REVIEW ARTICLE

An Overview on Properties and uses of Bhendi Fiber Reinforced Polymer Composites

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ABSTRACT: In today's fast-paced culture, issues like the environment, ecology, and new regulations from the government are important worries. Researchers and scientists are therefore looking for renewable and biodegradable natural fiber reinforced composites. Natural fibers over synthetic fibers have clear advantages, such as low density, equivalent strength, non-toxicity, low cost, and minor waste disposal difficulties. Researchers have looked into the potential applications of natural fibers in great detail. Fibers including bhendi, abaca, coir, jute, bagasse, vetiver, banana, and sisal, however, have gained increased prominence in this decade. The bhendi bahmia (*Abelmoschus esculentus*) plant is one of the various sources of natural fibers. A substantial amount of bhendi plant stem is yearly left on the field after the veggies have been harvested without being appropriately used. However, the biomass from bhendi plants is a low-cost, renewable resource that may be exploited to produce bast fibers and other environmentally beneficial products that are valuable for industry. The bhendi tree, which is indigenous to tropical Asia, produces steam after harvesting its fruit, which is used to make bhendi fibers. When utilized as a reinforcing material, bhendi fibers have greatly improved the mechanical, chemical, and physical properties of polymer composites. The current paper offers a complete investigation of bhendi fiber reinforced composites and their potential applications. The performance of bhendi fiber reinforced polymer composites is affected by a number of variables, including fiber length, orientation, and configuration; moisture content; and surface treatments.

KEYWORDS: Bhendi fiber for textile, composites, natural fiber, agricultural waste, mechanical properties.

https://doi.org/10.29294/IJASE.9.4.2023.3072-3084

INTRODUCTION

In the field of engineering design, the choice of materials for the creation and manufacturing of a sustainable product is crucial. The mechanical and physical properties of the material must be taken into account in order to design a better product that will increase customer satisfaction. Processing may be done quickly, effectively, and affordably thanks to composites consisting of multiple different materials. Composite materials are produced to order and have a specific property that permits the attributes to be modified by altering the various reinforcement phases and matrix [1,2]. The matrix phase takes the form of a polymer matrix, metal matrix, or ceramic matrix (i.e. laminate or sandwich), whilst the reinforcement phase takes the form of whisker reinforced, particle reinforced, fiber reinforced, or structural. Fiber reinforced composites are frequently used in the aerospace and automotive industries due to their exceptional properties, such as their light weight, high strength, high durability, chemical resistance, wear resistance, fire resistance, electrical resistance, and corrosion resistance. Additionally, they are utilized in building and infrastructure. Polymer composites can be reinforced with a variety of fiber types, including carbon fiber, glass fiber, and natural fiber. Prior to now, only synthetic fiber reinforced polymer composites were used due to their superior mechanical properties and low cost. Carbon and glass fibers are two types of synthetic fibers. Sustainability is a topic that all academics in the current day are concerned with. When it comes to swapping out non-sustainable products for sustainable ones, every industry is faced with a challenging issue. Due

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Received: 28.02.2023 **Accepted:** 17.03.2023 **Published on**: 22.05.2023

to growing environmental concerns and the depletion of conventional energy resources, we have begun harnessing renewable sources of raw materials to produce new components. The aforementioned elements necessitate that natural fibers be used instead of synthetic fibers in polymer matrix composites. The use of natural fibers (NFs) rather than synthetic fibers (SFs) to enhance composite materials has been the focus of much of this scientific study on novel materials [3,4]. In order to reinforce different thermoplastic (TP) and thermoset (TS) resins while maintaining high strength, high hardness, and low concentration of weight ratio, researchers are currently concentrating on the utilization of cellulose fibers (CFs) and agro-residues [5-7]. Natural fibers have many benefits over synthetic fibers, such as being more affordable, less dense, more flexible, more impact resistant, less abrasive to equipment, having a lower specific gravity, being process friendly, posing fewer health risks, emitting less greenhouse gas, being CO_2 neutral, and being recyclable. Since they are good for the environment, natural fiber reinforced composites are widely used in the car industry. Due to the reduced weight, less gasoline will be used, which ultimately results in less emission of dangerous gases. Composites reinforced with natural fibers are also used in the sports and electronics industries. Natural fiber reinforced polymer composites can be used to create a variety of items, including as bicycles, laptop cases, and tennis rackets [8-10].

