Flax Fiber: Novel Material as a Reinforcing Agent in Various Polymer Composites

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ABSTRACT

Synthetic Fibers are derived from the petrochemical route, which is an issue for the environment. Natural fibers are novel materials that are sustainable, cost-effective, and environmentally friendly options to be reinforced in various polymer matrices. Natural fibers have tremendous potential to replace synthetic fibers like glass, Aramid, etc., also they are giving a boost to the rural economy as they are waste material for the agricultural sector. A combination of high mechanical performances and plant-based origin, flax fibers are Flax is the key member in the family of traditional natural fibers. High volume of research articles and reviews targeted on the processing technologies and characteristics of flax-based sustainable composites in various diverse applications, along with semi- structural materials. This article compiles the recent developments in the processing and characterization of polymer composites reinforced by this novel fiber. The moisture absorption of flax fibres, as well as the poor interfacial adhesion between flax fibres and the matrix.

Keywords: Flax fiber, Composites, Semi-structural, Natural fibers

INTRODUCTION

Material selection in the design and manufacturing of a green product is crucial in the area of engineering design. The materials are utilized to analyze their physical properties and also their mechanical properties to shape the product into a better product and achieve its customer satisfaction level. The polymer composite materials are one of them, which offer the ease of processing, productivity, and economy (Faruk et al., 2012; Al-Oqla and Sapuan, 2014; Sanjay and Suchart, 2019). The composites are design-specific materials that possess a special quality in which the properties can be adjusted by changing the different reinforcement and matrix phase (Bledzki and Gassan, 1999; Yogesha, 2017).

Compared to the synthetic fibers, the natural fibers possess many advantages as they are readily available, in large numbers, and cheap (Arpitha et al., 2017; Madhu et al., 2019b). The natural fibers are utilized instead of synthetic fibers in order to reduce the weight of the composites. The density of natural fibers (1.2–1.6 g/cm3) is lower compared to glass fiber (2.4 g/cm3), because of which the lightweight composites are manufactured. Because of this reason, there is a rise in demand for the application of natural fiber-based composites in many industries. So, natural fibers like hemp, jute, sisal, banana, coir, and kenaf are widely utilized to manufacture the lightweight composites (Sreekala and Thomas, 2003; Thakur et al., 2014; Oksman et al., 2016). The natural fiber-based composites have been utilized in the automotive interior linings (roof, rear wall, side panel lining), furniture, building, packaging, and shipping pallets, etc. (Oksman, 2001; Lau et al., 2018; Sood and Dwivedi, 2018; Santhosh Kumar and Hiremath, 2019). Natural fibers are obtained from a range of plants and animals, for example, chicken feathers and hair (Aziz and Ansell, 2004; Huda et al., 2006; Kicinska-Jakubowska et al., 2012). Plant fibers contain structural components such as cellulose, lignin, hemicellulose, pectin, waxes, and water-soluble compounds, as indicated in Figure.

Hydrophilic nature of Cellulose is one of the factors influencing the interfacial interaction of the polymer matrix with thefibers, given that thematrix itself is hydrophobic in nature. The most efficientway of improving the interaction of the fibers and the polymer matrix is through chemical treatment of the natural fibers. The process not only eliminates theOHfunctional groups on thefibersurface but also enhances surface roughness, thereby enhancing interfacial interaction of the matrix with the fibers (Liu et al., 2005; Mahjoub et al., 2014; Manimaran et al., 2017; Athith et al., 2018; Sanjay et al., 2019a). Natural fibers must be studied to assist in the production of green composites.

FIGURE 1

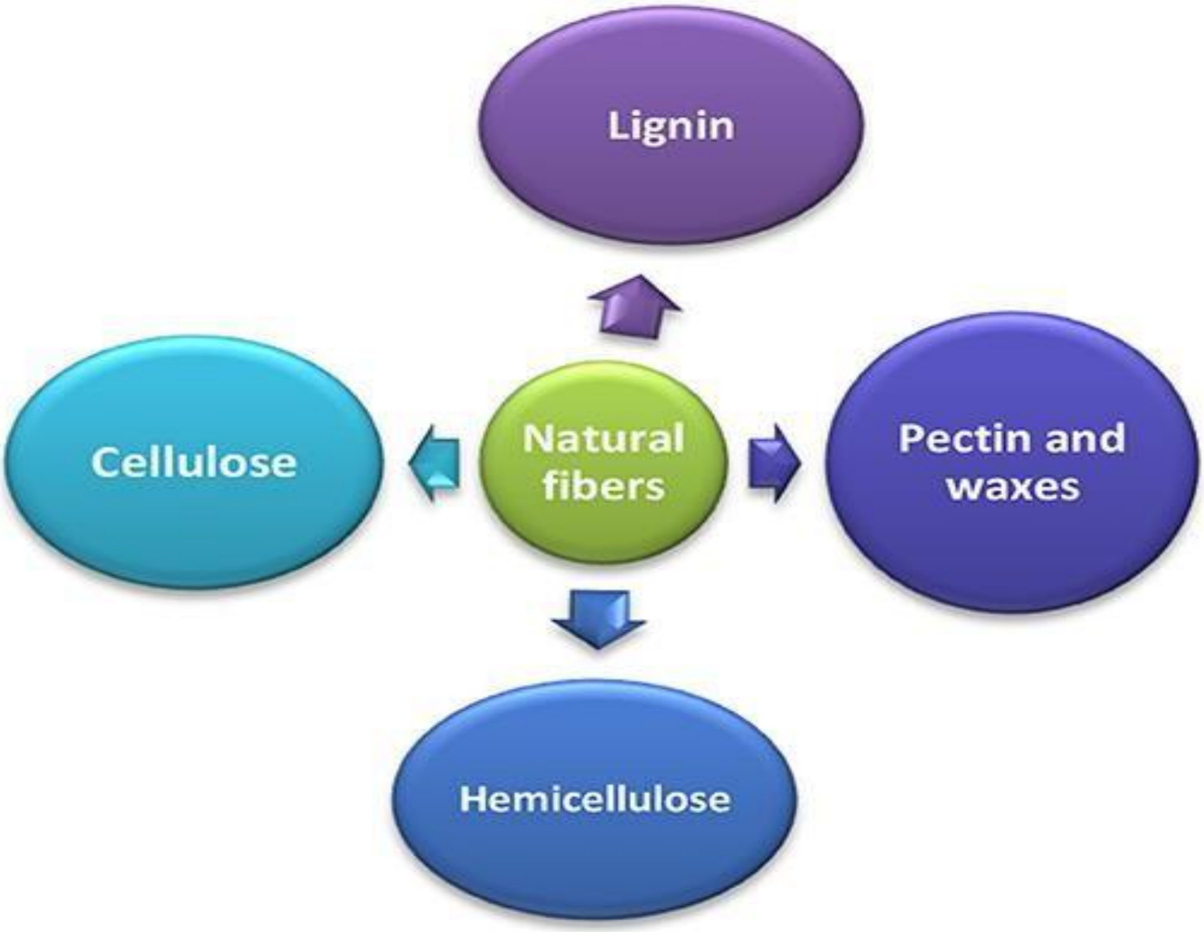


Figure 1. Constituents of plant fibers (Faruk et al., 2014).

