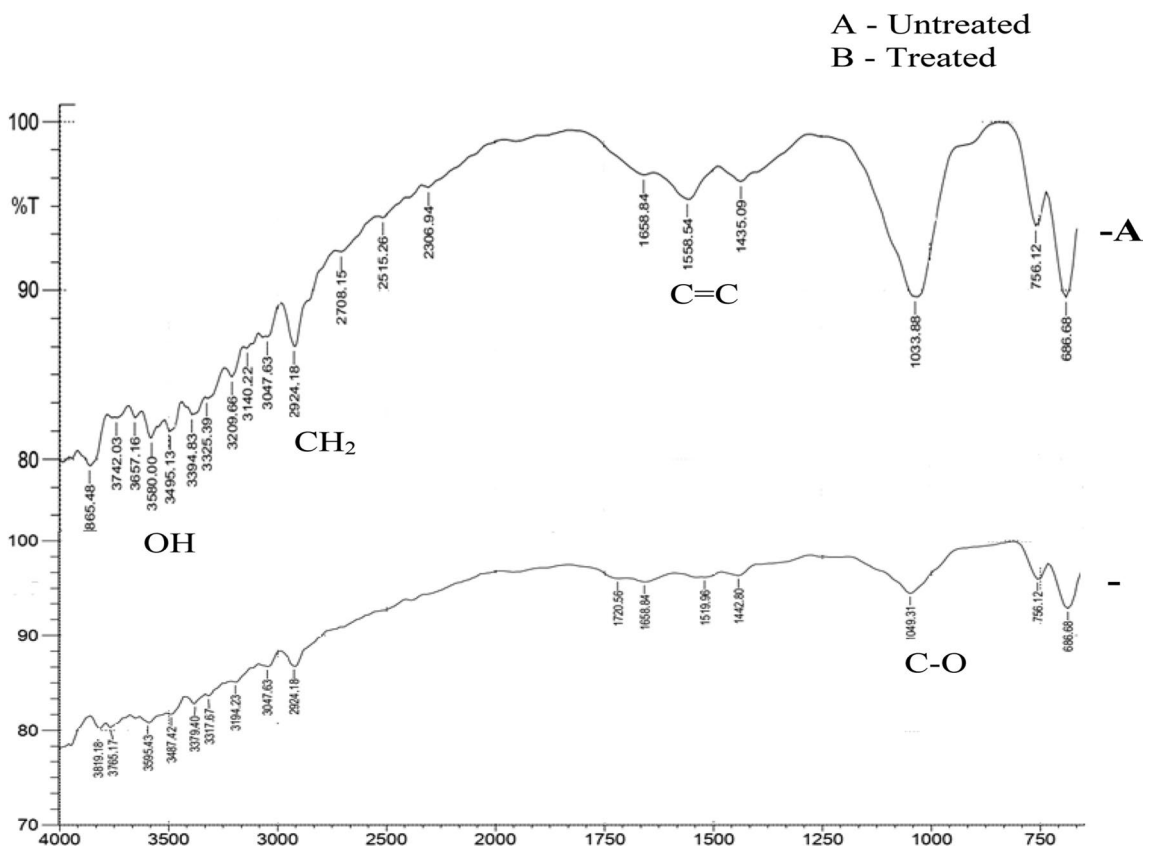

Fig. 3 FTIR spectra of treated and untreated composites (Alavudeen et al. 2015)

