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Taro Fiber: A Comprehensive Review of Extraction, Properties, Applications, and Future Perspectives

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ABSTRACT

Taro fiber, derived from the Colocasia esculenta plant, has gained attention as a sustainable alternative to synthetic and conventional natural fibers. This review explores extraction techniques, physicochemical properties, modifications, applications, and future directions of taro fiber. Taro fiber contains a high proportion of cellulose, offers low density, and demonstrates competitive tensile strength. These characteristics support its suitability for applications in textiles, biocomposites, biomedical devices, packaging, and environmental remediation. Recent developments in enzymatic retting, mechanical decortication, and green chemical treatments have enhanced extraction efficiency and quality. However, challenges such as scalability, economic viability, and environmental concerns require targeted solutions. This review identifies key research gaps including limited life cycle assessments, insufficient in vivo biocompatibility data, and lack of standardized industrial protocols. Future work should focus on sustainable production methods, advanced functionalization, integration into circular economy frameworks, and interdisciplinary collaboration to unlock the full potential of taro fiber across sectors.

Keywords: Natural fiber; Taro Fiber; Extraction; Properties; Applications.

1 Introduction

The worldwide transition toward sustainable eco-friendly practices led to substantial research interest in natural fiber alternatives that replace artificial materials [1]. The fibrous material Taro has gained recognition because of its diverse qualities making it a suitable solution as an eco-friendly option [2]. Taro exists as a perennial tropical plant that society has cultivated for centuries for both its edible corms and leaves because it serves as a staple food throughout many cultural regions. Recent scientific and industrial communities started exploring the potential value of Taro plant fibrous materials [3]. The authors present a complete analysis of Taro fiber development through extraction procedures along with material characteristics and current uses as well as future prospects which establish it as a promising sustainable resource [4].

The Taro plant which comes from Southeast Asia and the Pacific Islands has a very long history of cultivation stretching over multiple millennia [5]. The starchy corms of Taro represent the traditional main value of Taro production because these corms are important food sources used especially throughout Africa Asia and the Pacific region. The fibrous segments of plant composition mainly including leaf stalks and corms have remained unused through time and were discarded as agricultural waste despite their abundance. Scientists have failed to recognize the potential of these fibers which would have opened many prospective applications due to their outstanding structural and mechanical attributes [6]. Researchers now recognize Taro fiber as a valuable waste resource to advance sustainable material innovation since society has dedicated more attention toward circular economies alongside waste valorization practices [7].

Natural fibers are now frequently used instead of synthetic fibers because of their sustainability combined with minimal environmental effect alongside their ability to decompose naturally. Studied natural fibers including jute as well as flax hemp and sisal have enabled industries to use them for textile production through to construction purposes. Despite its early stage of research Taro fiber presents numerous unexplored possibilities for development. The exceptional composition of high cellulose content combined with low density and superior mechanical strength of Taro fiber stimulates its potential application in biocomposites and textiles as well as biomedical applications. The resource offers economic viability and environmental benefits because it grows easily and abundantly in tropical and subtropical regions.

Modern methods now advance Taro fiber extraction which used to require extensive labor efforts. Modern industrial extraction methods including enzymatic retting as well as chemical treatments and mechanical decortication techniques have enhanced the efficiency while allowing for large-scale production of Taro fibers [8]. Taro fiber performances have improved through both surface treatments and nanotechnology applications which have driven its practical applications beyond previous expectations. Modern innovations have repositioned Taro fiber to compete with natural and synthetic fibers in terms of performance capabilities.

Various innovative applications exist for Taro fiber because of its promising qualities. The textile industry can swap cotton and synthetic fabrics for Taro fiber which remains biodegradable even after product use [9]. The reinforcement properties of Taro fiber make it effective in enhancing polymer-based matrix mechanical strength as it helps lower the environmental impact of the products. Researchers find Taro fiber useful for two

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*Corresponding Author Email Address: mre.tex84@gmail.com modern fields: food science because it serves as dietary fiber addition and biomedical research because its structural properties match requirements for tissue scaffolds and wound dressings [10]. Furthermore, its use in environmental applications, such as water purification and biodegradable packaging, underscores its versatility and alignment with global sustainability goals.