Source, Properties, and Applications of Natural Fibers

Kenaf (Hibiscus cannabinus)

The kenaf fibers are one of the important fibers belongs to bast fibers, and it is mainly used for paper and rope production (Hamidon et al., 2019; Omar et al., 2019). Kenaf is a fibrous plant. They are stiff, strong, and tough, and have high resistance to insecticides. These plants were cultivated 4,000 years ago in Africa, Asia, America, and some parts of Europe (Saba et al., 2015; Zamri et al., 2016; Shahinur and Hasan, 2019b). The fibers are extracted from flowers, the outer fiber, and the inner core. The outer fiber is known as bast, which makes 40% of the stalk's dry weight, and the inner core comprises of 60% of the stalk's dry weight. The kenaf plants, upon harvesting, are processed by using a mechanical fiber separator, and the whole stalk is used in pulping. The extracted fibers must be treated chemically or bacterially to separate it from the non-fibrous substances like wax, pectin, and other substances (Suharty et al., 2016; Arjmandi et al., 2017). These fibers can be converted into fine woven fabrics. Kenaf fibers are environmentally friendly as they are completely biodegradable. In the olden days, these fibers were used for textiles, cords, ropes, storage bags, and the Egyptians used them for making boats. Nowadays, these fibers are made as composites along with other materials and are used in automotive, construction, packaging, furniture, textiles, mats, paper pulp, etc. (Nishino et al., 2003; Anuar and Zuraida, 2011; Atiqah et al., 2014; Kipriotis et al., 2015).

Hemp (Cannabis sativa)

Hemp is one of the kinds of plants species grown mainly in Europe and Asia. It grows up to 1.2–4.5 m and 2 cm in diameter (Bhoopathi et al., 2014; Réquilé et al., 2018). The inner girth is surrounded by a core, and the outer layer is the bast fiber, and it is attached to the inner layer by a glue-like substance or pectin. These fibers are used in rope, textiles, garden mulch, an assortment of building material and animal beddings. In recent developments, it is used to fabricate different composites (Li et al., 2006; Martin et al., 2013; Väisänen et al., 2018). The hemp plants are harvested, and the woody core from bast fibers is separated by a sequence of mechanical processes. The woody core is cleaned to obtain the required core content, and sometimes it is cut to the desired size. While the separated bast fibers are further processed to form yarn or bundles (Clarke, 2010; Duval et al., 2011; Fang et al., 2013; Raman Bharath et al., 2015; Sam-Brew and Smith, 2015).

Jute (Corchorus capsularis)

The jute an important natural fiber grown in parts of Asia, including India, Bangladesh, China, and Myanmar (Khan and Khan, 2014; Das, 2017; Shahinur and Hasan, 2019a). The jute plant grows up to 15–20 cm in 4 months, and the fibers are extracted after harvesting, which is about 4 months from cultivation. The retting process is done either with the help of chemicals ($N2H8C2O4$, $Na2SO3$, etc.) or biologically (Rahman, 2010). In biological retting, the stalks that are harvested are arranged in bundles and allowed to soak in water for about 20 days (Banik et al., 2003; Behera et al., 2012). This removesthe pectin between the bast and the wood core, which helps in the separation of the fibers. Then these fibers are allowed to dry.

Flax (Linum usitatissimum)

The flax fibers have been produced since the prehistoric period. These fibers are separated from the stems of the plant *Linum usitatissimum* is mainly used to produce linen (Ruan et al., 2015; De Prez et al., 2018; Bourmaud et al., 2019). These are cellulosic plants but they are more in crystalline form. These fibers measure up to 90 cm in length and have a diameter of 12–16 µm. The Netherlands, Belgium, and France are the leading manufacturers of these fibers. These fibers are used in furniture materials, textiles, bed sheets, linen, interior decoration accessories, etc. (Van de Weyenberg et al., 2003; Charlet et al., 2010; Angelini and Tavarini, 2013; Ramesh, 2019). The fiber extraction involves the retting and scorching; both these processes will make some alterations in the properties of the fibers. The retting involves the enzymes that degrade the pectin around the flax fibers, which results in the separation of fibers. Canada is the largest flax producer and exporter in the world, producing about 872,000 tons (Bos et al., 2006; Zafeiropoulos and Baillie, 2007; Martin et al., 2013; Zhu et al., 2013).

Ramie (Boehmeria nivea)

Ramie is one of the herbaceous perennial plants cultivated extensively in the region native to China, Japan, and Malaysia, where it has been used for over a century as one of the textile fabrics (Nam and Netravali, 2006; Rehman et al., 2019; Yang et al., 2019). Ramie is a non-branching, fast-growing plant that grows up to 1–2 m in height. The fibers extracted from the stem are the strongest and longest of the natural bast fibers. They are used to make sweaters in combination with cotton, also it is used in upholstery, gas mantle, fishing nets, and marine packings, etc. (Cengiz and Babalik, 2009; Marsyahyo et al., 2009; Sen and Jagannatha Reddy, 2011b). In addition to this attempt has been made to develop bio-based products by utilizing them in the field of automotive, furniture, construction, etc. The ramie fibers are extensively used for the production of a wide range of textiles, pulp, paper, agrochemicals, composites, etc. The processing of the ramie fibers is similar to linen from flax (Angelini and Tavarini, 2013; Bunsell, 2018).

Nettle (Urtica dioica)

Nettle is a commonly grown herbaceous plant that consists of 35–40 different species generally grown in Europe, Asia, Northern Africa, and North America (Bacci et al., 2009; Akgül, 2013; Lanzilao et al., 2016). The plant usually grows up to 2 m in length, and the leaves are soft and green, which are 3–15 cm long. The leaves and stems are generally hairy and have stinging hairs on them (Cummings and Olsen, 2011; Fang et al., 2013; Bourgeois et al., 2016). The fiber extraction is done by harvesting the plants during the flowering period. The fiber is extracted either by retting the stalks or by decorticating. The typical applications of nettle fibers are in the textile industry, bioenergy, animal housing, etc. Nowadays, attempts have been made to use the nettle fibers on an industrial scale (Bacci et al., 2009; Mortazavi and Moghaddam, 2010).

