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Unlocking the Potential of Milkweed as a Sustainable Plant Fibre Source for Textiles

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Abstract: Although better known as a plant critical to the larval survival of Monarch butterflies, milkweed is also getting recognized as an alternative plant fiber, which can contribute to environmental sustainability. While milkweed belongs to the very large *Asclepiadaceae* family having more than 2000 species, most of the textile application research is focused on *Asclepias syriaca*, found predominantly in America and *Calotropis gigantea*, a native of South and South East Asia. The main focus is on the use of the silken hair attached to the seeds inside the ripened pods of these plants, while fiber extraction from milkweed stems is now receiving special attention. Milkweed fiber's special attributes, primarily linked to its hollow structure, make them suitable for a variety of textile applications. The presence of hollow channels along the fiber's length make it lightweight and give its insulation property. This review aims to capture the salient findings of recent researches concerning the fibers' distinct traits, their extraction processes and key textile applications. Gaining an understanding of the natural properties of milkweed floss and stem fibers and the challenges faced in using them in textile applications hold the key to unlocking their potential as a source of sustainable fibers. Extant research identifies the difficulties encountered in spinning the milkweed fibers, as also in sourcing them on a sustainable basis as the challenges on the way of taking full advantage of this natural, renewable and biodegradable textile fiber.

Key Words: Milkweed fibers, Sustainable plant fibres, Milkweed floss fiber, Milkweed stem fiber

I. Introduction

Growing environmental concerns have intensified the search for sustainable textile fibers, in recent times. Many researchers are exploring various natural fibers as substitutes for petroleum-based materials [8]. Several vegetable fibers including Milkweed remain under-utilized. Frequently underestimated or dismissed as a nuisance, milkweed floss possesses substantial untapped potential as a textile material [18, 27]. However milkweed has been regarded by US farmers as a problematic weed, which should be eradicated to prevent farm-yield losses [4]. At the same time, what cannot be ignored are the wholesome economic benefits that can flow from regular cultivation of milkweed. Apart from providing floss and bast fibers for the textile industry and habitats for the monarch butterflies, it can help use the marginal lands productively and raise rural incomes [28]; its seeds can yield biodiesel usable in tropical countries [14] and the cultivation itself can richly benefit the soil by improving its biodiversity and health [6].

1.1 The Milkweed Plant

Milkweeds commonly grow along roadways, abandoned farms, and open spaces [3]. These are perennial plants. Its leaves are dark green and waxy placed opposite to each other with a prominent, white mid-vein and pointed tips. They spread more robustly by the sprouts from underground roots than seeds [5]. They bear five-petal flowers in the shades of orange, red, purple, yellow or pale white and pod-like fruits with tufted seeds. These seeds, aligned in overlapping rows, have white, silky hairs known as coma, floss or silk. When the follicles mature, the pods burst open, releasing seeds with fibrous wings to be carried around by the wind. Milkweed plants produce a milky substance when their plant cells are damaged [1, 15, 33].

1.2 Milkweed Plant and Harvesting of Seed Fibers

Milkweeds are found on every continent and its different species have adapted well to their local environments ranging from arid and sandy to moist and swampy soil conditions, as well as from hot and dry to temperate and humid climates. Cultivating them is cost-effective, and their parts serve multiple uses [20]. They require minimal water and no chemical fertilizers or pesticides [28]. They produce fruit pods containing both floss and seeds after the second year of planting [16]. During the fall, the milkweed's horn-shaped pods burst open, releasing 50 to 100 seeds, each accompanied by a delicate, silky floss acting as a parachutes to disperse the seeds in the air [18]. Due to their light weight, they can be easily swept away by the winds when pods burst open. Hence, harvesting involves plucking the ripe pods when they are still green and manually opening the pods later for gathering the floss [8].

In the case of Indian milkweed, the plant yields seedpods up to 10 years, after 2 to 3 years of planting, with higher yields between 4 to 8 years of age. Floss can be harvested 6 to 7 times in the lifetime of a plant with 100 to 140 gm. of floss per harvest.

A single plant usually bears 1 to 7 seedpods in each season. As the dry weight of floss per fruit is about 0.8 gm., 1265 follicles will be needed to gather 1 kg of fiber [22].

