International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

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Prospect of waste banana fiber use in industry: A narrative review

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International Journal of Science and Research Archive, 2023, 10(02), 828–839

Publication history: Received on 03 November 2023; revised on 10 December 2023; accepted on 13 December 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.10.2.1045

Abstract

In recent years, there has been significant research and investigation into the utilization of natural plant fibers. These fibers are increasingly recognized for their superiority over synthetic alternatives due to their biodegradable nature, renewable source, lightweight composition, and enhanced biochemical and tensile characteristics. Banana fiber holds significant importance due to the widespread use of bananas globally. Different components of the banana plant, including the fruit, fruit skin, flower buds, leaves, and pseudo-stem (banana trunk), are employed for diverse industrial applications. The pseudo-stem constitutes a significant proportion of the biomass derived from banana waste and possesses high-quality fiber that exhibits promising potential for various industrial applications. These applications include the production of sanitary pads, textiles, pulp and paper, food products, reinforced composite materials for automobiles, construction materials, aerospace components, and other composite materials. Additionally, the residual waste generated from its production can be effectively employed for the development of bio-based products, thereby making a direct contribution to a country's economy. In summary, this review study provides valuable insights for many stakeholders, including farmers, businesspeople, planners, scientists, and the government, to facilitate informed decision-making and promote socioeconomic advancement within the country.

Keywords: Banana fiber; Sustainable usage; Eco-friendly; Composite; Circular economy

1. Introduction

The increasing apprehension regarding global warming, the implementation of rigorous environmental legislation, and the growing consciousness within communities have emphasized the importance of forest conservation and the mitigation of plastic pollution. There is a growing need from several industries for sustainable materials as alternatives to both forest-based raw resources and synthetic polymers [1]. Agricultural residues represent a notable category of sustainable materials that are currently being investigated for their possible utilization in various industrial applications. Agro waste leftovers serve as valuable sources of natural fibers, presenting an environmentally sustainable substitute for manufactured polymers. The global output of natural fibers is experiencing a notable growth due to the rising demand for products derived from these fibers. In addition to their environmentally benign nature, natural fibers include supplementary attributes including renewability, lightweight composition, exceptional absorption capabilities, and favorable mechanical qualities [2]. Furthermore, it should be noted that these materials possess the characteristic of being biodegradable and capable of being recycled. Industries are currently utilizing and conducting research on many natural fibers such as hemp, jute, sisal, kenaf, cotton, flax, ramie, and banana fibers. Banana fiber, derived from the pseudostem, exhibits superior fineness and spin ability compared to alternative fibers [3]. The pseudo-stem of the banana plant is a significant component of biomass waste that remains after the harvesting of the fruit. This waste has the potential to serve as an alternative source for companies that rely on fiber-based materials [4]. Banana fiber is

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currently highly regarded for use in the textile and garment industries because it is also acknowledged for having good properties. To raise awareness and make banana fiber specifically available to our market, numerous researchers are currently working on it [5, 6].

The banana plant, classified as a perennial member of the Musaceae family, exhibits a variable height ranging from 10 to 40 feet and produces fruit with a maximum length of 12 inches. Subtropical and tropical countries are the primary contributors to the global banana production. Based on the data provided by FAOSTAT (2018) [7], the global output of fruit is predicted to be approximately 115.7 million metric tons on a yearly basis. India is the global frontrunner in banana production, accounting for 26.7% of the entire output. This amounts to approximately 30.81 million metric tons of bananas produced annually, cultivated on an area of 0.88 million hectares. China, Indonesia, Brazil, Ecuador, and the Philippines are among the prominent producers in this industry [8]. India's contribution to global exports is a mere 0.38%, primarily due to the significant portion of its produce being consumed domestically. Ecuador holds the position as the primary exporter of bananas globally, contributing around 27.6% to the overall volume of worldwide exports. Subsequently, Costa Rica, Colombia, and Belgium follow suit in terms of banana exportation [9]. The center core of the banana plant, known as a pseudo-stem, is composed of leaf sheaths that round it (Figure 1).