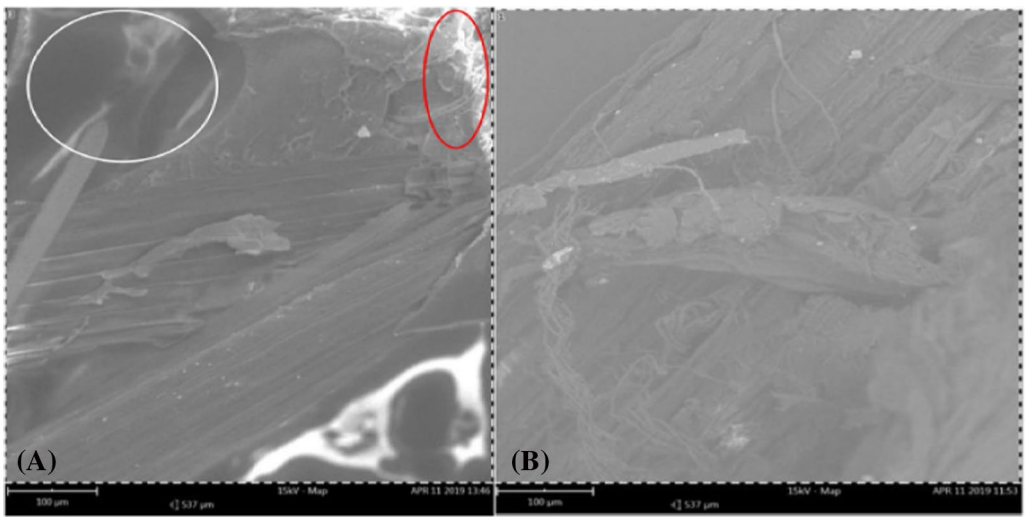

Fig. 4 SEM micrographs of **a** untreated and **b** treated composites (Alavudeen et al. 2015)

fibres on the composite surfaces were twisted, bent, and almost broken; hence, there were a negligible number of voids around the fibres and a few pull-outs of fibre. These findings indicate the high compatibility of fibre and resin (Bakri and Jayamani 2016; Bennet et al. 2014). This means that processed plantain fibres have better

adhesion to the polystyrene matrix than untreated fibres. Since composites need to have high tensile strength and good interfacial adhesion to be used successfully in structural applications (Singh and Palsule 2014), more research is required to obtain solid and robust PFRPC for optimum treatment concentration and structure of the fibre–matrix.

Physicomechanical properties of *Musa* spp. fibre-reinforced composites

Several studies have been performed to predict the various mechanical properties of polymer-reinforced banana fibre composites, such as tensile strength and flexural strength. The outstanding mechanical properties exhibited by the banana fibres are shown in Table 5. Tensile checks were conducted under ASTM-D 3379-75 (Reddy and Yang 2003). The physicochemical properties of natural *Musa* spp. fibre are shown in Table 4.

Banana–polyester composites

Several studies have been performed with the base matrix of commercially sourced unsaturated polyester resin (HSR 8131), ECMALON 4411, C-451, and P-9509 (Adeniyi et al. 2019; Geethama et al. 1995; Idicula et al. 2010; Shesan et al. 2019; Cadena et al. 2017; Rao et al. 2010). Alavudeen et al. (2015) investigated the relationship of other polyester composites that made use of other forms of natural fibres, banana fibre–polyester composites were used. It was observed in the study (Fig. 3a, columns B and F) that banana fibres had greater tensile strength compared to sisal fibres (Geethama et al. 1995). Rao et al. (Cadena et al. 2017) (Fig. 3a, columns D and G) also confirm the result. In the same research, however, Rao et al. (Cadena et al. 2017) found that both bamboo and vakka fibres used in reinforced composites had higher tensile strength compared to banana fibres (especially bamboo fibres).

Compared to others, studies by Samivel and Babu (Rao et al. 2010) at a slightly lower fibre loading showed that banana fibre-reinforced composites also have higher tensile strength than those of kenaf. We may also infer that the natural fibre-reinforced composites have tensile strength which decreases significantly at low fibre loading. It can be summarized that banana fibre-reinforced polystyrene composites have 55–75 MPa as their tensile strength for fibre loading within the range of 30 to 40%. The perceived tensile strength decreasing order in comparison with other fibres is bamboo, vakka > banana > sisal, kenaf. Bananas can be an option of choice for material developers interested in obtaining maximum tensile strength from their composites based on the position and availability of various natural fibre sources.

Figure 5b shows the flexural strength comparison of other fibre materials to banana fibre. It was revealed in Idicula et al. (Geethama et al. 1995) study (columns C and I) that composites of banana fibre have lower flexural strength compared to sisal. This was also reiterated (columns G and J) by Rao et al. (Cadena et al. 2017). Further analysis by Rao et al. (Cadena et al. 2017) also found that banana fibre-reinforced composites' flexural strength is lower than that of both bamboo and vakka composites. However, Samivel and Babu (Rao et al. 2010) explained that, compared to kenaf fibres, banana fibre-reinforced composites have greater flexural strength. It is difficult to draw some inferences considering the banana fibre's loading with flexural power, as there tend to be large variations between studies. The perceived decreasing order of flexural strength is bamboo, vakka, sisal > banana > kenaf in contrast to other fibres. Based on this, it follows that banana fibre-reinforced composites in the flexural strength domain do not perform favourably with those of other natural fibre-reinforced composites.

