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REVIEW ARTICLE

Utilization of pineapple leaf: an alternative for paper and textile industries

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ABSTRACT

Among various fibers available which are derived from plant, the leaves of pineapple (*Ananas comosus* L.) deemed an agro-waste have demonstrated significant promise for commercial utilization as a substitute raw material within the paper and textile industry. The exceptional fiber characteristics of pineapple leaf fiber surpass those of other natural fibers abundant in cellulose, offering cost effective, eco-friendly and strong fiber resilience. The appeal of incorporating pineapple leaf fiber lies in its widespread availability and unique attributes such as biodegradability and low density, which contribute to achieving superior specific strength. The utilization of pineapple leaf fiber for commercial aims has begun to establish a market, enhancing the value of pineapple cultivation and providing additional revenue streams for entrepreneurs and farmers, while also promoting agricultural diversification. This review explored the potential applications of pineapple leaf fiber not only in agriculture but also as a source of alternative raw materials for textiles and as non-wood materials for paper manufacturing. The broad utilization and adoption of pineapple leaf fiber could play a significant role in mitigating deforestation and detrimental impacts on agriculture..

Keywords: Agriculture waste, paper, pineapple leaf fiber, textile

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INTRODUCTION

Natural fibers have been increasingly recognized for their significant contribution as a substitute for synthetic oil based fibers, apart from textile industry and various other applications. Among numerous natural fibers, plant fibers are regarded as notable candidates to substitute conventional glass/ synthetic fibers as they are low cost, eco-friendly, biodegradable and renewable (Siakeng et al., 2019). Pineapple, a widely cultivated fruit in tropical and subtropical region is known for its abundance and only about 25% of the produce can be marketed in food sector, with the remaining 75% (crown, leaves, stem, and peel) being disposed as agro-waste (Ramli et al., 2018). Approximately 384,673 metric tons of wastes including leaves were burned or thrown away in 2008, which may have led to contamination and issues with landfills. Pineapple leaf fibers are utilized in very small amounts as feedstock and for production of energy (Halim et al., 2018). During post-harvest, after the fiber from the abandoned or discarded leaves is extracted, pineapple leaf bunches are mostly used for textiles, paper and composite

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materials. Pineapple leaves produce strong, white, silky fibers that can be spun on a cotton or jute spinning equipment to create fine textile-grade yarn (Asaolu et al., 2016). The leaves, an overlooked component of the plant present an opportunity for commercial exploitation on a large scale (Siakeng et al., 2020). Together with bass, bast, seed, straw and wood fibers, pineapple leaf fibers are among the six primary forms of plant fibers (Ramamoorthy et al., 2015) which is gaining popularity in various application nowadays. A hectare of pineapple plantation may produce about 15 tonnes of PALF per year (Leao et al., 2010b).

The number of hexagonal regions on the outer layer of every pineapple leaf fiber (PALF) is the same and is independent of both size and contour (Singha et al., 2020). Because of its great tensile strength, simplicity of extraction from the leaves, environmental friendliness (Motaleb et al., 2018), pineapple leaf fiber is among the numerous natural fibers which could be utilized as a practical and plentiful replacement for the costly synthetic fibers (Rafiqah et al., 2020),The quality of PALF can be likened to that of many leaf fibers, displaying notable attributes such as bright white colour, length and strength positioning it as a top-tier choice among the prevalent leaf fibers. Due to its comparatively low microfibrillar angle and high cellulose content (70-80%) and, this natural fiber has a high specific strength and stiffness and is commonly employed in composite sector (Lopattananon et al., 2006). It is more superior to other vegetal fibers due to its high fineness index. Because of this unique quality, PALF is very appropriate for a wide range of industrial applications, particularly woven fabric and yarn (Leao et al., 2015).

After harvest, PALF is also regarded as a waste by many farmers. But it also provides them with fresh revenue to use. The textile industry will benefit from PALFs increased awareness of its advantages instead of synthetic fibers, which will encourage farm owners to use the leaves from pineapples (Jose et al., 2016). Research is being done to determine the best time to collect pineapple leaves in order to acquire high-quality fibers (Pandit et al., 2020). Natural fiber's abundant and diverse supply helps ease the strain on agriculture and forests. Using a variety of raw materials will support maintaining the natural ecological equilibrium. To reduce the waste of renewable resources, it is crucial to fully utilize pineapple leaf fiber by increasing industrial consumption. It takes a lot of work to assess its potential in paper and textile industries rather than treating it as waste (Halim et al., 2018). This paper is an overview of the existing literature which indicates that pineapple leaf fiber can be a promising alternative raw material in textile and paper industries.