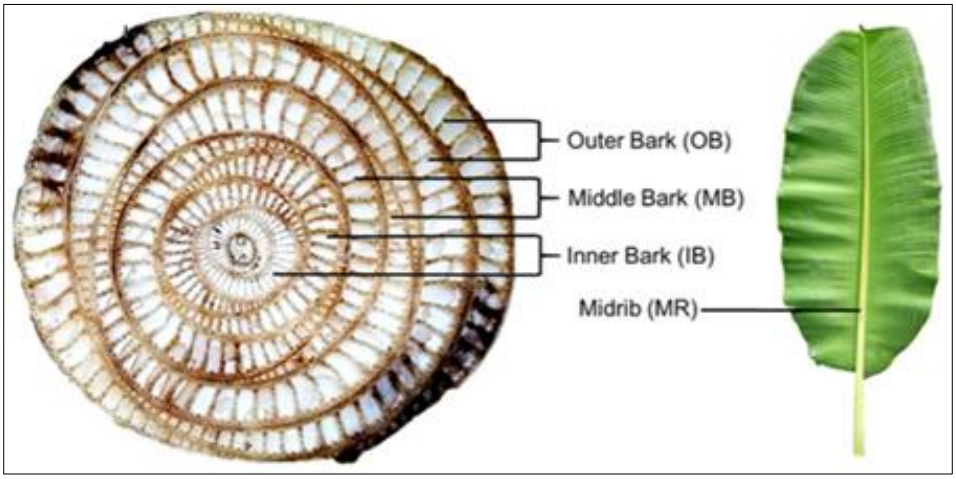

Figure 1 Cross section of pseudo stem of banana tree (left) and banana leaf (right) [Retrieved from Motaleb et al. 2020 [10]]

The banana pseudo-stem produces fruits singularly for its lifespan, after which it is replaced, ultimately resulting in its disposal as waste following the completion of fruit harvesting. It is estimated that each hectare of banana plantation yields approximately 220 tons of biomass waste. India is responsible for the production of around 190 million tons of biomass waste only derived from banana plantations. According to the FAOSTAT 2018 data [7], the global cultivated land area amounts to around 5.72 million hectares, resulting in the production of 1.243 billion metric tons of garbage. The predominant component of the biomass waste derived from banana plants is the pseudo-stem. As a result of limited expertise and resources, the disposal of this waste is commonly carried out through incineration or deposition in bodies of water such as lakes, rivers, or shallow regions. This practice consequently contributes to the emission of greenhouse gases and poses a significant environmental hazard. This underscores the need of effectively harnessing banana biomass waste, particularly in nations such as India, which holds the position of being the foremost banana fruit producer.

Different components of the banana plant, including leaves, pseudo-stem, pith, and fruit peels, have been found to have diverse applications in both food-related and non-food-related contexts. These applications encompass various uses such as flavoring agents, colorants, livestock feed, and nutraceuticals in the food industry [11]. Additionally, the non-food industry has explored the utilization of banana parts for purposes such as manufacturing tea bags, producing biofertilizers, treating wastewater, paper production, textile production, and creating composites [12, 13]. The potential of utilizing the banana pseudostem for the extraction of high-quality fiber is currently being investigated. Similar to other natural fibers, the mechanical characteristics of banana pseudo-stem fiber are equal to those of conventional reinforcements. As a fiber derived from plants, it offers supplementary advantages to the industry by serving as an environmentally responsible substitute[4]. In conclusion, this review study offers significant insights for many stakeholders, such as farmers, business professionals, planners, scientists, and governmental entities, to allow well-informed decision-making and foster socioeconomic progress within the nation.

1.1. Properties of Banana Fibers

Cellulose, hemicelluloses, and lignin make up banana fiber. Depending on whatever section of the stem is used to remove the fiber, the quality of the fiber varies. When taken from the inner part of the stem, banana fibers are extremely fine, silky, and have a natural shine [14]. The coarse and rough fibers produced by the outer strands of the stem are mostly utilized to manufacture ropes, carpets, and baskets. Banana fiber is extremely robust and long-lasting because it is entirely natural [15].

Although look is comparable to bamboo and ramie fibers, fineness and spin ability are superior to those of these two [16]. Banana fiber has excellent mechanical qualities. These fibers are strong, fire-resistant, and light in weight. Depending on what portion of the stem it is made from, banana fiber can appear fairly glossy [17]. Strong moisture absorbing and moisture releasing characteristics are shared by banana fiber. As a result, it is primarily worn in the summer. Banana fiber can be produced and harvested without the use of chemicals [18]. Biodegradable, all-natural banana fiber has no harmful effects on the environment. The qualities of natural fibers can be enhanced by blending banana fiber with cotton, silk, or other natural fibers to produce a range of garments [19].