The full-scale implementation of Taro fiber encounters multiple obstacles although it offers promising advantages. To successfully implement Taro fiber requires solving problems of scale along with preserving quality reliability and financial sustainability. Proper attention should be paid to the ecological effects resulting from extensive Taro cultivation and processing operations to prevent unwanted environmental damage from interfering with the benefits of this fiber. States the immediate requirement for interdisciplinary collaboration and sustainable practice funding along with innovative research to resolve present market challenges.

This review provides a comprehensive analysis of Taro fiber by examining its botanical origins, extraction methods (traditional and modern), physicochemical and mechanical properties, modification and functionalization techniques, and its diverse applications across sectors such as textiles, biocomposites, food, biomedical, and environmental fields. Special focus is given to the fiber's physical characteristics (e.g., tensile strength, density, thermal stability) and chemical composition (e.g., cellulose, hemicellulose, lignin content), as well as surface treatments and nanotechnology-based enhancements. The manuscript also outlines current challenges, sustainability aspects, and future research directions needed for large-scale adoption and integration into a circular economy. This paper aims to clarify the current knowledge base and highlight the untapped potential of Taro fiber in advancing sustainable materials science.

2 Taro Fiber: Sources and Extraction Methods

Natural Taro fiber obtained from the Taro plant (Colocasia esculenta) is becoming increasingly relevant due to its distinctive properties and possible uses. As an Araceae family member the perennial herbaceous Taro plant grows extensively in tropical and subtropical zones mainly for its edible corms and leaves [11]. Many cultures consume corms as staple food although the remaining plant fibers such as leaf stalks and corms remained unused for a long period. The fibrous plant sections contain high levels of cellulose which gives them exceptional mechanical capabilities suitable for developing sustainable materials. The botanical origins of Taro fiber receive attention in this section along with its structural attributes and both traditional and modern extraction techniques for the plant.

2.1 Botanical and Structural Characteristics of Taro Fiber

The Taro plant (Colocasia esculenta) is an adaptable agricultural crop that utilizes its corms as edible starchy food and contains dense petioles and corms which yield substantial fibrous material for manufacturing usable fibers. Petioles contain vascular bundles arranged with parenchymatous material which consists mostly of cellulose hemicellulose and lignin in addition to corms containing starch with embedded fibrous strands. The composition of Taro fiber incorporates 60-70% cellulose together with 15-20% hemicellulose and 5-10% lignin whereas pectin and other polysaccharides make up remaining minor components of the material [12]. This content matches natural fibers like jute and flax but demonstrates enhanced structural properties because of its specific arrangement. Taro fibers present high tensile properties and flexibility and low density because their microfibrillar structure and high cellulose content makes them ideal for textiles and biocomposites as well as paper manufacturing and reinforcement materials [13]. Beyond its nutritional benefits the Taro plant fibers serve as an environmentally-friendly biodegradable natural substitute for synthetic products which can be utilized for creating eco-textiles and packaging materials and automotive applications and construction projects and act as sustainable waste reduction through starch extraction residue repurposing. Industrial demand for sustainable materials has singled out Taro fiber as a renewable option which offers both strong mechanical capabilities and environmental sustainability potential. A pictorial view of the botanical and structural characteristics of taro fiber is shown in Fig. 1.