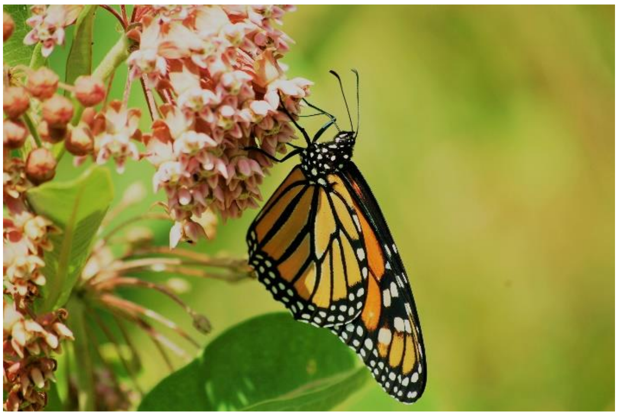

Figure 1: Monarch butterfly on common milkweed

Figure 2: Milkweed Fibers

1.3 Milkweed Varieties and Popular Names

Milkweed belongs to the *Asclepiadaceae* family having more than 214 genera and over 2,400 species [1]. In India alone 332 species belonging to 35 genera are found, mostly in the Southern and Western parts and the Himalayan region [29]. Common milkweed (*Asclepias syriaca*) and blood flower (*A. curassavica*), found in different parts of the world, are also popular as ornamental plants. The North American butterfly weed (*A. tuberosa*) boasts bright orange flowers. The *Hoya carnosa*, known as the wax plant for its waxy white blooms, is a favored indoor pot plant [1]. The species *Calotropis procera* is native to North Africa and the Middle East, and it has been effectively introduced to semi-arid areas in California and Australia [26]. Recently, two new species belonging to the *Asclepiadaceae* family have also been discovered from the shola forests of the Western Ghats in India [29].

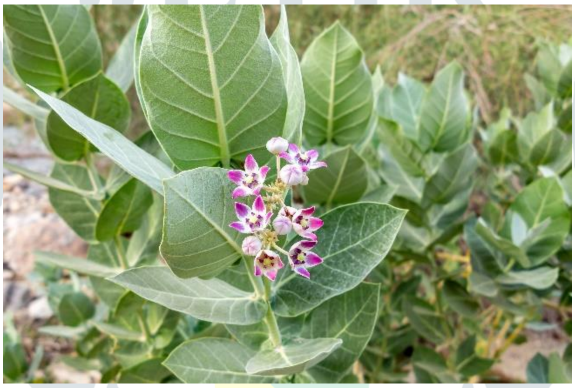

Figure 3: Purple Crown Flower Giant Indian Milkweed, *Calotropis gigantean*

Milkweeds are known by different names in different regions and languages: Swallow Wort, Dead Sea Apple, and Mudar [3]. The Persian name for milkweed is Estabragh (*Asclepias procerais*) [7], while a similar plant native to southern Asia and Africa goes by the name Akund (*Calotropis procera*) [26]. In Thailand, it is called Rux [28]. Other known names are: silkweed, cotton-weed, Virginia silk and wild cotton [5].

1.4 Varieties Researched for their Fiber Potential

Among these, common milkweed (*A. syriaca*) and swamp milkweed (*A. incarnata*) hold promise as potential sources for two types of fibers: a sturdy bast fiber obtained from their stems, and a silky floss collected from their seed pods. However, milkweed has not yet established a foothold in the fiber market [2]. The common milkweed plant can attain a height of up to 2 meters. It primarily thrives in the eastern regions of North America. Its flowering takes place in the summer, and the floss fibers are typically ripe for harvesting by the end of September [26]. *C. procera* and *C. gigantea* are commonly found in India, China, Thailand and the Philippines. Unlike *A. syriaca*, these species can develop into sizeable shrubs with stems reaching up to 3 meters in height and 25 cm in diameter. Both the *Calotropis* species yield fruits that contain floss fibers. Fruit maturation on these shrubs predominantly takes place during the hot season [26]. However, research done so far is focused primarily on extracting and using their seed fibers.