Pineapple Leaf (Ananas comosus)

The pineapple plant is one of the abundantly cultivated plants that is easily available. The pineapple leaf fiber is a crop waste after pineapple cultivation. It is a short tropical plant that grows up to 1–2 m, and the leaves are in cluster form consists of 20–30 leaves about 6 cm wide. Approximately 90–100 tons of pineapple leaves are grown per hectare. Among the different natural fibers, pineapple leaf fibers show good mechanical properties. Pineapple leaf fibers are multicellular and lignocellulosic. The fibers were extracted by hand using the scrapers (Kengkhetkit and Amornsakchai, 2012; Laftah and Abdul Rahaman, 2015; Todkar and Patil, 2019). The various applications are in automobiles, textiles, mats, construction, etc. The treated and surface-modified fibers are used for making conveyor belt cord, air-bag, advanced composites, etc. (Paridah et al., 2004; Jawaid and Abdul Khalil, 2011; Reddy and Yang, 2015; Al-Maharma and Al-Huniti, 2019).

Sisal (Agave sisalana)

Sisal is one of the most used natural fibers, and Brazil is one of the largest producers of this fiber. It is a species native to southern Mexico that consists of a rosette of leaves that grows up to 1.5–2 m tall (Naveen et al., 2018; Sanjay et al., 2018; Senthilkumar et al., 2018; Devaraju and Harikumar, 2019). The sisal produces about 200–250 commerciallyusable leaves in the life span of 6–7 years. The sisal fibers are having good range of mechanical properties and are used in the automotive industry, shipping industry (for mooring small craft and handling cargo), civil constructions, used as fiber core of the steel wire cables of elevators, agricultural twine or baler twine, etc. (Mihai, 2013; Ramesh et al., 2013; Nirmal et al., 2015; Aslan et al., 2018).

Date Palm (Phoenix dactylifera)

The date palm is known as a palm extensively grown for its fruit. The biodiversity of the date palm is all over the world, comprising around 19 species with more than 5,000 cultivators all around the world (Wales and Blackman, 2017; Alotaibi et al., 2019; Rivera et al., 2019). The date palm trees (Phoenix dactylifera L.) are the tallest among the Phoenix species and can grow up to 23 m in height (Al-Oqla and Sapuan, 2014; Gheith et al., 2018; Masri et al., 2018). The date palm rachis and leaves are accumulated in large quantities after the harvesting of the date palm fruits every year in the farming lands of different countries. These fibers can be used as potential cellulosic fiber sources. These fibers from leaves and rachis can be used as the reinforcement for thermoplastic and thermosetting polymers. Some researchers have found ways to use the date palm fibers in automotive applications (Alawar et al., 2009; Arunachalam, 2012; Liu et al., 2018).

Cotton (Gossypium)

Cotton belongs to the sub-tribe Hibisceae and family of Malvaceae is an important agricultural crop (Elmogahzy and Farag, 2018). It is the commonly used natural fiber for the production of cloths. The cotton is grown in tropical and subtropical regions, and China is the largest producer of cotton followed by India and the United States (Mwaikambo et al., 2000; Colomban and Jauzein, 2018). Among the various species of cotton, upland cotton (*Gossypium hirsutum*) and pima cotton (*Gossypium barbadense*) are the most popular (Zou et al., 2011; Al-Oqla et al., 2015; Sharma et al., 2017). The leaves of the cotton are removed and are collected and compressed into truckload-sized "modules." Later the modules are transported to processing plant known as the cotton gin. The gin separates the seeds, sticks, burrs, etc. from the cotton fibers. The cotton fiber is usedextensively in textile industries, and recently attempts have been made to develop the composites for industrial applications (Cheung et al., 2009; Gupta and Srivastava, 2016; Balaji and Senthil Vadivu, 2017).

Coconut Fiber (Cocos nucifera)

The coconut fiber is obtained from the husk of the coconut fruit. Among the different natural fibers, coconut fiber is the thickest. Coconut trees are mainly grown in tropical regions (Nair, 2010; Arulandoo et al., 2016;

Danso, 2017). The major share of the commercially produced coconut fiber comes from India, Sri Lanka, Indonesia, Philippines, and Malaysia (Pham, 2016). Coir fiber, in particular, is a light and strong fiber that has attracted scientific and commercial importance due to its specific characteristics and availability (Sen and Jagannatha Reddy, 2011a). Compared to other typical natural fibers, coconut fiber has higher lignin and lower cellulose and hemicellulose, together with its high microfibrillar angle, which offers various valuable properties, such as resilience, strength, and damping, wear, resistance to weathering, and high elongation at break. The coir fiber is used for making ropes, mats, mattresses, brushes, in the upholstery industry, agriculture, construction, etc. (Al-Oqla and Sapuan, 2014; Verma and Gope, 2014; Sengupta and Basu, 2016; dos Santos et al., 2018).

Kapok (Ceiba pentandra)

Kapok belongs to the Bombacaceae family. It grows in tropical regions (Arumugam, 2014; Zheng et al., 2015). Kapok fiber is silk cotton, and the color of the fiber is yellowish or light brown. The fibers enclose the kapok seeds. Kapok fibers are cellulosic fibers, light-weight, and hydrophobic (Prachayawarakorn et al., 2013; Wang et al., 2019). Conventionally, kapok fiber is used as a buoyancy material, oil-absorbing material, reinforcement material, adsorption material, biofuel, etc. (Tye et al., 2012; Dong et al., 2015; Zheng et al., 2015).

Bamboo (Bambusoideae)

Bamboo fiber is also known as natural glass fiber due to the alignment of fibers in the longitudinal directions (Zakikhani et al., 2014; Wang and Chen, 2016). It is one of theextensively available trees in the dense forests, especially in China, about 40 families, and 400 species are found (Fan and Weclawski, 2016; Van Dam et al., 2018). Bamboo fiber is used as reinforcement in polymeric materials due to its light-weight, low cost, high strength, and stiffness. Bamboo has been traditionally used for making houses, bridges, traditional boats, etc. The fibers extracted from bamboo are used as reinforcement for making advanced composites in various industries (Deshpande et al., 2000; Osorio et al., 2011; Zakikhani et al., 2014).

Silk (Bombyx mori)

Silk fibers have been extracted from silkworms for clothing purposes since ancient times. Silk is produced largely in China, South Asia, and Europe (Das and Natarajan, 2019; Shera et al., 2019). Fibers are extracted from the Cocoons which are the larvae of the insects undergoing complete metamorphosis. Silk fibers possess good mechanical properties such as high strength, extensibility, and compressibility (Yuan et al., 2010; Murugesh Babu, 2016; Castrillón Martínez et al., 2017; McGregor, 2018).