Bangladesh is fortunate to have access to a variety of natural fibers, such as bhendi or okra, sisal, coir, jute, vetiver, banana, bamboo, ramie, pineapple, etc., that can be used in place of synthetic fibers as reinforcement in polymer matrix composites. The fibers used to make bhendi are retrieved from the bhendi plant's steam. These fibers are lignocellulosic biomass fibers. Bhendi, a lignocellulosic bast fiber, is made from plant stem waste via the retting method [2,11,12]. Ash, extractives, cellulose, hemicellulose, lignin, and moisture make up bhendi fiber. It is a multi-cellular fiber, and jute fiber is more closely equivalent to it in terms of physical characteristics such final fiber length, breadth, length/breadth ratio, bundle toughness, and fineness[11]. Bhendi fiber has a great mechanical strength and is silky, white, light cream, or yellow in colour [13]. It has a ton of possibilities for fiber, yarn, and fabric uses in textiles, including rope, twine, fishing net, sacking, and decorative fabrics. It also has applications in handicrafts, paper laminates, carpets, mats, and fiber-reinforced composites [14-20].The following areas were the subject of extensive research after 2007. Two methods are being used to establish okra as a crop with several applications: (i) non-food grade usage; and (ii) systematic use of bhendi fiber in textiles. The okra plant, methods for harvesting the fiber from it, the fiber's physical, chemical, and mechanical characteristics, as well as jute fiber's potential for application in textiles, are all examined in this essay.

Bhendi Plant and Its Bast Fiber

Bhendi, also known as Hibiscus esculentus L., is a warm-season annual that grows tall and thrives in a range of soil types. Its scientific name is *Abelmoschus esculentus* (L.) Moench. It belongs to the family of mallow (Malvaceae) plants [21], which also includes hibiscus and cotton among other species.It is the only crop in the family Malvaceae that is a vegetable and whose products are extensively employed in the food business. It is also known as Bamia, Bhendi in Bangladesh, and Bhindi in other parts of the world (India), among many other names. It is also known as Guibeiro in Portuguese, Lady's finger in England, Guino-gombo in Spain, Gumbo in the United States, and many more [22-25]. It is quite popular in Bangladesh due to its easy cultivation, resistance to drought, reliable yield, and ability to adjust to different moisture levels [25-27]. It is cultivated for its young, green, nonfibrous fruit, which is primarily used as a vegetable [28,29]. Bhendi seeds contain both protein (30%) and oil (15-19%). In proportions comparable to those of soybeans, Bhendi produces oil and protein [25,30,31]. Additionally, the mature seeds may be roasted, ground, and utilized as a coffee alternative. The interest in fibers made from bhendi plant stems, which are typically viewed as agricultural waste after being harvested, has increased recently[2,21,32,33]. Bhendi appears to be native to the so-called Abyssinian center of origin of cultivated plants, which includes Ethiopia, Eritrea, and the eastern Anglo-Egyptian Sudan, though its origins are disputed. Currently, it is grown in Asia, the Caribbean, tropical Africa, and the southern United States. The bhendi plant is tolerant of hot and dry weather and can grow in a variety of soils. Bhendi plants grow 2 m-tall leaves that are 10–20 cm long, 5–7 cm wide, and have 5-7 lobes. The flowers are easily recognized by crimson or purple spot at the base of each of their five white to yellow petals and diameter of between 4 and 8 cm. An 18 cm long capsule containing the seeds has four to ten distinct ribs or ridges (Figure1). The young, immature seed pods of this plant are the only component that can be consumed. While only a few varieties of bhendi have yellow or dark red pods, the bulk of cultivars have green pods. These young, extremely mucilaginous pods are typically harvested 2 to 6 weeks after flowering. Different cultures view the bhendi plant's seeds as its most intriguing part because they generate edible oil with a pleasant flavor and perfume that is high in unsaturated fatty acids like oleic and linoleic acid.