In comparison with those of other materials, Fig. 6 shows the impact power of banana fibre-reinforced composites. Samvel and Babu (Rao et al. 2010) was the only published comparative research on the impact strength of banana fibre-reinforced polystyrene composites. Thus, banana has a much stronger impact of power than kenaf fibres.

Banana–epoxy composites

Adeniyi et al. (Alavudeen et al. 2015) compared the role of *Musa* spp. fibre in epoxy composites with other types of fibres from natural origin. The tensile properties of these epoxy composites were studied. Both comparative and non-comparative studies had also been undertaken by several authors (Arun et al. 2016; Sakthivei and Ramesh 2013; Yusuf et al. 2019; Samivel and Babu 2013; Mangalaraja et al. 2019). The study carried out by Arun et al. (2016), Sakthivei and Ramesh (2013) used commercially sourced epoxy resin LY556 and DGEBP-A. It was discovered that composites of banana fibre-reinforced epoxy have lower tensile strength relative to coir (Fig. 7, columns A and F). Banana fibre-reinforced composites had greater tensile strength (Mangalaraja et al. 2019) than hemp fibres (columns B and G). Banana fibre-reinforced composites also have improved tensile strength (Sakthivei and Ramesh 2013) than as in columns C and H. However, for sisal and banana fibres, as in columns E and I, the tensile strength of sisal fibres is greater (Alavudeen et al. 2015).

The perceived decreasing order of tensile strength is coir, sisal > banana > hemp, jute, as opposed to other fibres. When compared to other fibres that have been studied comparatively, banana fibres displayed an

Table 5 Summary of the physicomechanical properties of *Musa* spp. fibre composites (Kulkarni et al. 2019)

Composite	Fibre/resin ratio	Impact	Tensile strength	Flexural	Young's	Flexural	Water	Elongation	Hardness
	(wt% or *V* i) F	strength or energy (kJ/m^2)	(MPa or kN/mi)	strength (MPa or kNi)	Modulus (MPa)	Modulus (MPa)	Absorbance (%)	At break (%)	Number (or shore Di)
Banana–polyester	40:60c	18 MPa	74	80	–	–	–	–	–
Banana–polypropylene	30:70	–	66.26	33.72	–	–	–	–	–
Banana–epoxy	40:60	0.55 J	8.937	34.11	–	–	29.9	–	28
Banana–epoxy	–	6–12 J	58–62	0.73–0.89[i]	–	–	–	–	–
Banana–epoxy	50:50	16.92	17.92	58.06	718	9048	1.24	–	–
Plantain–polyester	4:96	–	–	62–81	–	–	–	–	–
Banana–pineapple leaf–polypropylene	3.75:1.25:95	–	20	28	1040	1000	–	4.5	73[i]
Banana–polystyrene	20:80	–	21.3	8.7[b]	1079.3	572.2[b]	–	6.1	–
Banana–high-density polyethylene	40:60	–	5.2[i]	–	230	–	–	1.4	–
Banana–polyester	0.4:0.6[i]	–	–	–	1385	2723	–	6	–
Banana–polyester	0.4:0.6[i]	36 kJ/mm^2	57	53	1352	2723	–	–	–
Banana–polyester	0.4:0.6[i]	37 kJ/mm^2	57	52	–	–	–	6	–
Plantain–polyester	–	–	40.28	–	–	–	–	–	–
Plantain–polyester	–	–	–	–	–	–	–	–	19 N/mm^2
Plantain–polyester	–	168	–	–	–	–	–	–	–
Banana–polyester	10:90c	63.6	–	80	–	2400	4	–	–
Banana–phenol formaldehyde	41:59[a]	27	26	50 g	440	2400 g	–	11	–
Banana–polypropylene	–	122 J/m	26	68	850	2700	–	–	–
Banana–polyester	40:60	115 J/m	–	29.1	–	1520	5.9	–	–
Banana–HDPE–nylon	38.8:61.2	5.2	31.6	44.6	1850	2070	1.5	–	–
Banana–polyurethane	15:85[c]	–	10.12	–	53.98	–	–	–	–
Banana–polystyrene	40:60	–	–	–	–	–	10	–	–
Banana–LDPE	20:80[c]	–	10 Pa	–	150	–	2	25	–
Banana–polypropylene	30:70[d]	12 MPa	42.5	65	3450	3550	–	2.7	–
Banana–polyester	40:60	38	57	60	450	4500	27[e]	–	–
Banana–polyester	0.374:0.626[i]	–	60.9	91.4f	1080	2040	–	–	–
Banana–polyester	0.25:0.75i	120	13.46	98.25	–	–	1.03		
Banana–vinyl ester	30:70	3.41	17.65	48.21	–	–	–	–	–
Banana–epoxy	30:70	8.11	22.63	51.28	–	–	–	–	–
Banana–epoxy	30:70[c]	5 J	–	–	1656	–	0.1	–	63
Banana–betel nut–polypropylene	11.25:3.75:85	400 J/m	21.5	40	1000	1700	2.6	–	73.5
Banana–epoxy	16:84 [h]	13.25	16.12	57.33	642	8920	21	–	–