Possibilities to Enhance the Properties of Natural Fibers

The disadvantages of natural fiber composites include poor fiber-matrix interfacial bonding, poor wettability, water absorption, and moisture absorption. The hydrophilic nature of the natural fibers caused poor interfacial interaction between the polymer matrix and the fiber. Hence, it is required to optimize the fibers by chemical treatments and surface treatments (Gassan and Bledzki, 1999; George et al., 2001; Li et al., 2007; Manimaran et al., 2018; Rangappa and Siengchin, 2018; Sanjay et al., 2018; Yashas Gowda et al., 2018).

Chemical Treatments

The recent trends in the development of the newer materials have led to replacing materials like glass and carbon reinforced composites with the natural fibers reinforced composites, for example, in automobile interiors, pedestrian bridges, shipping pallets, composite roof tiles, furniture, toys, etc. (Senthamaraikannan et al., 2016; Senthamaraikannan and Kathiresan, 2018; Madhu et al., 2019a; Sanjay et al.,2019b). However, the main drawback of natural fibers as reinforcement is that they are incompatible with thermoplastics due to their hydrophilic nature, which results in poor interfacial interaction between the fibers and matrix. This results in the poor mechanical properties of the composites. Therefore, the modification of natural fibers is required to make them less hydrophilic. Here, an attempt is made to provide a brief overview of various chemical treatments on natural fibers (Sepe et al., 2018).

Alkaline Treatment

The natural fiber consists of lignin, pectin, waxy materials, and natural oils, which cover the outside layer of the fiber cell wall (Liu et al., 2004; Edeerozey et al., 2007; Hamidon et al., 2019). The chemical treatment alters the structure of the natural fibers, and sodium hydroxide (NaOH) is one of the chemical reagents used for this process (Rong et al., 2001; Baiardo et al., 2002; Sgriccia et al., 2008). The alkaline reagent is used to alter the structure of the cellulose in the plant fibers by cleaning the surface, and the process is called alkalization. Mwaikambo and Ansell treated hemp, jute, sisal, and kapok fibers with NaOH at 20°C for about 48 h and washed them using distilled water and acetic acid to neutralize the excess of NaOH. The thermal properties, surface morphology, and crystallinity index of the treated and untreated fibers were studied. The studies revealed that the chemically treated fibers showed better fiber-resin adhesion lead to an increase in interfacial energy and thus enhancing the thermal and mechanical properties of the composites (Mwaikambo and Ansell, 2002). Kenaf fiber mats were treated with the NaOH solution for 24 h at a temperature of 45°C. The mats were washed with tap water after the chemical treatment and were immersed in the distilled water containing 1% acetic acid to neutralize the excess of NaOH, and the mats were dried for 12 h at 45°C in an oven. The mats were then treated with 5% aminopropyl triethoxysilane diluted with an aqueous solution of methanol. The authors observed a significant increase in mechanical properties for the treated kenaf fiber modified PP composites (Asumani et al., 2012). In an interesting work, the retting process was used to extract the fibers from Napier grass, and the aqueous sodium hydroxide solution, about 2–5% is used to treat the Napier grass fibers at room temperature for about 30 min to remove the hemicelluloses and to clean the fibers. The fibers were then washed with distilled water repeatedly and dried at 100°C. TheAlkalization has reduced the amount of hemicellulose in fiber, thus resulting in better mechanical properties than those of untreated fiber (Reddy et al., 2012). The Carica papaya fibers were treated with the 5% concentration of NaOH by varying the soaking time from 15 to 90 min at room temperature. The excess of NaOH from the surface was washed repeatedly using distilled water and was dried for about 56 h. The fibers treated for 60 min with 5% alkaline solution showed the optimum results, which showed that complete elimination of hemicelluloses and lignin (Saravanakumaar et al., 2018).

Silane Treatment

The sugar palm fibers are treated with 2% saline and 6% NaOH for 3 h. The authors observed an improved interfacial interaction between the fiber and thermoplastic polyurethane after the treatment (Atiqah et al., 2018). Kabir et al. reviewed the treatment of silane on the surface of natural fibers. They stated that the silane groups act as a coupling agent between the fiber and the matrix, and hence improvements in mechanical properties are observed (Kabir et al., 2012). In an interesting work, Bodur et al. studied the changes in tensile strength and Young's modulus of composites treated with silane for different soaking times. The results were compared with untreated fiber composites. The authors observed significant improvement in strength when compared with untreated fibers. The improvement in strength is due to the formation of silanol (Si-OH) groups that form strong bonds with the –OH groups of the fibers. The remaining Si-OH undergoes condensation with adjacent Si-OH groups. The hydrophobic polymerized silane thus formed can attach to the polymer matrix via van der Waals forces. As a result, silane groups form an interface between the fiber and polymer and provide a good interfacial interaction. The high tensile strength of the low-density polyethylene composites is due to good interfacial interaction between the fiber and polymer matrix (Bodur et al., 2016).

Acetylation Treatment

Acetylation of the natural fibers is the process of introducing an acetyl group on the surface of the fibers. This process was used to reduce the hydrophilic nature of fibers, providing stability to the composites. The acetylation increases the fiber-matrix adhesion properties; hence, the strong bond provides good properties to the natural fiber-based composites (Hill et al., 1998; Rong et al., 2001; Sreekala et Thomas, 2003). The OH groups of the fibers react with the acetyl groups, thus making the fibers more hydrophobic. Generally, lignin and hemicellulose, which contain the hydroxyl group, react with acetyl groups to become hydrophobic. Normally, before treatment with glacial acetic acid, the natural fiber is alkali-treated. The alkali-treated fibers were soaked in glacial acetic acid for 1 h and later soaked for 2–5 min in acetic anhydride containing two drops of concentrated H_2SO_4. The fibers were then washed and dried at 80°C using an oven for 6 h (Paul et al., 1997; Manikandan Nair et al., 2001; Mishra et al., 2003).

Peroxide Treatment

The impact of peroxide treatment on the mechanical properties of the cellulose fiber-reinforced polymer composites has been studied by various researchers. The peroxides decomposed to form free radicals. The generated free radicals react with the hydrogen group of the cellulose fibers and polymer matrix. The peroxide treatment of natural fibers is carried out after alkalization. The alkaline-treated fibers were immersed in a ca. 6% concentration of benzoyl peroxide or dicumyl peroxide in acetone for about 30 min (Sreekala et al., 2000, 2002; Li et al., 2007).

Benzoylation Treatment

Benzoylation is used to decrease the hydrophilic nature of the fibers (Ali et al., 2016). The fiber-matrix bonding is improved by this treatment, which increases the strength of the composites. For benzoylation, the fibers are first treated with NaOH, followed by benzoyl chloride ($C6H5COCl$) treatment for 15 min. Later, the fibers were isolated and treated with ethanol for 1 min and finally washed with distilled water and dried in an oven at 80°C for 24 h (Manikandan Nair et al., 2001; Zhang et al., 2005). The thermal stability of the treated fibers was higher than that of the untreated fibers.