Figure 1: (a) Bhendi plant bearing mature and (b) growing fruits [25]

The weight of the plant is primarily made up of bast fibers, which are also found in bhendi (dry basis). There is a fiber on the outside of the plant's center. The bark fibers derived from jute, kenaf, flax, and hemp fibers are comparable in strength, luster, and brightness to bhendi bast fiber. The bhendi fibers bind together with pectin from the plant cell wall. The semi-woody, occasionally coloured stem of the bhendi plant has crimson or green undertones. The stem can grow to a height of 3 feet in dwarf varieties and up to 7 or 8 feet in other varieties. Bhendi fiber is separated from cementing and goopy components by retting [2]. The fiber can be removed from pectin and the plant core using various retting or degumming methods. As a result of microbial activity or a chemical reaction, retting causes the chemical bonds that keep the stem together to break down, causing the bast fibers to separate from the woody core. Examples of retting/degumming methods include dew retting, cold water retting, hot water retting, mechanical separation, chemical extraction, enzyme extraction, bacterial degumming, ultrasonic separation, steam explosion, and others [34-41]. Ten to fifteen days are needed to complete the water retting procedure for fiber. The retting period may be impacted by a number of factors, including weather, water quality, and quantity. With ample water and a warm, humid climate, microorganisms can proliferate more quickly, making these conditions perfect for retting. The fibers of premium, high-quality bhendi are stripped of the stem and repeatedly rinsed in water to eradicate any leftover impurities. Before further processing, the fibers are removed, properly dried, and stored away from moisture and light [21].

Water retting is one of the simplest and most widely used methods for removing fiber from a stem. The fresh bhendi plant is submerged in water for 10 to 20 days in ambient conditions, following a similar process to the extraction of jute fiber [32, 42, 43].Retting water may contain both moving and still water. The minimum amount of plant material required to get successful results when retting jute and flax fiber in still water is a hydro-module ratio of at least 1:20 by volume[18,44]. If embellished ribbon or crushed stems are used, water retting will go more quickly than usual [26]. When submerged in filthy water, bhendi fiber is removed before water retting because there are so many readily available bacteria that induce retting. Fiber extraction in this instance is of lower grade than water retting [45,46].The retting process may be accelerated by treating bhendi plants with urea or a compost culture solution before submerging them in a tank of fresh water [47]. Due retting is one of the earliest techniques for retting, although it requires more time than water retting and yields fiber that is less robust and of variable quality[48, 49].The retting procedure can be completed in 8 hours by chemically treating mechanically adorned ribbons with 0.5% ammonium oxalate at 75–80°C [11, 50]. The image of the bhendi bast fibers that were extracted by water retting is shown in Figure 2.

Figure 2: Image of water retting used to extract bhendi fiber [51]

Figures 3(a) and 3(b) show the longitudinal microstructure and cross sectional microstructure of bhendi fibers, respectively. In order to give the fiber its strength, non-cellulosic materials like pectin are often used to tightly bond a variety of small fibers together in plants. The region in Figure 3(a) between two microfibrils is known as the middle lamella. Okra fiber in particular has a cross-sectional shape that is polygonal. Figure 3(b) shows the bhendi fiber surface as well as how the fibers are anchored in non-cellulosic materials[21].