Table 5 (continued)

HDPE, high-density polyethene; LDPE, low-density polyethene; V_f volume fraction

[a] Obtained at 30 mm fibre length

[b] For composites developed from untreated fibres

[c] Unit in vol%

[d] Doped with 3 wt% maleic anhydrides

[e] Obtained at 30% fibre loading

[f] Obtained at a volume fraction of 0.392

[g] Obtained at 45% fibre loading

[h] Obtained at 15 mm fibre length

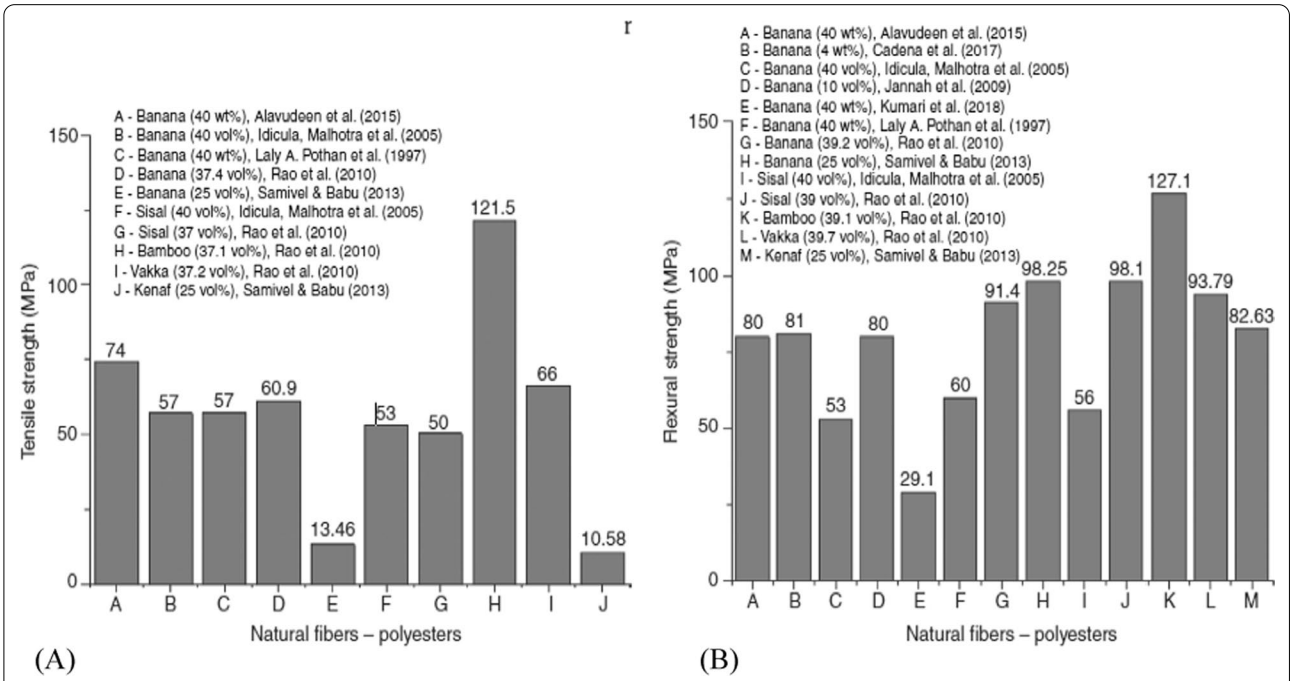

Fig. 5 Tensile (**a**) and flexural (**b**) strength of natural fibre-reinforced polyester composites (Kulkarni et al. 2019)