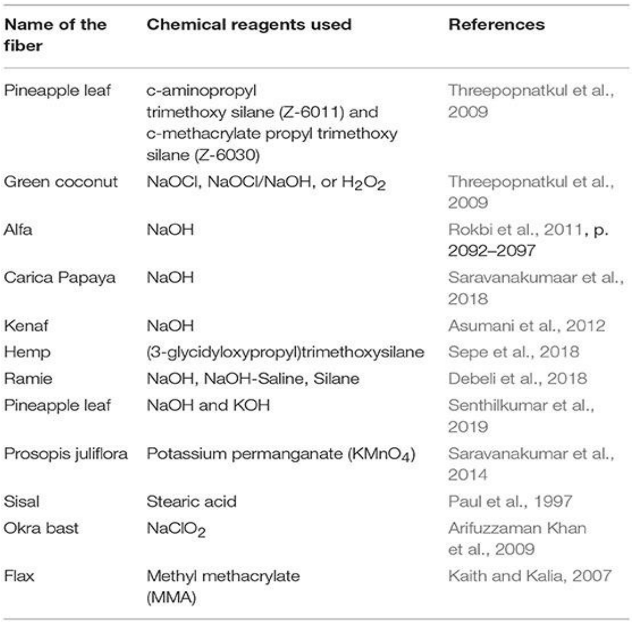
Potassium Permanganate (KMnO4) Treatment

The potassium permanganate is used as a chemical reagent to modify the interfacial interaction between the fiber and matrix. Different treatment methodologies are introduced. In one of the studies, the alkaline-treated fibers were treated with potassium permanganate for different concentrations (0.005–0.205 %) for 1 min and dried using the oven (Khan et al., 2006). Zaman et al. treated the jute fabrics with KMnO4 along with acetone for different concentrations (0.02, 0.03, 0.05, and 0.5%) and soaking times (1, 2, 3, and 5 min) and were dried in the oven (Zaman et al., 2010).

Stearic Acid Treatment

The non-woven jute fibers were immersed in different concentrations of stearic acid in anhydrous ethanol from 1 min to up to 4 h and dried at 100°C for 1 h (Dolez et al., 2017). The 1% stearic acid mixed in ethyl alcohol and poured into a steel vessel containing alkali- treated short Sansevieria fibers, along with stirring. Then the fibers were dried in a woven at 80°C for 45 min (Sreenivasan et al., 2012). Table 1 summarizes the different chemical treatments used for natural fibers.

TABLE 1:



Name of the fiber	Chemical reagents used	References
Pineapple leaf	c-aminopropyl trimethoxy silane (Z-6011) and c-methacrylate propyl trimethoxy silane (Z-6030)	Threepopnatkul et al., 2009
Green coconut	NaOCl, NaOCl/NaOH, or H_2O_2	Threepopnatkul et al., 2009
Alfa	NaOH	Rokbi et al., 2011, p. 2092–2097
Carica Papaya	NaOH	Saravanakumaar et al., 2018
Kenaf	NaOH	Asumani et al., 2012
Hemp	(3-glycidyloxypropyl)trimethoxysilane	Sepe et al., 2018
Ramie	NaOH, NaOH-Saline, Silane	Debeli et al., 2018
Pineapple leaf	NaOH and KOH	Senthilkumar et al., 2019
Prosopis juliflora	Potassium permanganate ($KMnO_4$)	Saravanakumar et al., 2014
Sisal	Stearic acid	Paul et al., 1997
Okra bast	$NaClO_2$	Arifuzzaman Khan et al., 2009
Flax	Methyl methacrylate (MMA)	Kaith and Kalia, 2007

Table 1. Chemical treatments for different natural fibers.

Effect of Treatments on Natural Fibers

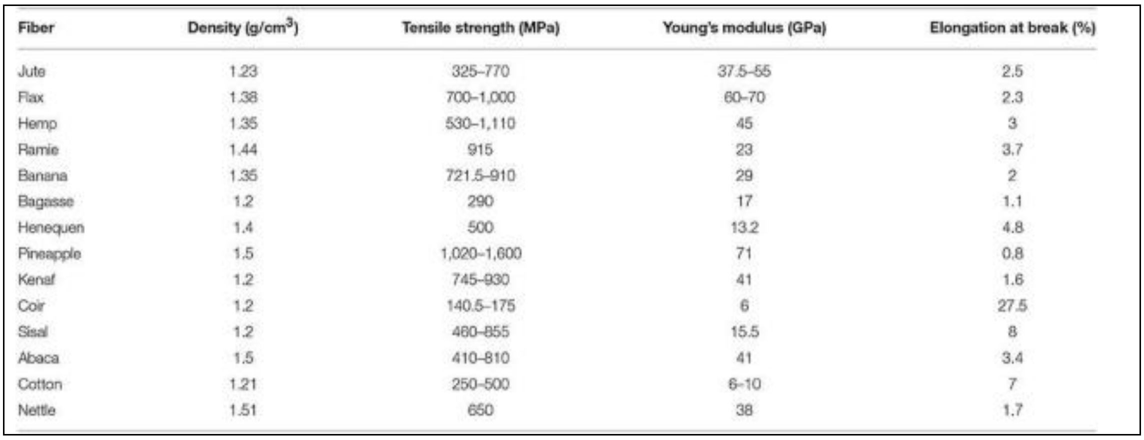
The chemical treatments of the natural fibers mainly enhance the properties of the fiber by modifying their microstructure along with improvement in wettability, surface morphology, chemical groups, and tensile strength of the fibers (Saba et al., 2014; Dolez et al., 2017; Preet Singh et al., 2017; Halip et al., 2018; Yu et al., 2019). The chemical treatment of the fiber improved the interfacial adhesion between the fiber surface and polymer matrix, thereby affecting the thermomechanical properties of the composites. The chemical treatment of ramie fibers has shown that the treatment of fibers with alkaline or saline solutions or the combined treatment results in the improvement of the tensile strength (Gassan and Bledzki, 1997; Thakur and Thakur, 2014; Varghese and Mittal, 2017; Debeli et al., 2018; Sanjay et al., 2019a). The chemical treatment is one of the important techniques used to reduce the hydrophilic nature of the natural fibers, and it also improves the adhesion with the matrix. The structural and morphological changes can be observed with the treatment of the fibers, and this is mainly due to the removal of non-cellulosic substances from the natural fibers. The significant improvements of the properties of the composites are reported after different chemical treatments along with the increase in the thermal stability of the composites reinforced with natural fibers (Singh et al., 1996; Xie et al., 2010; Xu et al., 2013; Chen et al., 2018).