1.5 Textile History of Milkweed Fiber

Milkweed has a rich history of use across the U.S. and southern Canada for its fibers. Prehistoric textiles in the Pueblo region contain milkweed stem fibers. The Tewa people of the Rio Grande use these fibers for making string and rope. At Zuni Pueblo, seed fibers are spun into yarn and woven, particularly for dressing the dancers [3]. Milkweed fibers have been used in Thailand for textiles locally known as Rux fabric [28]. Milkweed floss also gained prominence during WWII when the U.S. government collected them from South American plants for life jacket production. By the late 1980s, interest shifted towards milkweed floss for non-woven applications, leading researchers to study its potential as an alternative natural resource [8]. Although its use declined after WWII, companies have revisited its potential in the last two decades. Some have produced comforters and pillows using milkweed floss instead of down, while others investigated its capability to extract crude oil from seawater [17].

1.6 Precautions Required in Handling Milkweed Plant and its Parts

Handling milkweed requires caution due to potential allergic reactions. The milky-white sap can cause mild to severe skin reactions, while eye contact might lead to corneal endothelial toxicity with symptoms like blurred vision and pain. Wearing gloves and washing hands after contact with the live plant is recommended. Handling dried seedpods necessitates working in an unventilated space to prevent the fibers from dispersing in the air. Care should be taken to avoid loose fibers near the face or inhaling fine seed down [18].

II. RESEARCH OBJECTIVES

The overall aim of this review paper is to rekindle the interest in milkweed as a sustainable fiber source for the textile industry. The specific objectives are as follows:

- To analyze and report on the findings of extant research on the properties and features of milkweed plant and its fibers
- To create an understanding of the limitations of milkweed floss for its use in textiles and the opportunities identified by researchers for overcoming the limitations through blending.
- To provide insights into the research initiatives for extracting textile quality fibers directly from the milkweed stems.

III. METHODS AND MATERIALS

This review is based on 35 research papers and articles out of 42 obtained from research paper repositories such as Researchgate, Academia.edu, Google Scholar and ScienceDirect - using multiple keywords such as 'milkweed fiber', 'milkweed floss', 'milkweed stem fiber', 'mudar fiber' and 'rux' fiber. Preliminary scanning was done to create classified collections based on the focus areas of the paper. Detailed analysis of the papers were done to elucidate and illuminate the specific objectives of this review paper. Secondary information was also obtained from select websites using similar keywords on web search engines like Google and Bing.

IV. SURVEY OF THE RESULTS AND DISCUSSION

Milkweed holds promise for a diverse array of applications, encompassing the textile industry, composite manufacturing, paper production, oil absorption, as well as thermal and sound insulation [26].

4.1 Properties and Morphology of Milkweed Fibers.

Research done over the past 4 decades encompassed the use of milkweed floss and stem fibers. An understanding of the properties these fibers is necessary to focus on their practical applications.

4.1.1 Properties and Morphology of Milkweed Floss Fiber and their innovative applications

Milkweed fibers, derived from the plant's fruit pods, are lightweight due to their hollow structure. Unlike cotton, milkweed fibers lack convolutions and have a lower cellulose content [9]. Milkweed fibers are shorter fibers, with thin walls consisting of inner and outer layers and micro-fibrils in between. The wall thickness impacts the fiber's hollowness, which in turn influences its insulation properties [8]. Hair like fibers obtained from around the seeds of several milkweed species are already being used as an insulating material for lining jackets and other winter wear [29].

The fiber length of milkweed ranges from 9.5 to 43 mm depending upon the growth location. Milkweed fibers possess a thin cellulosic cell wall alongside a wide hollow lumen. This lumen can constitute up to 77% of the fiber's volume, resulting in a distinctive morphology that stands in contrast to other natural fibers [26]. The diameter of typical milkweed fiber is between 20 to 30 µm. These fibers exhibit a crystallinity of 39% and primarily consist of cellulose, hemicellulose, and lignin - constituting 51%, 19%, and 18% respectively [19]. The cell wall thickness of *A. syriaca* variety has been documented to measure 1.27 µm. Across various types and species, the average fiber diameter is approximately 20 µm. Notably, milkweed fibers exhibit a higher wax content in comparison to other natural fibers [26].