CHARACTERISTICS OF PINEAPPLE LEAF FIBER

The medium length, white coloured, silky, smooth fiber found in pineapple leaves has a high tensile strength. The outer surface of PALF is soft and delicate as compared to other natural fibers and it may absorb substances to keep its colour vibrant (Asim et al., 2015). PALF has high stiffness, high strenght and strong affinity for water because of its high cellulose content (Bengtsson et al., 2005). PALF, also known as multicellular lignocellulosic fiber, is a structure resembling threads and is firmly bonded with pectin in a bundle (Rahman, 2011). PALF contains considerable amount of impurities and chemical constituents, the dominant constituents include cellulose 80%, 6-12% hemicellulose and 5-12% lignin (Asim et al., 2015; Jose et al., 2016) providing more strength as they are the fiber's main structural component (Paster et al., 2003), hemicellulose polysaccharides, which are made up of xylose, arabinose, glucose, galactose and mannose which act as a separating agent between lignin and cellulose, and which function as a separating agent between cellulose and lignin (Hansen and Bjorkman, 1998), lignin and some impurities or minor chemical components which include fat, colour pigment, pectin, pentosan, uronic anhydride, wax, inorganic substances among others (Padzil et al., 2020). Pineapple fiber consists of microscopic cell-like multicellular fibers which are tightly bonded with the support of pectin. 70.82% of the fibers are made of cellulose, and they are oriented similarly to cotton fibers (82.7% cellulose). Consequently, almost all the mechanical, physical, or even their chemical properties are comparable to cotton fiber (Singha et al., 2020) and the use of reinforced biocomposites may be improved as it has low microfibrillar angle with high cellulose content (Asim et al., 2018).

One of the beneficial characteristics of PALF is that the fiber is resistant to wilting and minimal water loss during carbon dioxide absorption. This efficiency is because the stomata open at night rather than during the day, facilitating decarboxylation of accumulated malic acid. This is due to PALF's crassulacean acid metabolism (CAM) feature (Padzil et al., 2020). PALF offers numerous advantages, including low lignin content, high fineness index, high aspect ratio, environmental friendliness, biodegradability, renewability, high stiffness, specific strength and a low mass type (Leao et al., 2015; Nikmatin et al., 2015).

Pineapple leaf fiber contains more cellulose compared to other organic fibers, including banana fibers, coir and petroleum palm frond. Its physical strength surpasses that of jute, making it ideal for yarn production (Das et al., 2018). Pineapple leaf fiber is a vital organic fiber known for its significant rigidity and toughness, similar to jute fibers in terms of flexural and torsional strength. These exceptional properties make PALF an excellent choice for reinforcing composite matrices in various industries.

METHODS OF PINEAPPLE FIBER EXTRACTION

Pineapple leaf fiber extraction is done by the following three methods which are- manual (hand stripping/ scrapping), retting and mechanical. PALF features a ribbon-like structure composed of vascular bundles present in clusters of fibrous cells. Extraction involves removing the epidermal tissue from the leaves (Jose et al., 2016).

Manual extraction (Hand Stripping/ scrapping)

The scrapping process is a traditional method used to extract PALF typically performed on a long bench. A tool known as "ketam" is commonly used for this purpose (Rafiqah et al., 2020). This method, also referred to as hand scraping method is manually performed. It begins with scraping pineapple leaves, followed by washing the extracted fibers under running water and drying them directly in sunlight (Yusof et al., 2015). By using broken porcelain (Pandit et al., 2020) or ceramic plate with pressure and quick movements over the pineapple leaf extracts the fibers beneath it (Uddin et al., 2017). Two types of fibers, liniwan and bastos, are produced using this method. After scraping, the fibers undergo thorough washing using running water and left to air-dry. Microorganisms dissolve pectic substances in the soft cells, separating fiber bundles from the woody core material (Pandit et al., 2020).

Mechanical fiber extraction using decorticating machines

In mechanical extraction, decorticating machine with three distinct rollers namely feed roller, leaf scratching roller and a serrated roller is used (Singha et al., 2020, Banik et al., 2011). The extraction process begins with feeding pineapple leaves through a feed roller, which removes the waxy layer with another roller. A serrated roller then creates spaces, and the leaves travel through a roller with sharp, thick serrated blade attached. This roller breaks the leaves so that retting bacteria can enter more easily (Banik et al., 2003; Kannojiya et al., 2013). In a day, around 15 kg green fiber is collected using this process (Das et al., 2010). The waxy layer from PALF surface is removed using blades built into the machine. The number of blades, their sizes and their angles are carefully selected to prevent the leaves from snapping during the process which is crucial for effective extraction. This technology is more efficient but time-consuming. PALF produced by the decorticating machine is softer, brighter, and has a creamy white color, contrasting with the brown color of fibers produced by conventional methods (Yusof et al., 2015). The Raspador machine is a mechanical extraction device used to crush green pineapple leaves. Fibers are collected by washing the tender green portions of leaves. The collected fibers are then brushed with a comb to remove the spongy parts, resulting in fine threads. However, fibers extracted using this process are coarser compared to those retrievedd manually, even though the extraction time is faster (Jose et al., 2016).