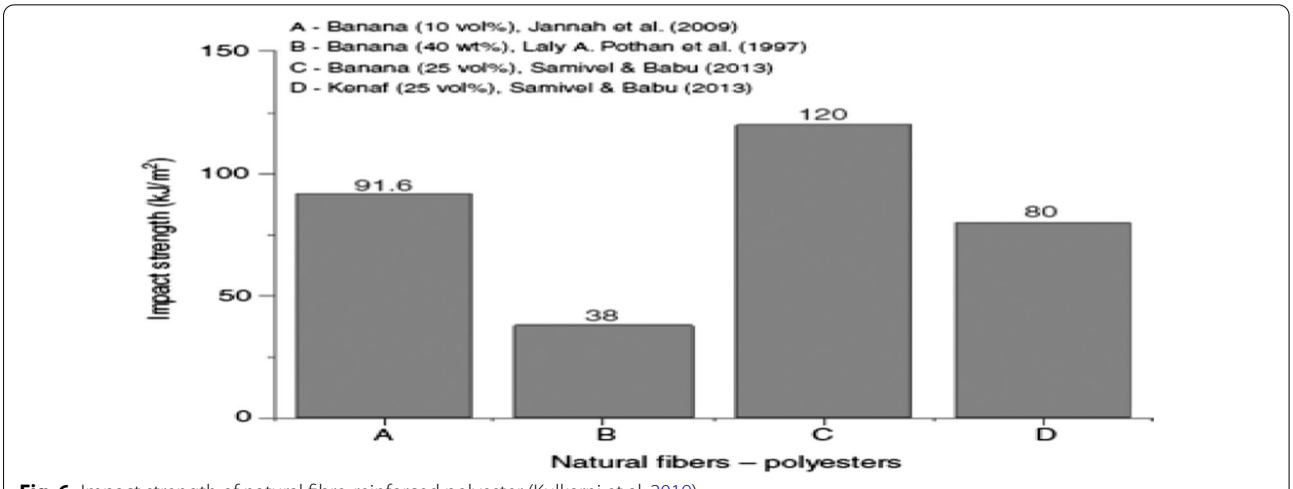

Fig. 6 Impact strength of natural fibre-reinforced polyester (Kulkarni et al. 2019)

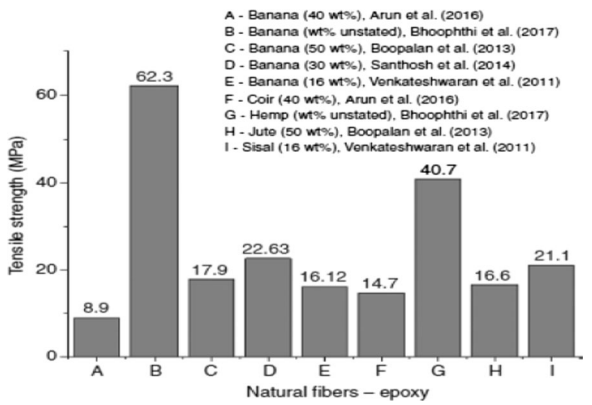

Fig. 7 Tensile strength of natural fibre-reinforced epoxy composites (Kulkarni et al. 2019)

intermediate tensile strength. Therefore, the preference of banana fibres over other natural fibres will be subjectively dependent on the availability of these fibres at the site when considering tensile strength as the property of interest. Compared with coir, flexural strength for banana fibre-reinforced epoxy composites is greater in Fig. 8a (columns A and E) (Arun et al. 2016). The flexural intensity in columns B and F is only slightly higher compared to that of jute (Sakthivei and Ramesh 2013). Compared to banana fibres, sisal fibre-reinforced epoxy composites possess greater flexural strength in columns D and G (Bhoopathi et al. 2017). The perceived flexural strength decreasing order in comparison with other fibres is sisal > banana > coir, jute. It can be inferred that when compared with those of other natural fibres, banana fibre-reinforced composites have an intermediate flexural strength (Kulkarni et al. 2019).