Milkweed's shorter, narrower walls result in coarser fibers. The fineness of seedpod milkweed fibers is approximately 0.944 mg/cm (94.4 mtex), which is about 33% less than cotton fiber [8]. Milkweed floss fibers also have a low percentage of cellulose of around 55% whereas flax or hemp fibers have 20% more. The lignin content of milkweed floss fiber range from 13 to 21.3%, while bast fibers normally possess a very low lignin in their composition.

Milkweed fibers possess a hydrophobic and oleo phobic surface due to natural waxes present in them, resulting in a water contact angle of 140°. Research indicates that milkweed fiber floss can absorb over 100 g/g of engine oil. Comparatively, milkweed fibers exhibit superior oil sorption capacity relative to kapok, cotton, wool, polypropylene (PP), and wool fibers. Because of their water repellency and lower density than water, milkweed fibers had been used previously as fillers in life jackets - prior to the arrival of advanced synthetic fibers [19].

The smooth and silky character of the floss fibers poses considerable challenges in transforming milkweed fibers into yarn. They also lose their moisture to heat and become fragile and slippery, rendering them unsuitable for use, if spinning is not done in good time. The challenges of spinning milkweed floss is also aggravated by the lack of cohesion and crimp [32].

Although the yarn spun from floss will exhibit a silky appearance, it would lack strength. Fibers obtained from seed-pods are also shorter compared to those derived from stems. However, milkweed floss can be carded alongside other fibers, contributing both warmth and a shiny finish to the blend [2]. It has been found that milkweed fiber's diameter and staple length are comparable to rabbit hair. Its tenacity and color are between wool and cotton fibers and it behaves similar to cotton while dyeing [23]. As compared to cotton, the floss fiber possesses very little extensibility and its linear density is also lower. However, it has relatively higher moisture regain [22]. The unique properties of milkweed floss have also paved the way for a number of innovative uses. The hollow channels along the fiber, allowing water vapor to flow, leading to enhanced moisture permeability compared to cotton. Utilizing non-woven layers of milkweed fibers extracted from seedpods offer excellent moisture absorbency in various applications [8].

The development of products utilizing milkweed floss has been a collaborative venture of USDA's Agricultural Research Service involving the University of Nebraska and private corporations. Their experience indicates that 10 pounds of dried milkweed pods yield approximately 2 pounds of floss, 3 pounds of seeds, and 5 pounds of pod biomass. Prototypes created from these components have demonstrated the potential for diverse milkweed floss products, including blending with down for use in comforters, pillows, and clothing as loose-fill insulation; creating fillings for items like quilts, jackets, and disposable absorbent products bad blending with cotton and weaving to craft linen-like fabrics. The key challenge lies in determining which of these applications are economically viable at specific levels of milkweed production and associated costs [16]. As the percentage of milkweed in the blend rises, the fabric's air and water permeability diminishes. The decrease in spaces between yarns, resulting from an enlarged yarn diameter and increased yarn hairiness due to a higher milkweed blend ratio, leads to reduced air and water vapor permeability in Cotton/Milkweed blended fabrics [12].

In the past two decades, numerous companies have revisited the potential of the soft and lustrous milkweed material. Some have shifted their focus towards manufacturing comforters and pillows using milkweed floss instead of down [17]. The UVM Extension Northwest Crops and Soils Program (NWCS) is researching milkweed's viability as a commercial crop, contingent on market demand. A Canadian company has developed milkweed fiber processing techniques, utilizing the "floss" from pods. These strands are hollow and waxy, yielding warmth, water resistance, lightness, and high oil absorption. Canada produces oil absorbent products for chemical spill kits, and premium winter clothing brands explore milkweed floss as a goose down substitute. The NWCS's work reveals milkweed's potential in various sectors due to its unique attributes and emerging market interest, from eco-friendly spill solutions to particleboard applications [4].

Another notable development is the prototype of a machine dedicated to mechanize floss collection. This innovation could serve as a motivation for the commercial scale farming of milkweed. This prototype includes a pod harvester, a pod conditioner, two-step driers and a spike tooth cylinder processor, which help automate the entire process of collecting pods from the plants and extracting the floss from them with minimal waste of materials and time [13].