Natural Fibers as Reinforcement for Composite Materials

Over the past few decades, attempts have been made in developing the materials that replace the existing materials to have better mechanical and tribological properties for various applications (Arpitha and Yogesha, 2017; Abdellaoui et al., 2019). In view of this, the monolithic materials are replaced by the fibers and materials such as carbon, glass, aramid fibers, which are extensively used in aerospace, automotive, construction, and sporting industries, etc. (Balakrishnan et al., 2016; Pickering et al., 2016; Asim et al., 2018). However, these materials have some disadvantages, such as non-biodegradability, non-renewability, high-energy requirement for production, and also harmful to the environment, as the production of these materials releases enormous amounts of carbon dioxide into the atmosphere. Therefore, to overcome all these drawbacks, researchers have made an attempt to study the different natural fiber-reinforced composites that have better properties so that they can replace synthetic fibers in various applications (Wambua et al., 2003; Li et al., 2007; Sanjay et al., 2015; Mochane et al., 2019). As the demand for the newer materials, which have better properties than the existing ones, upsurges, the researchers have tried different types of natural materials with different natural fibers obtained from fruits, seeds, leaves, stems, animals, etc. (Sanjay et al., 2019a). The properties of a few important natural fibers are presented in Table 2. As discussed above, the natural fibers are modified by using different chemical treatments, thus modifying the properties and increasing the properties of natural fiber composites.

Also, the polymers and other synthetic materials have been used along with the natural fibers to enhance the properties of the natural fibers, and these ideas have led to the development of several hybrid composites reinforced with natural fibers and filler materials (Sawpan et al., 2011; Boopalan et al., 2013; Pickering et al., 2016; Sanjay et al., 2016; Madhu et al., 2018).

TABLE 2



Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Jute	1.23	325–770	37.5–55	2.5
Flax	1.38	700–1,000	60–70	2.3
Hemp	1.35	530–1,110	45	3
Ramie	1.44	915	23	3.7
Banana	1.35	721.5–910	29	2
Bagasse	1.2	290	17	1.1
Henequen	1.4	500	13.2	4.8
Pineapple	1.5	1,020–1,600	71	0.8
Kenaf	1.2	745–930	41	1.6
Coir	1.2	140.5–175	6	27.5
Sisal	1.2	460–855	15.5	8
Abaca	1.5	410–810	41	3.4
Cotton	1.21	250–500	6–10	7
Nettle	1.51	650	38	1.7

Table 2. Properties of natural fibers (Pandey et al., 2010; Ku et al., 2011; Komuraiah et al., 2014; Gurunathan et al., 2015).

Chemical Composition of Flax Fiber

S.No.	Type of Fiber	Cellulose(%)	Lignin (%)	Hemicellulose(%)	Ash (%)	Silica(%)	Wax(%)	Pectin(%)
1.	Flax	65-72	2.2-3.3	17.5-20.8	-	-	-	-

Tensile Strength of Flax based epoxy Composites

S.No.	Fiber Loading	Tensile Strength (MPa)
1	0 %	28 ±2
2	5 %	24 ±2
3	10 %	27 ±1
4	15 %	29 ±2
5	20 %	21 ±1

Tensile strength of treated Flax-based epoxy composite (at 15% fiber loading)

S.No.	Treatment Method	Tensile Strength (MPa)
1	Untreated	29 ± 2
2	Alkali Treated	36 ± 2

Properties of Natural Fiber Composites

Environmental awareness has attracted researchers to make new composites with more than one reinforcement of natural resources through hybridization. Hybridization involves a combination of fillers and natural fibers that results in increased mechanical properties of the composites (Khan et al., 2005; Borba et al., 2013). A large amount of literature is available that shows the mechanical properties of the natural fiber composites. The mechanical performance of fiber-reinforced composites can be affected by many factors, including the volume or weight fraction of the reinforcement, the orientation of the fibers, the fiber aspect ratio, fiber-matrix adhesion, fiber alignment, distribution, use of additives, and chemical treatment of fibers. It is important to add that the moisture absorption of theComposites also affect the mechanical behavior of the composites, which leads to the poor interfacial bonding between fiber and hydrophobic matrix polymer (Zakikhani et al., 2014; Biswas et al., 2015; Kinloch et al., 2015; Pickering et al., 2016; Dixit et al., 2017).

In the automotive industry, asbestos-based brake pads and lining couplings, etc., are not preferred due to their carcinogenic nature. The replacements for asbestos fiber include ceramic fiber, steel fiber, alumina fiber, glass fiber, carbon fiber, aramid fiber, and their combinations. However, the production cost of these fibers is very high, and they are not environmentally friendly. Xin et al. studied the friction and wear properties of treated sisal fiber reinforced composites as a substitute for asbestos-based brake pads. The treated sisal fiber reinforced composite exhibits properties equivalent to the commercial friction composite. The authors recommend that treated sisal is an ideal substitute for asbestos for brake pads (Xin et al., 2007).

The thermal stability is vital and, at present, is recognized to be one of the most important elements in the use of fibers as reinforcement for the composite. The chemical treatment of the natural fibers will improve the interfacial bonding between the matrix and fibers leads to improvement in thermal properties of the composites (Panaitescu et al., 2016; Balan et al., 2017; Zegaoui et al., 2018).

Joseph et al. studied the thermal stability and crystallization behavior of sisal/polypropylene composites. The sisal fibers were treated with a urethane derivative of polypropylene glycol (PPG/TDI), maleic anhydride-modified polypropylene (MAPP), and KMnO4. The thermal properties of the composites were measured using thermogravimetric analysis and differential scanning calorimetry. The authors observed superior thermal properties for the treated fiber reinforced composites (Joseph et al., 2003). The crystallinity also influences the thermal stability of the natural fiber composites. As the crystallinity of the material increased, the thermal degradation temperature also increased (Nasser et al., 2016). The thermogravimetry analysis of date palm trunk (DPTRF), leaf stalk (DPLST), sheath or leaf sheath (DPLSH), and fruit bunch stalk (DPFBS) fibers was carried out, and analysis revealed that DPFBS and DPLST fibers have good thermal stability and might be applied in industrial manufacture of composites, which require high thermal resistance (Alotaibi et al., 2019).

The pineapple reinforced polyethylene composites were studied for the electrical properties and found that due to the increased interfacial polarization and orientation with an increase in the number of fibers in composites, the dielectric property increases (Jayamol et al., 1997). Similarly, the composites prepared using the sisal fiber showed electric anisotropic behavior (Chand and Jain, 2005). It is observed that the chemical treatments like alkali, stearic acid, peroxide, acetylation, and permanganate decrease the dielectric property of composites due to the decrease in hydrophilicity of the composite (Li et al., 2000). The electrical properties of phenol formaldehyde composites modified with banana fiber have been studied. The dielectric constant decreased with fiber loading and fiber treatment. For hybrid composites with glass fiber, the dielectric constant decreased with increasing glass fiber concentration (Joseph and Thomas, 2008).