Banana fibre-reinforced epoxy composites have higher impact strength relative to jute fibres in Fig. 8b (columns A and D) (Sakthivei and Ramesh 2013). Sisal fibres, however, demonstrate higher impact strength relative to banana fibres, as seen in columns C and E (Bhoopathi et al. 2017). The perceived declining order of tensile strength for other fibres is sisal > banana > jute. As for the other mechanical properties of banana fibre-reinforced epoxy composites; it can be concluded that, compared to other recorded natural fibres, flexural strength for the banana fibre-reinforced composites were intermediate (Kulkarni et al. 2019).

Banana fibre–cement composites

Several scholars documented the inclusion of banana fibre in cement as reinforcement (Mukhopadhyay et al. 2008; Venkateshwaran et al. 2011; Bledzki and Gassan 1999; Savastano et al. 2005). The air-cured banana fibre-reinforced cement composites were investigated by Zhu et al. (Savastano et al. 2005) and found that flexural strength is about 25 MPa at a fibre load of 14% by mass and the fracture toughness value was 1.74 kJm^2. They indicated that these mechanical properties were ideal for the use of building materials with water absorption of less than 25%. The Brazilian fibres (sisal, banana waste, and Eucalyptus Grandis residue from the pulp mill)

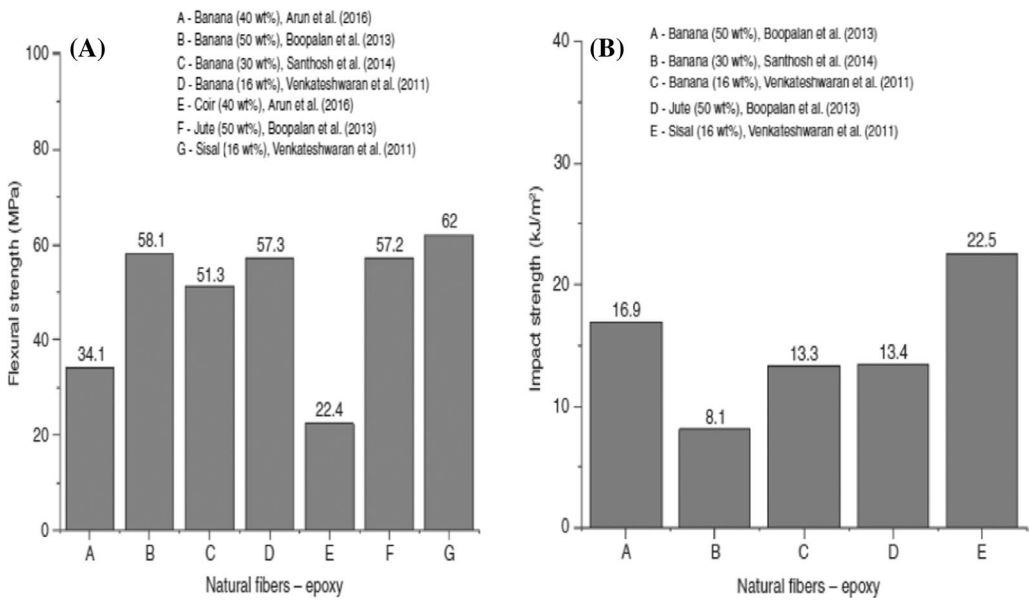

Fig. 8 a , **b** Flexural and Impact strength of natural fibre-reinforced epoxy composites (Kulkarni et al. 2019)

were examined by Savastano et al. (Bledzki and Gassan 1999) as reinforcements for cement-based composites. The study observed that the inclusion of 12% by weight of Brazilian waste fibre pulps into cement produced composites in the range of 1.0–1.5 kJ/m^2 with a flexural strength of about 20 MPa and fracture toughness. Only for low-cost housing construction can these values of composites be used. Besides, banana kraft pulp with a high aspect ratio in ordinary Portland cement offers greater fibre–matrix bonding with increased fibre fracturing and reduced fibre pull-out, and lower toughness (Rao and K. and MohanaRao et al. 2007).