Table 1 Physical and Chemical Properties of Banana Fiber [retrieved from Paswan et al. 2012 [20]]

Fibers	Width or diameter (µm)	Density (kg/m3)	Cell L/D ratio	Microfibrillar angle (degree)	Initial modulus (GPa)	Tensile strength (MPa)	Elongation (%)
Banana pseudo-stem	80–250	1350	150	10 ± 1	7.7–20.0	54–754	10.35

1.2. Eco-friendly Properties of Banana Fiber

A natural bast fiber is banana fiber. The pseudostem of the banana plant is used to harvest banana fiber. Banana plants must be removed after bearing fruit since they cannot be used to produce the fruit again. The demand for bananas rises with population growth, and as there are more banana tree plantations, there is more annual waste from banana plantations. Therefore, it is important to make an effort to turn this waste into wealth [21].

Manufacturing procedures are influenced by the idea of sustainable and environmentally friendly development. Waste biomass from various plants is now frequently exploited to obtain natural fibers [1]. A study found that billions of tons of banana plant stems are discarded annually. Farmers typically burn off the fruit waste after harvesting it or dump it into rivers and lakes, but if done improperly, this can be dangerous to the environment. Banana trees can be grown without the use of pesticides or other chemicals [22]. A study found that, if made in big quantities, banana cloth could be less expensive than cotton and linen. Additionally, banana fabric shines well and has good moisture absorption, much like linen. Many people in the fashion industry are aware of the need for environmentally friendly and sustainable choices to protect natural resources and the environment. Promoting environmentally friendly clothing and textiles aims to reduce social and ecological impacts, including the carbon footprints associated with textile production [23]. Using agricultural waste as a raw material instead of damaging the environment is encouraged by banana fabric. Farmers will also gain from it. According to research, the income of Indian farmers has increased by up to 300% [24]. Additionally, it provides chances for rural villages and hilly regions to improve their quality of life, and women from the villages can work in the manufacturing of a variety of bio-products from banana trash [25].

2. Methods for Extraction of Banana Fiber

2.1. Banana fiber removal

Tuxing refers to the process of removing the gummy cellulose-like substance off the banana stem in order to separate the fibers from the stem. This can be eliminated manually or mechanically [26]. When these plant trunks are softened by soaking in surrounding rivers, it is possible to separate the fibers efficiently and effectively; this procedure is known as retting. By retting, hemicelluloses and lignin, which are present in the pseudostem of the banana plant, are greatly diminished. The grade of retrieved pseudo-stem fiber varies according on the local climate, soil, and irrigation [27].

2.2. By hand extraction

Historically, taxation was performed manually, which is a tedious and time-consuming operation. Manually, these sheaths are separated and lightly rolled before the stem's coating is scraped off using a metal scraper [28]. The fibers were then cleansed and dried. If care is not used when scraping, the fiber will be destroyed. Manual fiber extraction is not suitable for industrial applications [29].

2.3. Extraction by means of mechanical extraction

A specialized machine is devised and built to automate the mechanical extraction of fiber. This machine consists of two horizontal beams and a carriage with an attached, reciprocating special comb. A cleaned banana sheath is placed on the platform, which is attached to the machine, before being clasped at both ends by jaws. With this procedure, fiber damage can be prevented. The fibers are then washed and dried in a 200°C chamber Mechanical extraction of banana fiber is an eco-friendly technique for producing fibers of excellent quality and quantity [30].

2.4. Chemical Extraction

In an alkaline solution, banana peels are cooked for chemical extraction. These sheaths are softened, and the fibers and cellulose are separated. The fibers are then combined into a long thread for spinning [31].

Figure 2 Extraction of fibers from banana stems [adopted from Ortega et al. 2016 [32]]

3. Sustainable Application of Banana Fiber

In the textile business, banana fiber is widely utilized as a blending component in nations including the Philippines, Malaysia, Japan, and Korea. It is simple to combine with other natural fibers like jute and mesta. Because of this, a wide range of industrial items, including gunny bags, door mats, carpets, yarn, ropes, geotextiles, trinkets, luggage carriers, interior ornamental crafts paper, tissue paper, paper bags, and more, can be made using this fiber [33]. Additionally, it has various industrial applications, including those of a natural sorbent, a foundational component in bioremediation and recycling, and a natural water purifier [34]. Banana fiber is used in Europe, among other places, to make socks and gloves.