Applications

Automotive and aircraft industries have been actively manufacturing different kinds of natural fiber parts for their interior components (Sanjay et al., 2016; Puttegowda et al., 2018). Insulation materials are also made from natural fibers for different application areas, such as blowing insulation, pouring insulation, impact sound insulation materials, and ceiling panels for thermal insulation and acoustic soundproofing (Akin, 2010). Natural fibers show a sustainable future in architecture, with a wide variety of building materials, shapes, and even improving current commonly used materials. The use of synthetic fibers in the field of architecture could be substituted with natural fibers. It is used as material for sunscreens, cladding, walling, and flooring (Steffens et al., 2017). The natural fibers such as flax, hemp, sisal, and wool are now used in Mercedes-Benz components (Holbery and Houston, 2006). The coir/polyester-reinforced composites were used in the mirror casing, paperweights, voltage stabilizer cover, projector cover, helmet, and roof (Khondker et al., 2005). The flax fibers were used in the GreenBente24 boat (Ticoalu et al., 2010). Rice husk fiber, cotton, ramie, jute fiber, and kenaf are used in various applications like building materials, furniture industry, clothing, ropes, sewing thread, fishing nets, packing materials, and paper manufacture (Sen and Jagannatha Reddy, 2011b). Lots of efforts have been made to increase the use of natural fiber composites inthe automotive industry, particularly in car interiors. Besides the use for car interior parts, it is also used for manufacturing exterior auto body components (Shuit et al., 2009; Monteiro et al., 2010; Shinoj et al., 2011; Mohammed et al., 2015).

Degradation of the Natural Fibers Reinforced Polymers

In the present scenario, there is an increase in awareness regarding environmental pollution due to industrial waste, which has led to replacing the harmful synthetic materials with more eco-friendly materials. The use of plastics has increased, especially for household and commercial use. The use of plastic products leads to the accumulation of non-biodegradable waste and is a threat to the ecological system. Therefore, extensive research has been carried out over the last decade on the biodegradation of plastics. Natural fibers, along with the synthetic biodegradable materials, can be used to develop biocomposites, which have benefits for the environment like biodegradability, renewability of base material, and reduction in emission of greenhouse gases. Degradation offers a lot of advantages, such as the reduction of plastic waste and the reduction in the cost of waste management (Fakhrul and Islam, 2013; Gunti et al., 2018).

Degradation of the composite occurs with the breakdown of the composite materials, as well as with the loss of mechanical properties. In the outdoor environment, the degradation of natural fiber reinforced composites is influenced by atmospheric moisture, temperature, ultraviolet light, and activities of microscopic organisms. The degradation occurs by the breakdown of hemicelluloses, lignin, and cellulose of the fiber. This can cause damage to the bonding between fibers and the polymer matrix. This leads to the lowering of the mechanical properties of the composites (de Melo et al., 2017). The kenaf/POM composites were subjected to weathering by exposure to moisture, water spray, and UV light in an accelerated weathering chamber, and the materials showed lower tensile strength. This result was attributed to the degradation of the cellulose, hemicelluloses, and lignin of kenaf fibers (Abdullah et al., 2013). The effect of weathering on the degradation of jute/phenolic composites was investigated by Azwa et al. (2013). It shows that 2 years of UV exposure on jute/phenolic composites has decreased the tensile strength by about 50%. The authors observed resin cracking, bulging, fibrillation, and black spots after exposure to weathering.

It is necessary to promote the use of natural fibers as reinforcement in the polymer so that the materials become biodegradable to some extent. Proper degradation of plastics must be a better way to avoid the harmful effects on the environment. Therefore, one must always look for the plastics that are compostable or degradable. However, this cannot be implemented for every material, but can be reduced with the use of biopolymers to some extent (Chauhan and Chauhan, 2015; Thiagamani et al., 2019).

Future Market Trends

In current market trends, natural fiber-reinforced polymers are experiencing comprehensive growth with good prospects in the automotive and construction industries. Bast fiber, such as hemp, kenaf, flax, etc., is preferred for automotive applications. On the other hand, wood plastic composite is the material of choice for the construction industry. Looking at the developments of the current trends, Europe is predicted to remain the largest market for natural fiber-reinforced composites due to the high acceptance level of environmentally friendly composite materials by automotive industries, government agencies, and the growth in small-scale environmentally friendly industries. The improvement in materials performance will drive the growth of natural fiber reinforced polymer composites in new potential areas. Natural fiber composites are new in electrical, electronics, and sporting segments; however, it has the potential to capture a good market share in the future.

CONCLUSIONS

Increased environmental awareness has resulted in the utilization of natural fiber as an effective reinforcement material in polymer matrix composites. Natural fibers are proficient materials that can replace the existing synthetic fibers. The fibers are usually extracted from plants and animals, and often offer poor resistance to moisture, and the incompatible nature of fibers becomes the main disadvantage. Therefore, modification of material properties has been done through chemical treatments of natural fibers, which improve the adhesion between the fibers and matrix and enhance the mechanical properties of the composites. In the near future, the natural fiber will become one of the sustainable and renewable resources in the composite field, which can replace synthetic fibers in many applications.

REFERENCES

1. Abdellaoui et al., 2019
2. Abdullah et al., 2013
3. Akgül, 2013
4. Akin, 2010
5. Alawar et al., 2009
6. Ali et al., 2016
7. Al-Maharma and Al-Huniti, 2019
8. Al-Oqla and Sapuan, 2014
9. Al-Oqla et al., 2015
10. Alotaibi et al., 2019
11. Angelini and Tavarini, 2013
12. Anuar and Zuraida, 2011
13. Arifuzzaman Khan et al., 2009
14. Arjmandi et al., 2017
15. Arpitha et al., 2017
16. Arpitha and Yogesha, 2017
17. Arulandoo et al., 2016
18. Arumugam, 2014
19. Arunachalam, 2012