4.1.2 Properties and Morphology of Milkweed Stem Fiber

Extracting fibers from stems is a time-consuming process that results in less uniform fibers when contrasted with the seed fibers [26]. Although milkweed stem fibers possess higher cellulose content than milkweed floss fibers, this content is lower than that found in cotton and linen. Conversely, milkweed stem fibers have notably reduced lignin content in comparison to milkweed floss fibers, but this lignin content is higher than that of cotton and linen fibers. These compositional differences highlight the unique characteristics of milkweed stem fibers and underscore their potential applications in various contexts [20].

The aspect ratio, which is the ratio of fiber length to fiber width, determines fiber flexibility. Milkweed fibers vary in length depending on whether they are extracted from the plant's stem or seedpod. Ashori and Bahreini found that Milkweed stem fiber has an average aspect ratio that's 76% higher than seed fibers [8]. This makes them suitable for absorbent materials, potentially replacing conventional options.

The stem fiber has valuable properties like higher cellulose content than the floss fiber, strength equivalent to cotton and elongation greater than linen. It is also heavier per square meter than the cotton apart from its tensile and abrasive strength. As compared to cotton and linen, the stem fiber has a lower crystallinity. The milkweed stem fiber is coarser as their single cells are smaller and narrower as compared to cotton, linen and the floss [20, 25].

Milkweed stems display high sensitivity to alkaline extraction. Even relatively gentle alkali treatments have yielded milkweed stem fibers with elevated cellulose content. This suggests that careful alkaline processing can effectively enhance the cellulose content of milkweed stem fibers, potentially paving the way for their utilization in various applications [20].

4.2 Research Initiatives towards Blended Yarns and Fabrics

Milkweed's unique characteristics, including its smooth texture, brittleness, and lack of cohesion, pose challenges in spinning a pure milkweed yarn. Similar processing issues arise, such as web falling in carding, roller lapping, and breaks in draw frame, speed frame, and ring frame, even with a 60% milkweed blend. While yarns from Cotton-Milkweed blends display inferior physical properties compared to pure cotton yarns, chemically modified milkweed fibers exhibit better physical attributes than untreated ones [11]. Milkweed floss, which has a short length, is combined with cotton and processed using ring and rotor spinning methods. This blending approach helps create yarns with improved spinnability and desired qualities [9].

Blending of floss has been attempted not only with cotton but also with other natural and synthetic fibers. Tuntawiroon et al. reported in 1984, their successful blending of locally sourced milkweed fiber (RUX) with cotton and rayon to make blended yarn and fabric in Thailand [28]. Varshney and Bhoi also blended floss fibers with cotton in 1988 but found the resulting yarn and fabric inferior to those of cotton [31]. In 2009, Sakthivel and Ghosh reported successful blending of locally sourced floss fiber (Mudar) with J34 cotton in multiple proportions such as: 75/25, 66/33, 50/50 and 33/66. Their research used slow speed spinning and found that the resulting yarns did not show any of the inherent limitations of the Mudar fiber [22]. In 2016, Karthik and Murugana have done fiber migration studies of cotton and milkweed blends and revealed that the packing density of cotton and milkweed blend decreased with the increase in milkweed proportion [10].

Louis and Andrews have also [34] highlighted the challenges in carding Milkweed fibers (derived from seedpods and stem) from inadequate fiber cohesion and crimp. They recommend blending these fibers with other fibers like cotton to mitigate spinning issues. Using the rotor spinning system, they created blended yarns of various cotton/Milkweed ratios. These yarns were subsequently transformed into knitted fabrics, which underwent chemical treatment to ensure dimensional stability. This approach aims to enhance the spinning process and fabric properties by leveraging the benefits of both Milkweed and cotton fibers [8].

The fibers' lack of cohesion leads to increased drooping during carding, while their brittleness further exacerbates damage. To address these issues, surface modification is recognized as an effective strategy to enhance Milkweed fiber cohesion and reduce losses during carding. Alkali-treated milkweed fibre blended yarns show better yarn properties due to improvement in fiber friction and elongation values followed by dyed and untreated milkweed fibres [11]. Researchers also suggest improving spin-ability by blending Milkweed fibers with similar natural or synthetic fibers. Additionally, dyeing the fibers or applying spinning oil on their surface is proposed to modify the spinning process. These strategies aim to mitigate the difficulties posed by Milkweed fibers' unique characteristics in spinning operations [8]. However, yarns and fabrics produced from cotton/milkweed blends have been found to demonstrated notably lower breaking strength compared to those made from 100% cotton yarns and fabrics [11].