Banana fibre–thermoset plastic composites

The banana fibres use in thermoset–plastics composites manufacture had been earlier investigated (Poletto and Zattera 2015; Geethama et al. 1995; Jannah et al. 2009; Zhu et al. 1994; Mishra et al. 2000; Pothan et al. 2003; Pothan et al. 2003). It was discovered that the use of banana fibre in the scanning electron microscope analysis of cotton fabric that the composites unique module appears to be in similar order compared to glass-fibre-reinforced plastic (UdayKiran et al. 2007). The swelling actions and mechanical properties of fibre/novolac composites were researched by Mishra et al. (Zhu et al. 1994), using a compatible agent (maleic anhydride). It was discovered during the study that the maleic anhydride, when applied, significantly led to a reduction in the steam and water absorption rates associated with an improvement in the module, stiffness, and impact strength of Young, thus mechanical properties' improvement (Rao and K. and MohanaRao et al. 2007). The research also established the treatment of composites with maleic anhydride, ensuring a higher consistency of composite materials reinforced with plant fibre. Joseph et al. (Jannah et al. 2009) investigated the relationship between glass fibres and banana fibres, and phenol–formaldehyde-reinforced composites' mechanical properties. They determined that glass fibres and banana fibres, at optimum fibre length have maximum tensile stress of 40 and 30 mm, respectively. They discovered also that banana/phenol–formaldehyde composites increased Young's modulus and tensile strength values up to 320 and 400%, respectively, with fibre loading application of 48% when a neat resin was used. The composite's Flexural modulus was increased to 25% for banana/phenol–formaldehyde composites by increasing the fibre loading up to 45% (Bhoopathi et al. 2017). The polymeric materials' structure and viscoelastic behaviour for different applications to assess their relevant stiffness and damping characteristics have been investigated using dynamic mechanical test methods over a calculated range of temperatures and frequencies (Bhoopathi et al. 2017). Pothan et al. (Mishra et al. 2000; Pothan et al. 2003) discovered that better fibre/matrix bonding occurred at 40% fibre loading in their study on dynamic mechanical analysis of banana fibre strengthened with polyester composites, with debonding occurring at 10 and 20%, respectively, when analysed through SEM. Idicula et al. (Nystrom et al. 2007) found at random that using a short banana and polyester-reinforced sisal fibres, the composites provided the highest value in their work with a fraction of 0.40 by volume. Using composites with relative sisal and banana volume fraction, high tensile strength, flexural modulus, and lowest impact strength, improved fibre/matrix adhesion and stress transfer, composites with relative sisal volume, and a 3:1 fraction of banana volume are obtained.

When the matrix of the polyester was mixed with banana/sisal fibre it resulted in a decline in the thermal conductivity efficiency of the composite. This demonstrated that polymeric matrix thermal conductivity was more significant. The treated fibre exhibited a major improvement in banana/sisal fibre density and thermal conductivity value, while the opposite effect was seen for composites of pineapple leaf fibre (PALF)/glass fibre. Pothan et al. (Mukhopadhyay et al. 2008) studied the fibre/matrix interaction feature with chemical surface adjustment on complex mechanical properties and found 80 °C and 130 °C failure modulus curves and damping curve, respectively. The peaks around 130 °C are correlated with the matrix 'Tg' glass transition temperature and that is due to the interlayer transition around 80 °C.

Uday et al. (Pothan et al. 2006) found in their work that polyester-reinforced banana fibre has a tensile strength of 59 MPa when the fibre length was 30 mm and 51% fibre weight. Haneefa et al. (Poletto and Zattera 2015) in their study on the hybridization of banana fibre and glass fibre identified improved Young's modulus \and tensile strength with an increased glass fibre's volume fraction due to greater compatibility polystyrene matrix with the glass fibre.

Banana fibre–thermoplastic composites

Banana fibre applied as reinforcement in thermoplastic composites has been documented in several studies (Idicula et al. 2006; Sapuan et al. 2006; Maleque et al. 2006; Habibi et al. 2008; Paul et al. 2008). Sapuan et al. (Idicula et al. 2006) and Maleque et al. (Sapuan et al. 2006) studied the mechanical properties of woven banana fibres reinforced with epoxy composites. The x direction maximal stress value was estimated to be 14.14MN/m^2 and 3.398MN/m^2 in the y direction. Analysis of the traction, flexural effects, and fracture surface of woven pseudo stem banana fibre reinforced with epoxy composite by hand lay-up technique was also studied. Tensile test results reveal that, relative to unreinforced epoxy,