After extraction, retting and degumming is followed to split the coarser fibrous strands, which occurs due to generic reasons:

a) Biological natural retting, the active ingredients being bacteria or fungi (dew retting)

b) Chemical retting or degumming, the active ingredients are dilute acids, bases or enzymes

The following methods can be used to perform chemical degumming on pineapples: preparation (soaking in acid, H_2SO_4) → cleaning → boiling in NaOH solution → washing → bleaching → water extraction → oiling → drying. Chemical degumming of pineapple fibers involves treating the fibers with solution of acids, alkalies or enzymes at different temperatures and durations, typically in an anaerobic environment. The finest fibers are produced by retting with 5% sodium hydroxide for 12 h (Pandit et al., 2020).

Degumming is used to remove the sticky materials found in leaves of pineapple such as lignin, pectin's and pentosan. In 3% sodium carbonate (Na_2CO_3), the extracted PALF was submerged for one hour at room temperature as part of the alkaline treatment. Subsequently, the fibers were washed and rinsed repeatedly with distilled water to remove any remaining alkali, followed by drying directly under the sun (Yusof et al., 2015). Extracted fibers are treated with a 2–4 w/v% of NaOH solution at 95°C for 2 hours. The treated fibers are subsequently washed using water and neutralized using mild acid. This process removes hemicelluloses, lignin, oils and wax from the fiber, with hemicellulose removal observed as a peak decline in content. Besides increasing tensile modulus, strength and absorbency, this treatment enhances the properties of PALF compared to untreated fibers (Munawar et al., 2008). In addition to degumming procedure, fiber extraction can also be achieved by combining acids like sulphuric and oxalic acids with detergent (Jose et al., 2016).

Extraction of fibre by retting

The process of separating fiber bundles from cortex or wood, which involves breaking down the cementing material that holds the fibers in the bundles together, is called retting. This loosening is achieved by removing various pectic components from the cementing tissue. Retting is facilitated by microorganism, typically involving a two-stage process: (1) physical stage where the fibers swell and some soluble substances are extracted and (2) the growth of microorganisms such as fungi or bacteria (Pandit et al., 2020). For retting procedure, scraped pineapple leaves are submerged into a water tank filled with a substrate liquor mixture at a ratio of 1:20, containing either 0.5% urea or diammonium phosphate (DAP) to accelerate the retting process. Warm water is particularly effective in loosening the fibers, facilitating absorption of various chemical constituents such as fats, ash content, lignin, pentosans, wax, nitrogenous matter and pectin. Afterward, the fibers are mechanically separated by cleaning them with pond water (Asim et al., 2015; Kannojiya et al., 2013). Retting process typically lasts 15–18 days for PALF immersed in a tank filled with water during which unwanted materials adhering to the surface of PALF were detached successfully resulting in clean fibers (Jose et al., 2016). The extracted fibers are dehydrated by hanging in open air or using a ball mill. Alternatively, a disc mill can be employed to extract PALF from freshly cut pineapple leaves (Kengkhetkit and Amornsakchai, 2012). Compared to conventional procedures, these technologies are not only simpler, but they also yield larger volumes of fiber and smaller-sized fibers. Damp heel milling is one of the slower physical grinding techniques that produces PALF with a wider variety of primary fibers than other methods (Sreekala and Thomas, 2003).

APPLICATIONS OF PINEAPPLE LEAF FIBERS

PALF has found applications in number of industries, including paper manufacturing, textile thread for clothing, and extraction of nanocellulose (Hazarika et al., 2017). The nanaocomposites produced with cellulose nanofibrils (CNF) derived from pineapple fibers have a variety of uses, including high volume goods like packaging, automobile components, textiles, absorbents and adsorbents (Prado et al., 2020). PALF is currently utilized to produce yarns for textile materials and is particularly suitable for carpet making due to its ease of chemical processing and dyeing with aesthetically pleasing fabric (Asim et al., 2015). In Tripura, pineapple besides being consumed, the leaves serve as the source of pina, a textile fabric that is used among other things, as an element in wall paper and furniture (Debnath et al., 2012). Industrial textiles can use PALF, which has a very high initial modulus. Surface modified PALF is introduced for manufacturing machinery parts such as conveyor belt cord, V-belt cord, lightweight duck cord, transmission cloths, airbag tying cords, and several specialist types of clothing etc. Other products that can be manufactured with PALF includes coasters, handbags and many more items related to interior design (Basu et al., 2003). It is also utilized to produce table linens, ropes, bags, mats and various clothing items where lightweight, stiff and sheer fabrics are required. It is commonly blended with silk or polyester to create textile fabrics (Tamata and Mahajan, 2020). Besides, PALF can be utilized in cosmetics, pharmaceuticals, and biopolymer coatings for chemicals (Singha et al., 2020).