20. Asim et al., 2018
21. Aslan et al., 2018
22. Asumani et al., 2012
23. Athith et al., 2018
24. Atiqah et al., 2018
25. Atiqah et al., 2014
26. Aziz and Ansell, 2004
27. Azwa et al., 2013
28. Bacci et al., 2009
29. Baiardo et al., 2002
30. Balaji and Senthil Vadivu, 2017
31. Balakrishnan et al., 2016
32. Balan et al., 2017
33. Banik et al., 2003
34. Behera et al., 2012
35. Bhoopathi et al., 2014
36. Biswas et al., 2015
37. Bledzki and Gassan, 1999
38. Bodur et al., 2016
39. Boopalan et al., 2013
40. Borba et al., 2013
41. Bos et al., 2006
42. Bourgeois et al., 2016
43. Bourmaud et al., 2019
44. Bunsell, 2018
45. Castrillón Martínez et al., 2017
46. Cengiz and Babalik, 2009
47. Chand and Jain, 2005
48. Charlet et al., 2010
49. Chauhan and Chauhan, 2015
50. Chen et al., 2018
51. Cheung et al., 2009
52. Clarke, 2010
53. Colomban and Jauzein, 2018
54. Cummings and Olsen, 2011
55. Danso, 2017
56. Das, 2017
57. Das and Natarajan, 2019
58. de Melo et al., 2017
59. De Prez et al., 2018
60. Debeli et al., 2018
61. Deshpande et al., 2000
62. Devaraju and Harikumar, 2019
63. Dixit et al., 2017
64. Dolez et al., 2017
65. Dong et al., 2015
66. dos Santos et al., 2018
67. Duval et al., 2011
68. Edeerozey et al., 2007
69. Elmogahzy and Farag, 2018
70. Fakhrul and Islam, 2013
71. Fan and Weclawski, 2016
72. Fang et al., 2013
73. Faruk et al., 2012

74. Faruk et al., 2014
75. Gassan and Bledzki, 1997
76. Gassan and Bledzki, 1999
77. George et al., 2001
78. Gheith et al., 2018
79. Gunti et al., 2018
80. Gupta and Srivastava, 2016
81. Gurunathan et al., 2015
82. Halip et al., 2018
83. Hamidon et al., 2019
84. Hill et al., 1998
85. Holbery and Houston, 2006
86. Huda et al., 2006
87. Jawaid and Abdul Khalil, 2011
88. Jayamol et al., 1997
89. Joseph et al., 2003
90. Joseph and Thomas, 2008
91. Kabir et al., 2012
92. Kaith and Kalia, 2007
93. Kengkhetkit and Amornsakchai, 2012
94. Khan and Khan, 2014
95. Khan et al., 2005
96. Khan et al., 2006
97. Khondker et al., 2005
98. Kicinska-Jakubowska et al., 2012
99. Kinloch et al., 2015
100. Kipriotis et al., 2015
101. Komuraiah et al., 2014
102. Ku et al., 2011
103. Laftah and Abdul Rahaman, 2015
104. Lanzilao et al., 2016
105. Lau et al., 2018
106. Li et al., 2007
107. Li et al., 2000
108. Li et al., 2006
109. Liu et al., 2018
110. Liu et al., 2004
111. Liu et al., 2005
112. Madhu et al., 2019a
113. Madhu et al., 2019b
114. Madhu et al., 2018
115. Mahjoub et al., 2014
116. Manikandan Nair et al., 2001
117. Manimaran et al., 2018
118. Manimaran et al., 2017
119. Marsyahyo et al., 2009
120. Martin et al., 2013
121. Masri et al., 2018
122. McGregor, 2018
123. Mihai, 2013
124. Mishra et al., 2003
125. Mochane et al., 2019
126. Mohammed et al., 2015
127. Monteiro et al., 2010

128. Mortazavi and Moghaddam, 2010
129. Murugesh Babu, 2016
130. Mwaikambo and Ansell, 2002
131. Mwaikambo et al., 2000
132. Nair, 2010
133. Nam and Netravali, 2006
134. Nasser et al., 2016
135. Naveen et al., 2018
136. Nirmal et al., 2015
137. Nishino et al., 2003
138. Oksman, 2001
139. Oksman et al., 2016
140. Omar et al., 2019
141. Osorio et al., 2011
142. Panaitescu et al., 2016
143. Pandey et al., 2010
144. Paridah et al., 2004
145. Paul et al., 1997
146. Pham, 2016
147. Pickering et al., 2016
148. Prachayawarakorn et al., 2013
149. Preet Singh et al., 2017
150. Puttegowda et al., 2018
151. Rahman, 2010
152. Raman Bharath et al., 2015
153. Ramesh, 2019
154. Ramesh et al., 2013
155. Rangappa and Siengchin, 2018
156. Reddy et al., 2012
157. Reddy and Yang, 2015
158. Rehman et al., 2019
159. Réquilé et al., 2018
160. Rivera et al., 2019
161. Rokbi et al., 2011
162. Rong et al., 2001
163. Ruan et al., 2015
164. Saba et al., 2015
165. Saba et al., 2014
166. Sam-Brew and Smith, 2015
167. Sanjay et al., 2016
168. Sanjay et al., 2019a
169. Sanjay et al., 2015
170. Sanjay et al., 2018
171. Sanjay et al., 2019b
172. Sanjay and Suchart, 2019
173. Santhosh Kumar and Hiremath, 2019
174. Saravanakumaar et al., 2018
175. Saravanakumar et al., 2014
176. Sawpan et al., 2011
177. Sen and Jagannatha Reddy, 2011a
178. Sen and Jagannatha Reddy, 2011b
179. Sengupta and Basu, 2016
180. Senthamaraikannan and Kathiresan, 2018
181. Senthamaraikannan et al., 2016

182. Senthilkumar et al., 2018
183. Senthilkumar et al., 2019
184. Sepe et al., 2018
185. Sgriccia et al., 2008
186. Shahinur and Hasan, 2019a
187. Shahinur and Hasan, 2019b
188. Sharma et al., 2017
189. Shera et al., 2019
190. Shinoj et al., 2011
191. Shuit et al., 2009
192. Singh et al., 1996
193. Sood and Dwivedi, 2018
194. Sreekala et al., 2000
195. Sreekala et al., 2002
196. Sreekala and Thomas, 2003
197. Sreenivasan et al., 2012
198. Steffens et al., 2017
199. Suharty et al., 2016
200. Thakur and Thakur, 2014
201. Thakur et al., 2014
202. Thiagamani et al., 2019
203. Threepopnatkul et al., 2009
204. Ticoalu et al., 2010
205. Todkar and Patil, 2019
206. Tye et al., 2012
207. Väisänen et al., 2018
208. Van Dam et al., 2018
209. Van de Weyenberg et al., 2003
210. Varghese and Mittal, 2017
211. Verma and Gope, 2014
212. Wales and Blackman, 2017
213. Wambua et al., 2003
214. Wang and Chen, 2016
215. Wang et al., 2019
216. Xie et al., 2010
217. Xin et al., 2007
218. Xu et al., 2013
219. Yang et al., 2019
220. Yashas Gowda et al., 2018
221. Yogesha, 2017
222. Yu et al., 2019
223. Yuan et al., 2010
224. Zafeiropoulos and Baillie, 2007
225. Zakikhani et al., 2014
226. Zaman et al., 2010
227. Zamri et al., 2016
228. Zegaoui et al., 2018
229. Zhang et al., 2005
230. Zheng et al., 2015
231. Zhu et al., 2013
232. Zou et al., 2011