3.1. Yarn

Banana fiber yarn is a type of rope created from extracted banana fiber (Fig. 2). One of the most fundamental abilities for converting any linear material into a functional stage is making rope [35]. For pulling and attaching, rope is a length of fibers that have been twisted or braided together to increase strength. It is too flexible to offer compressive strength despite having tensile strength [36]. The banana tree's decomposing bark actually has three layers. The toughest layer is the outer one, which is typically used for weaving. The inner layer, which contains the silkiest fiber, is used to spin

yarns and create beautiful apparel such as sarees, three-piece suits, t-shirts, underwear, etc. The middle layer creates rope that is used to make thick material (Fig. 3) (Retrieved from [Mohiuddin et al. 2014 [25]].

Yarn from inner layer | Yarn from middle layer | Yarn from outer layer

Figure 3 Making yarn from banana fiber [adopted from Mohiuddin et al., 2014 [25]]

Saree | Shirt | Female's dress | Night dress

Coaster | Table mat | Stylish hand bag | Shopping bag

Laminated fabric | Laminated fabric | Normal fabric | Eco Shopping bag

Figure 4 Various useful items constructed from banana fibers [adopted from Mohiuddin et al., 2014 [25]]

3.2. Clothing and Textiles

Fabric refers to materials created from rope or yarn, whereas clothing refers to the numerous sorts of clothes constructed from cloth [37]. Producing fabric and clothing from banana fiber follows the same steps as producing cotton material. Additionally, it is possible to create synthetic and laminated fabrics by combining specific amounts of different fibers, such as cotton or jute (Fig. 4).

3.3. Paper

For the production of writing paper, check paper, anti-grease paper, and hard board, banana fiber can serve as a substitute raw material (Fig. 4) [34, 38]. Banana plants are first harvested for their basic paper components, and then they are harvested for their fibers. Before creating pulp, the gathered fibers are soaked in water. After that, the extracted fiber undergoes a 3-5-day microbial bleaching process utilizing Trichoderma and Pythium [34]. By breaking the links between lignocellulose complex structures, lignin, and hemicelluloses, these fungi act on cellulose, causing the breakdown and leaching out of these materials [39]. It improves the paper's brightness, softens the fiber, and makes the pulping process simpler.

After the microbial treatment, the banana fiber needs to be cleaned to get rid of any contaminants, including bacteria, and beat into pulp. During the beating process, all of the additives must be introduced in the specified quantities and exact proportions. Typically, the bonding between the fibers in paper pulp is modified or improved using starch, polysaccharide resins, and natural gums (glue). During the size process, wetting and penetration ability are attempted to be slowed. Sizing decreases porosity, which also affects absorption capacity. Following the completion of numerous procedures, pulp is used to create the finished paper [38]. Shopping bags, folders, greeting cards, invitation covers, scribing pads, envelops, art paper, printing paper, and other items are made from this paper. Additionally, writing paper is also made from banana fiber using the standard industrial technique, but with the pulp of bamboo or wood instead of banana fiber [34] (Fig. 5).

Cheque paper | Anti-grease paper | Banana fiber paper

Figure 5 Paper products made from banana fibers [Retrieved from Mohiuddin et al. 2014 [25]]

3.4. Production of solid board

Banana fiber is combined with scutcher, cotton rags, waste paper, and paddy straw in varied amounts to produce hard paper and boards [34]. (Fig. 6). This sort of board is replacing older boards on the market in a variety of applications.

Banana fiber board | Paper made products | Fiber made rope | Fiber made products

Figure 6 Fiber board and paper made products from banana fibers [adopted from Mohiuddin et al. 2014 [25]]

3.5. Handicrafts

Banana fiber is used to make a variety of crafts. It consists of numerous dolls, key chains, bags, coasters, table mats, pillows, and other ornamental wall hangings (Fig. 6). Participating in this industry can help women, in particular, improve their economic and social situations [40].

3.6. Environmental Friendly Bag

Banana fiber can be used to create an eco-bag, which degrades naturally [40]. Compared to a bag made entirely of cotton, this eco-bag made of banana fiber is robust, wrinkle-resistant, and absorbent-resistant. To raise the standard of the eco-bag, several designs and color schemes are mandated (Fig. 6).

3.7. Natural fertilizer

Vermicomposting can be used as organic fertilizer on agricultural areas [41]. At a research farm and farmers' fields, respectively, experiments and demonstrations using scutcher-based vermicomposting are being carried out on a variety of crops, including sugarcane, bananas, papaya, ginger, etc. Vermicomposting has been discovered to have effects that are comparable to bio compost in bananas and sugarcane, which can maintain the health of crop fields [40].