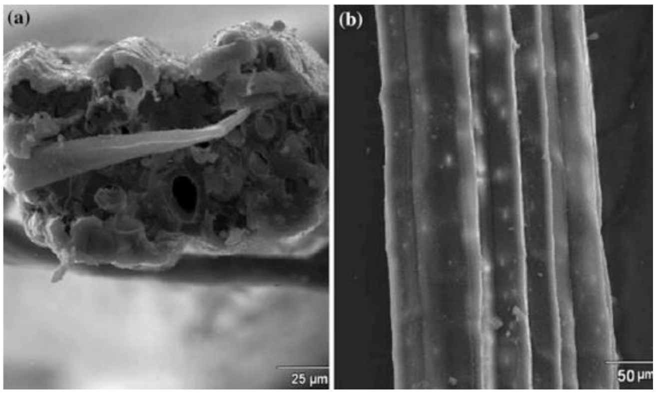

Figure 3: SEM images of bhendi fiber of (a) cross-section and (b) longitudinal view [21]

Water retted bhendi fibers have a composition that is very similar to some other bast fibers (jute, flax, hemp, ramie, etc.) that are frequently used as reinforcement in natural fiber composites, according to Khan et al.,[32].These bast fibers contain 60-70% cellulose, 15-20% hemicellulose, 5-10% lignin, 3.4% pectin, 3.9% fats and waxes, and 2.7% Pectin and lignin act as a bonding agent [52]. Table 1 compares some common bast fibers with bhendi fibers, listing their diverse chemical compositions and physicomechanical traits as well as their use as reinforcement in natural composite materials. Bhendi fiber's qualities don't differ all that much from those of other fibers. The bhendi plant's fiber responds differently depending on its species, cultivation region, age of the plant, and position (main stem or branch). Additionally, it has been discovered that okra fibers begin to degrade at a high temperature, 220°C, whereas jute, kenaf, and hemp fibers degrade at, respectively, 205, 219, and 250°C[21]. Bhendi fiber displays diffraction peaks on the XRD diagram at 15.6°, 21.8°, and 34.0° that are connected to cellulose I[42]. While the unique 101 and 10 peaks of cellulose I, which are positioned at 14.7° and 16.6°, respectively, overlap in the crystalline peak with a maximum at 2θ = 15.6°, the peaks at 21.8° and 34.0° are related to the 002 and 040 lattice planes of cellulose I [53].

Physical Properties

Water absorption is a crucial and undesirable characteristic of composite materials, depending on the intended application. The mechanical properties and use of composite materials are directly impacted by water absorption. Diffusion, capillary action, and water molecule transfer are the three basic ways by which natural fiber reinforced composite absorbs water [54-57]. Diffusion phenomena occur within the micro-channels of the polymer chains. Capillary transport occurs in the spaces between the fiber and the matrix if proper impregnation of the fiber with the matrix was not achieved during the creation of the composites. The microcracks in the composites allow water molecules to pass through and onto the matrix, causing the composite to inflate. The three different kinds of water absorption methods that were previously mentioned are known as the Fickian diffusion model, anomalous or non-Fickian, and an intermediate instance between the two [58].

Table 1: Chemical compositions and mechanical properties of some bast fibers

Chemical compositions	Fibers					
	Bhendi	**Flax**	**Hemp**	**Jute**	**Kenaf**	**Ramie**
Cellulose (wt%)	60-70	64.1-71.9	70.2-74.4	61-71.5	31-57	68.6-76.2
Hemicellulose (wt%)	15-20	16.7-20.6	17.9-22.4	12.0-20.4	21.5	13.1-16.7
Lignin (wt%)	5-10	2.0-2.2	3.7-5.7	11.8-13	8-19	0.6-0.7
Pectin (wt%)	3.4	1.8-2.3	0.9	0.2	3-5	1.9
Moisture (wt%)	4-6	8-12	6.2-12	12.5-13.7		7.5-17
Wax (wt%)	3.9	1.7	0.8	0.5		0.3
Physicomechanical Properties						
Density (g/cm^3)	1.15-1.45	1.5	1.47	1.3-1.49	1.5-1.6	1.5-1.6
Diameter (μm)	40-180	40-600	25-250	25-250	2.6-4	34-49
TS (MPa)	234-380	345-1500	550-900	393-800	350-930	400-938
TM (GPa)	5-13	27-39	38-70	13-26.5	40-53	61.4-128
Eb (%)	2.5-8.6	2.7-3.2	1.6-4	1.16-1.5	1.6	1.2-3.8
Ref.	8, 13	8, 31	8, 31	8, 31	8, 31	8, 31