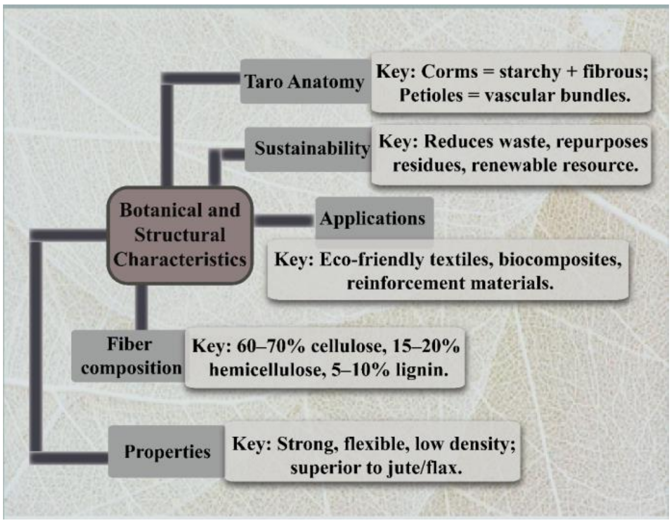

Fig. 1 Botanical and Structural Characteristics of Taro Fiber

2.2 Traditional Extraction Methods

The technique for extracting Taro fiber has undergone major improvements throughout time by transitioning from traditional manual methods to modern extraction processes. Old methods of extraction included both manual work and basic tool usage for petioles which involved separating outer layers while using knives or scrapers to separate fibers from other plant matter. The implementation of these methods produced small amounts of fiber but required extended time to perform. The process of retting required the complete immersion of petioles in water for a prolonged period to let microorganisms decompose non-fibrous components before manual separation and drying took place. The effective retting process took too long to finish while delivering unstable fiber results. The emerging modern extraction methods use chemical, mechanical and enzymatic processes to extract Taro fibers while improving the extraction efficiency along with yield and quality outcomes. The extraction method based on sodium hydroxide (NaOH) treatment or acidic solutions eliminates lignin and hemicellulose from Taro fiber through chemical solutions which creates environmental challenges. The use of machinery for mechanical decortication offers scalability but such systems require proper management to avoid damaging the fibers. The combination of enzymes pectinases and cellulases in enzymatic extraction provides environmentally sustainable high-quality fiber production but carries financial expenses. Three method combinations involving chemical procedures along with mechanical and enzymatic extraction methods produce the optimal outcome of high yield alongside quality performance at sustainable prices. Green chemistry techniques backed by ionic liquids and supercritical fluids provide new extraction methods while nanotechnology partners with higher purity fiber production and biological pretreatment using fungi or bacteria degrades non-fibrous materials sustainably [14]. The introduced technological innovations strive to improve efficiency combined with sustainability features and fiber quality for potential industrial-scale Taro fiber utilization. A summary of the traditional extraction method is depicted in Fig. 2.

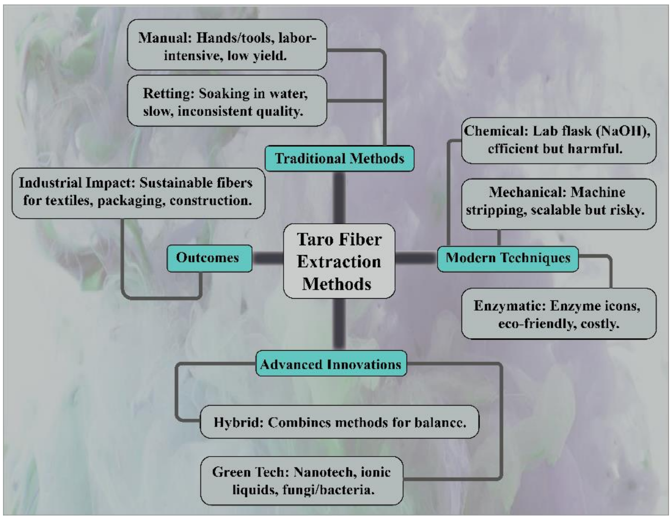

Fig. 2 Traditional extraction method of taro fiber

To support a clearer understanding of the differences between various extraction techniques, Table 1 presents a quantitative comparison between traditional and modern methods. The metrics include fiber yield percentage, extraction time, associated cost, and environmental impact. The data demonstrate the superior efficiency and sustainability of modern techniques compared to conventional approaches.