3.8. Sanitary Napkins

The International Institute for Environment and Development (TIIED) has developed a program to educate African women on the production of inexpensive and environmentally friendly sanitary pads from banana fibers Many scientists are working to promote and produce a biodegradable residential product [42].

4. Market opportunity

The market potential for banana fiber and related products is shown in the review above. There are enough raw resources, and since Bangladesh's soil is suited for growing banana trees, there is room for additional expansion [43].

It is well known that cotton costs are rising yearly on a global scale. On the other hand, Bangladesh imports close to 96–97% of its cotton from abroad each year. 18 thousand taka are needed annually. Investigating the many natural fiber sources is crucial to resolving this dilemma. In addition, the banana tree is completely useless and seen as a waste, save for its fruit. Banana fiber has already been investigated for its potential to partially replace the consumption of cotton and jute fiber in many nations [40]. The local market has a significant demand for handicrafts, clothing, paper and paper goods, vermicomposting, food created from the central core of banana trees, natural colors, and clothing. If these products can be made from materials like banana fiber, they will be less expensive than comparable products now on the market [9].

5. Prospects of Banana Fiber Composites

The utilization of banana fiber composites is seeing a growing trend in various applications owing to their remarkable mechanical qualities and promise for sustainable development. The utilization of these applications is seen in several sectors such as building and construction, automobile, sports equipment, and packaging industries. The utilization of banana fiber composites in the building and construction sectors has witnessed a notable rise due to their status as an environmentally friendly substitute for conventional synthetic composites. The utilization of these composites in roofing materials, flooring materials, and wall panels has demonstrated a significant paradigm shift, presenting numerous advantages in comparison to synthetic composites [44]. To begin with, it should be noted that banana fiber composites possess characteristics that render them environmentally sustainable and capable of undergoing natural decomposition. Consequently, these attributes make them a highly appealing choice for the implementation of eco-conscious construction initiatives. This holds significant importance, particularly in light of the growing global awareness regarding the environmental ramifications associated with construction activities. Furthermore, it should be noted that these materials possess a commendable strength-to-weight ratio, rendering them very suitable for various applications such as roofing, flooring, and wall panel installations. The reason for this is that composites provide a favorable combination of strength and durability, rendering them well-suited for many building and construction purposes. Nevertheless, a constraint associated with the utilization of banana fiber composites within the building and construction sector pertains to their restricted accessibility, potentially resulting in escalated expenses. However, in spite of this constraint, the utilization of banana fiber composites within the building and construction sector is anticipated to expand due to the increasing environmental awareness among individuals and their inclination towards eco-friendly construction materials [45].

Banana fiber composites have been widely used by the automotive industry as a prominent material for the manufacturing of composite components, including bumpers and body panels. These composite materials exhibit an exceptional strength-to-weight ratio, rendering them a superior selection for automotive applications that necessitate the reduction of weight. Moreover, their exceptional resistance to impact and capacity to endure adverse weather conditions render them very suitable for meeting the rigorous requirements of the automobile sector. Despite the numerous advantages, a major limitation of incorporating banana fiber composites within the automobile industry lies in their comparatively restricted accessibility when compared to conventional synthetic composites, potentially resulting in increased expenses [46]. The utilization of banana fiber composites in the production of sports equipment, such as golf clubs and tennis rackets, has been widely adopted by the sports equipment sector. Composite materials possess numerous advantages when compared to conventional materials, such as a notable strength-to-weight ratio and enhanced durability. Consequently, they are highly suitable for implementation within the sports industry, where the attainment of an optimal equilibrium between strength and weight is of utmost importance. Furthermore, the utilization of environmentally friendly and sustainable materials is in accordance with the principles upheld by numerous sports fans and consumers. Nevertheless, akin to various other industries, the utilization of banana fiber composites in sports encounters a constraint in the form of restricted accessibility. Consequently, this limitation may potentially lead to a larger financial burden compared to conventional synthetic composites. However, the growing need

for environmentally friendly and efficient materials could potentially incentivize the advancement and manufacturing of composites made from banana fibers, hence enhancing their availability and cost-efficiency [47].