the ultimate intensity of banana-reinforced epoxy was improved from 25 to 47 MPa. The Young's module has also been enhanced from 1300 to 1850 MPa. Similarly, flexure power increased from 45 MPa to 75, and Young's flexural module increased from 1525 to 1825 MPa. In their work using agro-industrial residues like cotton stalk, rice straw, bagasse, banana plant waste, etc., the fracture surface analysis by scanning electron microscope showed that the banana fibre composite was characteristic of a ductile type of failure with limited plastic deformation. Habibi et al. (Maleque et al. 2006) reported that except for low-density polyethylene (LDPE), maleated low-density polyethylene (MLDPE) in the 0.75:0.25 blend-based composite ratios, Young's modulus exhibited a gradual increase in value with the inclusion of MLDPE in the blend, while elongation at break remained unevenly constant. Paul et al. (Merlini et al. 2011) discovered in their work on the effects of fibre loading on banana/polypropylene (PP) composite, that thermal diffusivity as well as thermal conductivity, both, respectively, decreased with increased fibre loading (from 0.24 W/mK for tidy polypropylene matrix to 0.217 and 0.157 W/mK for 0.10 and 0.50 of volume fractions, respectively). Chemical treatments (alkali, silane, permanganate, and benzoyl chloride) (Idicula et al. 2010) have also been found to cause increased thermal diffusivity in addition to conductivity (Bhoopathi et al. 2017; Paul et al. 2008).

Banana fibre-biodegradable composites

The preparation or surface modification of strengthening fillers like natural fibres to make them more compatible with protein matrices is the other well-studied way to increase the interface and compatibility of protein composites. For example, Kumar et al. (Zainuddin et al. 2008) treated banana fibres with alkali solution and the treated fibres resulted in improved tensile strength and composite modulus of protein. The tensile strength and modulus of the protein composite made of treated fibres showed an 82% and 963% increase in tensile strength and modulus, respectively, relative to soy protein film without fibres. The biodegradability test demonstrated that composites are 100% biodegradable (Zainuddin et al. 2008).

Conclusions

Considering the desire for materials that are cost-effective, eco-friendly, lightweighted, and durable in the manufacturing industry, Musa spp. fibre used as reinforcement material in composites manufacture comes in handy. In composite manufacture, banana fibre applied as a reinforcing component positively modifies the physical, mechanical, and structural characteristics of the composites. Composites dependent on these fibres have very strong potential in the manufacture of various sections' components in the manufacturing, automobile, machinery industries, as a result of low density, improved tensile strength, high tensile modulus, and low elongation split. Most countries like Nigeria, India, etc., harvest *Musa* spp. in very large quantities. The application of its fibre perceived as waste by the majority of their population in composites manufacture for producing useful industrial components would be very attractive for their economies. *Musa* spp. fibre and its composites could further be made attractive if a suitable cost-effective design method for the separation of its fibre and composite production is developed and engineered. This would enhance its research and application to a greater extent. This work seeks to provide a collective and articulate source of information for systematic and persistent research in *Musa* spp. fibre composites progress and application.

Abbreviations

SPP: Species; NFC: Natural fibre composites; ASTM: American Standard Testing; NaOH: Sodium hydroxide; OH: Hydroxide; MAPP: Maleic anhydride-grafted polypropylene; RTM: Resin transfer moulding; XRF: X-ray fluorescence; Cu–Zn: Copper–zinc; FTIR: Fourier transform infrared spectroscopy; T: Transmittance; IR: Infrared; MP: Megapascal; GP: Gigapascal; kg/m^3: Kilogram per metre cubed; UTM: Universal testing machine; SEM: Scanning electron microscope; PFRPC: Plantain fibre polystyrene composites; wt%: Weight percentage; KJ/m^2: Kilojoule/metre square; MLDPE: Maleated low-density polyethylene; LDPE: Low-density polyethylene.

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Authors' contributions

OR sourced and supplied the pieces of the literature used for the review; EE conceived and initiated the review process. He also sourced some of the literature. MM authenticated the information retrieved from the existing pieces of the literature supplied, and ODO proofread the article and guided text formatting, APC undertook the compilation and typesetting of the review article. With the submission of this manuscript, I undertake that it has not been published, accepted for publication, or under editorial review elsewhere and that all the authors have read and approved the manuscript for submission.

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Declarations

Ethics approval and concept to participate

Not applicable.

Consent for publications

Not applicable.

Competing interest

The authors declare no conflict of interest.

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