To calculate the percentage of water absorption, bhendi bast fiber reinforced phenol formaldehyde resin composites were kept in hot water (50°C) and cold water (20°C) for 24 hours [59]. As expected, it was found that hot water absorbed more water than cold water, maybe because the water molecules are more mobile in hot water. In the past, comparable moisture absorption patterns have also been observed [60]. In the same research, the treated fiber composites demonstrated less water uptake under the same circumstances than the untreated fiber composite. When compared to untreated fibers, the treated fibers had a better wettability with the matrix polymer, which may be the cause of this outcome.

Zaman et al.,[61]examined the performance of lady's finger fiber reinforced polypropylene composites in terms of water absorption. The results showed that the prepared specimens' capacity to absorb water grew linearly with increasing soaking time. The fibers were initially given an alkali treatment before receiving the best HEMA treatment. The samples were prepared utilizing the film stacking process and hot compression molding. The samples were assessed in accordance with ASTM D570-98 requirements. According to the results, composites become more water-absorbent as soaking times increase from 5 to 25 days while remaining constant. The treated specimens absorb less water because HEMA reduces the hydrophilic property of lady's finger fiber by reacting with the -OH group of cellulose.

The fiber length is another important factor for the rate of water absorption, according to Sule [62]. The author claims that composite fibers with noticeably longer lengths absorb much less water. According to a different study, the amount of water absorption increases along with the fiber concentration in composite materials. The greater moisture absorption capacity of the fibers compared to the matrix is most likely what is causing this behavior. Additionally, the biodegradation properties of composites can be accelerated by a higher hydrophilic fiber content[62]. On the other hand, as the fiber content of corn-starch composites reinforced with okra fiber increases, the amount of water absorbed decreases. The fibers' less hydrophilic cellulose nature than maize starch was the cause of this [63]. Figure 4 shows that, while maintaining constant, the amount of water absorbed rises with increasing immersion duration up to six days following. It was previously understood that as immersion duration grew, the amount of moisture absorbed increased until a specific point at which saturation was reached [60].

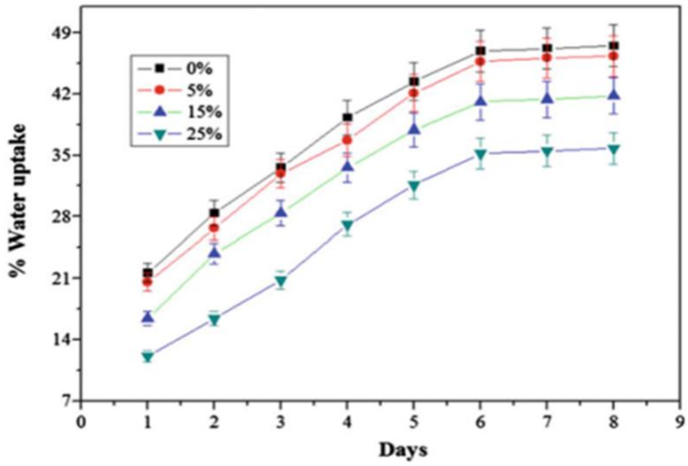

Figure 4: Water absorption of composites made of corn starch and bhendi bast fiber with various fiber loading rates [63].