A Canadian company has also successfully developed a high-performance fiber sourced from milkweed (*Asclepias syriaca*), a native plant in Canada. This innovative fiber possesses characteristics similar to cotton while having a luxurious silk-like feel. Blending it with other fibers at levels of 15 to 35% produces soft fabrics suitable for clothing. Despite this cotton-like feel, the hollow structure of the fiber provides thermal insulation comparable to goose down. Additionally, the fiber exhibits exceptional oil absorption capability, being able to absorb up to 40 times its weight in oil. Furthermore, it can float on water, opening up the potential for cleaning oil spills at sea. To ensure a continuous supply of the raw material, a farmer's cooperative named Cooperative Monarch has been established [24].

Likewise, Dre´an et al. [35] aimed to create plain fabric samples using Milkweed fibers from seedpods. They generated blended yarns from varying proportions of cotton and milkweed fibers, with a significant Milkweed content (up to 67%). Their findings indicated that increasing the ratio of Milkweed fibers posed greater challenges during the spinning process. This suggests that while blending Milkweed with other fibers can offer benefits, an excessively high ratio of Milkweed fibers might lead to complications in spinning [8].

4.3 Research Initiatives towards Extracting and Using Milkweed Stem Fibers

In a research project done by Narendra and Yiqi at Nebraska, US, the sensitivity of the milkweed stems towards alkali and heat has been leveraged. The project used the outer skin of the bark, manually peeled from the stem. The inner bark was left out as it was unsuitable for fiber extraction. The peeled barks were soaked overnight in a 0.5 N sodium hydroxide solution in a bark to solution ratio 10:1. After the overnight dipping at room temperature, the solution was heated to 80 degree C, after which the solution was drained out and the extracted fibers were washed in warm water first and then in cold water, which was neutralized with dilute acetic acid to remove the left-over alkali. Finally, the fibers were air dried. The obtained fibers had higher cellulose content, greater strength and elongation than the milkweed floss fibers, though crystallinity was lower. Overall, the extracted milkweed stem fibers had the properties that were necessary for applications in textiles, composites, etc. [20].

In another research undertaken at the Birla Institute of Technology and Science, Pilani, India, fibers from the stem of the local milkweed variety *Calotropis procera* were extracted using both the Alkali and Acid route and the results were compared. The plant stems were dried in the sun for eight days and then washed thoroughly and soaked in a water tank for another 8 days at ambient temperature for retting. After the retting was over, the stems were washed clean and the outer barks were retrieved by peeling. The alkali procedure was the same as in the Nebraska project. Maceration was performed by dipping the fibers in a mixture of 10% nitric acid and 10% chromic acid for 24 hours after heating the solution to 60 degrees for five minutes. In the Acidic extraction process, Crushed pieces of the stem were dipped in an oakridge tube filled with concentrated nitric acid and 80% acetic acid in a 1:10 ratio. The mixture was kept at 40 degree C for 40 minutes. Thereafter, the mixture was cooled and discarded. The fibers were then peeled out and ethanol was added and the fibers were centrifuged in a controlled step by step process. The results showed that as against the yield of 6% in the Alkali process, the Acid process yield was 26% and the cellulose content of the fibers extracted through the Acid process was 85% [25].

The third approach makes use of the mechanical process to extract milkweed stem fibers. In 2015, a team of researchers in Iran have developed a prototype machine, which can be used to extract fiber from the raw stems having 75% moisture content [21]. Another notable research relevant to the quality of milkweed stem fiber is the single step hydrogen peroxide treatment that helps produce cleaner milkweed stem fiber with enhanced attributes [14].

V. CONCLUSION

What the ongoing research reveals is that milkweed plant makes not only sound environmental sense but also complete economic sense. Every part of the plant offers value. While the fruit floss and stems can be a source of sustainable fiber for textiles and composites, its seeds can yield biodiesel. Its leaves and roots have medicinal uses. The toots can also help improve the soil health. It can also be a boon for the rural poor by creating employment opportunities from the marginal and fallow lands. It is time that milkweed cultivation gets the much needed institutional and industry support.

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