Banana fiber composites have emerged as a viable and environmentally-friendly substitute for synthetic composites within the packaging sector. The utilization of banana fiber in packaging has numerous benefits, including its environmentally benign nature, biodegradability, and notable strength-to-weight ratio. These characteristics render it very suitable for the packaging of products that require both low weight and high durability. Nevertheless, a constraint associated with the utilization of banana fiber composites within the packaging sector is their restricted accessibility, hence potentially resulting in elevated expenses when compared to conventional synthetic composites. Nevertheless, the utilization of banana fiber composites within the packaging sector is experiencing an upward trend due to heightened consumer awareness regarding the environmental implications of packaging and their increasing demand for sustainable packaging alternatives [48].

In addition to aerospace and medicine, other industries have the capacity to utilize banana fiber composites owing to their remarkable mechanical characteristics. Nevertheless, the restricted accessibility could continue to be a barrier in these sectors. Furthermore, the utilization of banana fiber composites holds promise in the aerospace and medical sectors, which demand the use of high-performance composites. Nevertheless, the restricted accessibility and elevated expenses associated with these composites could potentially present a hurdle within these particular sectors [49].

6. Prospects of Banana Fiber in Circular Economy

There has recently been a lot of study conducted globally to identify a different source for the manufacture of fiber. Agricultural waste products, like the leftover biomass from bananas, are excellent secondary sources for making natural fibers [50]. The proper management of agricultural residues will support circular bio economy concepts that focus on building a framework of renewable resources, like banana fibers, to be used for food management, health, land, and industrial systems using techniques like creating fibers from biomass waste, as well as significantly lessen the environmental issues brought on by current disposal practices. An economy that is powered by nature is the bio-economy. It is a new economic model that replaces various non-renewable wastes and reduces waste by using renewable products. The concept behind it is to make garbage into a valuable resource for society [51]. By creating polymers and serving various purposes, the biomass can help society by utilizing this circular bio-economy concept for plant fibers. Potential earnings for banana growers and the worldwide industry will come from the value of the finished goods and fibers. It is environmentally beneficial and decreases the need for polymers made from fossil fuels. There are obstacles to overcome, such as determining how much of these biomass waste fibers can actually be used in society [12]. Given that the global production of this waste into fibers is growing annually and that more strategies for utilizing this waste are now being investigated and developed, the prospects for its usage are positive. Due to its widespread production, the banana plant was chosen as the most crucial agricultural waste to concentrate on volume and its surplus biomass, which has a variety of uses and can help promote sustainability in a circular bio-economy by reducing waste [52]. Currently, the growth of industry and the mass creation of synthetic materials are the main contributors to climate change. Therefore, we draw the conclusion that building an integrated bio-refinery option will be prioritized in order to create fibers and other important goods from the recycling of agricultural residues, and low-cost technologies should be developed in order to support the circular bio-economy [53].

7. Conclusion

The pseudo-stem of the banana plant, which is typically discarded after the fruit is harvested, represents a valuable and high-quality source of dietary fiber. The extraction method plays a significant role in determining both the quality and amount of fiber. The utilization of banana fiber in many industrial contexts presents novel avenues for academic and industry exploration of its potential applications. The usefulness of banana fiber for various applications is primarily influenced by concerns related to its fiber content and strength qualities. The high cellulose concentration and low lignin content of banana fiber render it a very suitable option for use in the pulp and paper industry, an industry that is widely recognized for its significant environmental impact. Due to its remarkable absorption and tensile characteristics, banana fiber exhibits significant promise as a primary material for the production of sanitary pads. This is particularly relevant considering the present environmental concerns associated with the predominant use of plastic-based sanitary pads, which contribute significantly to pollution. Hence, banana fiber presents itself as a viable and cost-effective substitute for synthetic fibers, thereby contributing to environmental sustainability. One of the primary obstacles faced in the commercial utilization of banana fiber pertains to the effective and environmentally sustainable extraction of high-quality fiber from the pseudo-stem on a significant scale. The current body of research primarily consists of laboratory studies, thereby necessitating the need for further development and implementation of methods on an

industrial scale. There are several potential future applications that warrant exploration for banana fiber, including the development of plastic-free and environmentally friendly N95-type masks, personal protective equipment (PPE) kits, carry bags, eco-friendly clothing, mattresses, and carpets. Additionally, banana fiber may find utility in the realm of art and craft design. Further investigation is required to study the potential utility of capsule coatings in the field of medicinal research.

Compliance with ethical standards

Acknowledgments

The authors would like to thank all the writers who have contributed in the field of sustainable usage of banana fiber.

Disclosure of conflict of interest

The authors declare that they have no known conflict of interests.

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