Shah Alimuzzaman et al., [17] investigated the water absorption properties of okra and jute fiber reinforced polypropylene composites. The results of water absorption of irradiated and non-irradiated samples over varied soaking durations are shown in Figure 5. The results of the water absorption tests on the non-irradiated composites showed that jute composites absorb more water than bhendi composites due to jute's higher hydrophilicity. The absorption rates of both kinds of samples peaked in the first 10 hours then slowed. In comparison to the gamma-irradiated jute fiber composite, the values of the bhendi fiber composite were found to be lower. The phenomenon of water absorption can be explained by the anhydro-d-glucose cellulose structure. Natural fibers that include a hydroxyl (-OH) group in their chemical structure have a tendency to absorb water quickly. The chemical structure of each jute fiber and bhendi fiber has three hydroxyl groups. It was established that non-irradiated samples absorb the most water, whereas gamma-irradiated composites have the lowest. Through cross linking processes, gamma radiation reduced hydroxyl groups and increased crystalline regions, which gradually reduced the amorphous regions and reduced the water absorption behavior of the gamma irradiated composites. It is believed that at the crystalline region, the -OH groups of neighboring cellulose molecules are cross-linked or connected together. As a result, crystalline regions are devoid of any water storage spaces that are also impermeable to water absorption [64-66].

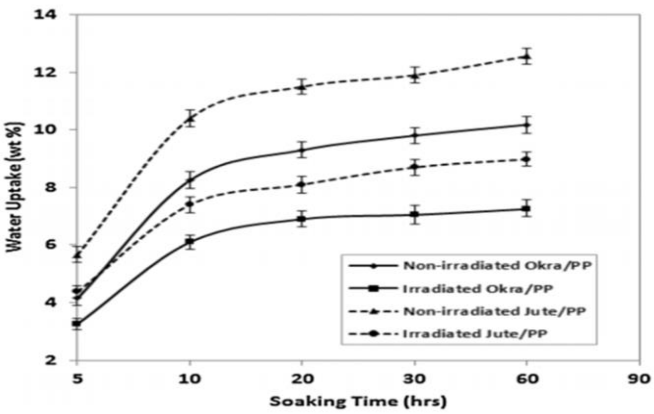

Figure 5: Water absorption of non-irradiated and irradiated (500 krad) composites vs soaking time [17]

Mechanical Properties

Construction, automotive, aerospace, and electronic components are just a few light-duty industries that have used thermoplastic and thermoset polymers. Despite the positive characteristics of these materials, they are fragile by nature. The crack begins to appear and spread quite quickly. Consequently, a solution to these problems is the development of polymer matrix composites, also known as polymer matrix materials[67].The general features of polymer matrix composites are influenced by a number of factors, including interfacial adhesion, shape and orientation of the dispersion phase introduced, and matrix parameters. Therefore, before using these materials in the real world, it is essential to understand how they behave.

All kinds of natural fibers, including those in nano-crystalline forms and woven fabrics, can be employed as reinforcing materials. For bhendi fiber reinforcing, short fiber types were chosen in the majority of research. To create homogenous composites, bhendi fibers that aren't too long can be easily integrated into polymer matrixes. The fiber's short length and random orientation also make it easier for the matrix polymer to wet it [68, 69].The bulk of studies examined the effects of fiber loading, which in different matrix systems can range from 0 to 40%. The mechanical properties of the composites in the majority of tests increased with an increase in fiber loading up until a specific point before the pattern started to shift[63,70].Chemical processing of bhendi fiber frequently improved its properties[70]. The hydrophobicity or surface roughness of the fiber is typically increased by chemical treatments, which enhances the fiber's capacity to interlock with polymer matrices[71].

A composite with a fiber loading of 10–40% consisting of short bhendi fiber and phenol formaldehyde (OF/PF resin) was developed [59]. The greatest tensile and flexural strengths were found to be at a short fiber loading of 30% weight. Additionally, composites with 30 weight percent of loaded showed 95, 168, 200, 111, and 159% higher tensile strength, tensile modulus, elongation at break, flexural strength, and flexural modulus, respectively, compared to unreinforced PF resin. The study shows that fiber has a strong reinforcing effect, which results in a uniform distribution of stress passing from a continuous polymer matrix to a dispersed fiber phase. The findings of this study also showed that alkali treatment significantly enhances mechanical properties by eliminating hemicelluloses; as a result, fiber surfaces become rougher, allowing for higher interlocking with matrix polymer. Similar findings were published by Gassan and Bledzki [72]. However, at strong alkali digestion (15% and 10 hours), the treatment did lead to a reduction in the mechanical strength of both the fiber and the composite. This can be the outcome of extended treatment with an increasing alkali concentration and chain breakage of the cellulose [73].