PALF serves as an economical raw material that can be used to make paper and pulp. In Thailand, pineapple paper fiber is produced and utilized in creating Pepp chair seats (Rajeshkumar et al., 2020). When compared to raw pineapple fibers supplied for animal feed, a single sheet of completed pineapple fiber paper can fetch significantly higher price (Mahatme et al., 2018). PALF paper and related paper products are known for their “environmentally friendly” qualities, which require fewer chemicals for pulping compared to wood fiber. The lower lignin content (4-5%) in PALF also facilitates easier fiber extraction for pulp production (Kumar, 2020). When impregnated with Poly lactic acid (PLA), the potential application of biopulped PALF as a paper packaging material exists. An optimal PLA concentration (4%) has been found suitable for preparing PALF/PLA sheets (Razak et al., 2015). Pineapple fibers are also used in paper industries as pulping material. PALF displayed outstanding and excellent paper properties (Nayan et al., 2014) due to its high cellulose content (70–82%) (Buana et al., 2013). An efficient method for biopulping PALG is Ceriporiopsis subvermispora. With a 0.3% fungus treatment, the resultant paper had consistent morphological fiber architectures and acceptable tensile and tear indices (Nayan et al., 2014). Better mechanical strength and hydrophobicity are also provided by upgraded PALF sheets containing biopolymer called poly (lactic acid) (PLA) which qualifies them as a green packaging material (Razak et al., 2015). Using PALF as a filler in bio-nanocomposite packaging helps provide a product substitute for packaging made of synthetic plastics and reduces agricultural waste by turning it into new and valuable products. Additionally, PALF is an excellent substitute for food packaging made of petroleum, which depletes resources more slowly. It is readily available, environmentally friendly that is comparable to starch, chitin and chitosan (Nikmatin et al., 2015).

To create 100% PALF yarn, with a few minor adjustments, PALF may be successfully spun in the cotton spinning system which is used to create fabrics, fancy carpets, mops, curtains etc. Polyester fibers and chemically treated PALFs are combined to create needle punched nonwovens for technical fabrics (Rajeshkumar et al., 2020). PALF is a fashionable textile fabric that is ranked between jute and cotton or jute and ramie. The qualities of all textiles are represented by PALF, which is nicely combined with cotton, ramie, jute and a few other synthetic fibers (Debnath, 2016). Among natural fibers, PALF is regarded as a possible textile fiber of commercial quality. The advancement of technical textile materials and fashion has led to the creation of twill and plain woven fabrics made from pineapple yarn and pineapple-jute mixed yarn. These materials are renowned for being lightweight, making them ideal for use as fashion bags, curtains and furnishings (Padzil et al., 2020). Before any application, the extraction process of PALF is crucial to obtain long fibers that is frequently used to make yarn, woven knit materials and non-woven mats (Leao et al., 2010a). Pineapple leaf fiber, with a high cellulosic content, at roughly 80% is an excellent option for fiber scientists as it has a density that is lower and skin-friendly with excellent tensile modulus strength compared to many other organic fibers (Singha et al., 2020). Handwoven from the pineapple leaf fiber and adorned with sophisticated embroidery, this highly-esteemed fabric has been used for centuries to create clothing and accessories that are integral to traditional Filipino cultural heritage (Kamarudin and Yusof, 2016). The Barong Tagalog, wedding robes and other formal dresses in the Phillipines are the primary uses of pineapple leaf fiber (Jalil et al., 2021). On the French online retailer Juch, a sneaker composed of PALF costs 50 euros (Cesarino et al., 2020).

CONCLUSION

Pineapple leaf fiber being a by-product of a large food based productive system and labeled as agro-waste with simple chemical modification can be converted to a value added product. Because spiny leaves are more difficult to handle during post-harvest processing, pineapple leaf bunches without spines are favored for producing fiber than those with spines. Farmers, consumers and the environment all gain from using PALF for domestic and technical textiles because of its many advantages. It is also recyclable and environmentally benign. PALF is characterized by qualities like length, luster, softness, strength, spinnability and whiteness. It holds the potential to generate more economic advantages for Indian farmers and increase job prospects in the textile industry. Pineapple fibers are also valuable in the conservation field, particularly for textile restoration. The commercial potential of fiber production from pineapple leaves can enhance pineapple cultivation, provide additional income for farmers and enterpreneurs, and also promote agricultural diversification.

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