Fortunati et al., investigated the mechanical properties of untreated and treated bhendi-reinforced PLA composites. They also looked into how various fiber fractions affected the mechanical properties [42]. The fact that all composite samples exhibit higher tensile moduli than neat PLA could be due to the matrix being constrained by the fiber's low-load properties. The nucleation influence of the short bhendi fiber, which was more obvious in composites constructed with alkali-treated fibers, may have increased the capacity of PLA to crystallize.

Additionally, Fortunati et al. examined the PVA composites with bhendi nano-crystal (NC) reinforcement that were created using the solution casting technique and had various fiber concentrations of 1, 2, and 10 weight percent. The results revealed significant variation in elongation at break [74]. For composites containing 1 and 2 weight percents of NC, respectively, elongation at break is decreased by 86 and 57%, whilst composites containing 5 weight percent of NC showed a 130% improvement over pure PVA. Because stress concentrations are produced when fibers are inserted into thermoplastic polymer matrices, it is common to observe a drop in breaking elongation[75].At 5% of the NC loading, PVA and cellulose structures may interact or create linkages. However, the composite's Young modulus at 5 wt% NC loading is not materially different from the composite's Young modulus at 10 wt% NC loading (Figure 6).

Sule et al., investigated bhendi : glass hybridization ratios and epoxy composites reinforced with bhendi bast and glass fibers at 15 weight percent total fiber loading in a range of fiber lengths (10, 20, 30, 40, and 50 mm) (90:10, 80:20, 70:30, 60:40, and 50:50)[62]. For the short bhendi fiber reinforced epoxy composites, it was found that the fiber length of 20 mm had the best tensile strength and elastic modulus. The optimum tensile strength, elastic modulus, elongation at break, and water absorption properties were shown by glass hybridization ratios of 50:50 in Bhendi.

Biodegradable short bhendi fiber reinforced corn-starch with fiber loading rates ranging from 5 to 25 wt% was created, according to Guleria et al., [63].The mechanical properties of the composites were evaluated using their tensile, compressive, and flexural strengths. It was found that all strength and modulus parameters of the composites increased with an increase in fiber content up to 15% loading before starting to decline. They asserted that the improvement in load transfer at the matrix-fiber interface was what caused the improvements in mechanical properties as reinforcement proportion increased. Over 15% fiber loading, however, caused fibers to group together, weakening the connection between the fiber and matrix and obstructing sufficient load transfer, which degraded the mechanical properties.

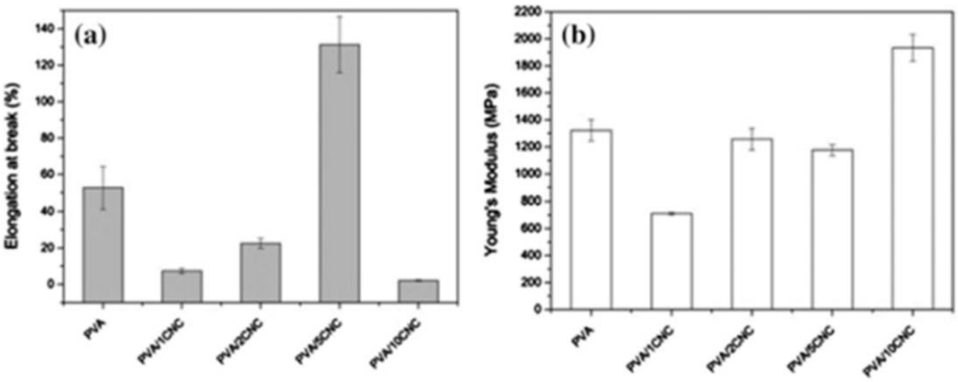

Figure 6: (a) Elongation at break and (b) Young's modulus values for polyvinyl alcohol (PVA) and PVA/cellulose nanocrystal (CNC) nanocomposites [74]

Possibilities for Using Bhendi Fiber

Strict environmental regulations, societal issues, and growing public awareness have all fueled the search for innovative environmentally friendly goods and practices [76]. When composites derived from renewable resources become commonplace, biodegradable composites based on renewable "feedstock" may soon compete with conventional polymers. Agro-residual biomass is now appreciated as a valuable resource, including the fiber from bhendi bast. From a technological perspective, bhendi bast fiber reinforced composites are well suited for use in circumstances requiring high stiffness at low weight. This has further environmental advantages for transportation applications because the lighter structure results in lower fuel consumption over the course of the vehicle's life as well as decreased emissions of greenhouse gases and other dangerous pollutants[71,77]. Okra bast fiber-reinforced composites share traits with composites reinforced with other natural fibers. Bhendi fiber composites may be used in a few different ways, according to a previous researcher. Srinivasababu [51]claims that a range of structural elements for cars can be made from bhendi bast fiber composites. Bhendi Bast fiber reinforced polyester composites have shown sufficient insulating and dielectric strength. Therefore, it might be used in the electrical or electronics industries. Due to its advantages, the hybrid composite can be used in the building and architectural sectors[62]. The environment will be preserved by using composite materials instead of hardwood, which is currently used as architectural elements in buildings. They can also be used as architectural landscaping, public, and private structures because of their minimal water absorption, pedestrian paths, and dividing panels. Recent studies on biocomposites made of bhendi fiber and PLA also show that the composites entirely degrade in soil after 40 days. Using bhendi fiber composites can reduce construction waste and increase energy effectiveness in addition to meeting urgent infrastructure needs. Bhendi may be more effective than other natural fibers at absorbing sound, stronger than composites made of glass fiber, and more efficient at managing energy.

The Cause of Inefficient Bhendi Fiber Utilization

Although bhendi fiber is currently not used commercially, research has demonstrated that it can be used in textile applications similar to jute fiber. The main reason for this might be the extensive production of bhendi fiber. Bhendi plantations can be found in Bangladesh, albeit they are small-scale and solely used to grow vegetables, not fiber. For bulk manufacture, a sufficient retting facility is also necessary, albeit these facilities are not always accessible. The farmer grows the plant primarily to make food rather than fiber. As a result, having the appropriate equipment, facilities, and technological know-how should aid producers in producing high-quality fiber.

CONCLUSIONS

Natural fiber commercialization is now lagging behind due to intense competition from synthetic fibers that can be produced on a big scale and have comparable fiber characteristics. Another concern that farmers should bring up is the practice of prioritizing certain cash crops over crops that yield fiber. Fibers made from agricultural waste are cheap, lightweight, eco-friendly, renewable, and biodegradable. Bhendi fibers, which are produced across several countries and continents, are an excellent example of a by-product from an agricultural productive system that primarily focuses on food-related uses. As a result, lignocellulosic fibers are made available at a low cost and have a wide range of possible applications. The introduction of these materials as fillers, perhaps with some reinforcing effect, in both conventional thermosetting and biodegradable thermoplastic matrices was one of many issues that were investigated in this area. It can be used as a vegetable, a source of protein, oil, and fiber for textiles and pharmaceuticals, as well as a fuel and a source of paper. After the fiber of the bhendi stem has been removed, retting is completed. Chemical modifications to the fibers have improved the composites' mechanical characteristics. Considering all of this, it can be said that the renewable bhendi bast fiber has a lot of promise for application in the industrial manufacture of high-quality composites that increase farmer and employee incomes, create jobs, and safeguard the environment. There should be more emphasis on quicker, more affordable, and environmentally responsible methods of modification as well as strategies to reduce the capacity of composites to absorb moisture. The findings generally imply that the packaging industry, which is mostly associated with the use of biodegradable matrices in short-life products, may be the most appropriate field of use for bhendi fibers in the material sector.

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