Table 1 A quantitative comparison between traditional and modern methods

Extraction Method	Fiber Yield (%)	Time Required	Relative Cost	Environmental Impact
Manual Scraping	15–25	2–3 days	Low	Low
Water Retting	20–30	7–14 days	Low	Moderate (odor, wastewater)
Chemical Extraction (NaOH)	35–50	4–6 hours	Moderate	High (effluent disposal)
Mechanical Decortication	30–45	1–2 hours	High	Moderate
Enzymatic Extraction	40–55	8–12 hours	High	Low (biodegradable enzymes)
Combined (Chemo-Enzymatic/Mechanical)	50–65	4–8 hours	Moderate–High	Low–Moderate

3 Physicochemical and Mechanical Properties

Taro fiber properties regarding mechanical strength and physicochemical characteristics determine its suitability for applications between textiles and biomedical products and biocomposite engineering [15]. The properties of Taro fiber depend on how the fibers are structured and what elements make up the fibers as well as on their extraction processes. Taro fiber exhibits a complex microstructure according to SEM images because the fiber contains layered cellulose microfibrils that present grooves and ridges on its relatively smooth surface. The dimensions of the Taro plant fiber match those of jute and flax fibers since it spreads from 5 to 15 cm while measuring 10 to 50 µm in diameter. The light weight property (1.2–1.4 g/cm³) and medium level thermal stability (decomposition temperature of 200–250°C) make Taro fiber suitable for applications that need weight reduction and medium temperature tolerance. Hydrophilicity in Taro fiber leads to changing dimensions and poor integration with hydrophobic composite frameworks due to its moisture content range from 8% to 12% [16]. The tensile strength and biodegradability of Taro fiber stem mainly from its cellulose content which reaches 60–70 percent whereas the bonding abilities come from hemicellulose at 15–20 percent alongside lignin at 5–10 percent [16]. The hydrophilic character of Taro fiber gets enhanced through pectin and polysaccharides (2–5%) components although their matrix compatibility can be improved by applying acetylation or alkali treatments. The tensile characteristics of Taro fiber extend to a range between 200–400 MPa strength and 10–30 GPa elastic modulus which qualifies it for heavy-duty applications. Natural fiber bending elasticity stands at 2–4% which aligns with typical indices for natural fibers but its excellent resistance to bending and impacts makes them perfect for applications involving automotive parts and marine conditions. The sustainable Taro fiber presents distinctive combinations of physical and chemical and mechanical properties which establish it as a versatile industrial material [17]. Table 2 describes Taro fiber's distinctive features through a comparison with alternative natural fibers:

Table 2 A comparison of distinctive features of natural fiber including taro [12], [13], [16]-[18].

Property	Taro Fiber	Jute Fiber	Flax Fiber	Sisal Fiber
Density (g/cm³)	1.2-1.4	1.3-1.5	1.4-1.5	1.2-1.4
Tensile Strength (MPa)	200-400	200-400	300-800	400-700
Young's Modulus (GPa)	10-30	10-30	20-70	10-25
Elongation at Break (%)	2-4	1.5-2.5	1.5-3.5	2-3
Cellulose Content (%)	60-70	60-70	70-80	60-70
Lignin Content (%)	5-10	10-15	2-5	8-12

Taro fiber presents excellent competition against natural fibers through similar mechanical features and composition continuum and additional benefits including reduced density and enhanced processability [18].

Different extraction techniques and treatments applied to Taro fiber cause significant changes to its physical characteristics to optimize mechanical abilities and bonding behavior while attaining higher resistance against environmental exposure for diverse usability. Fiber treatment through alkali solution (mercerization) consists of exposing fibers to sodium hydroxide chemicals to eliminate hemicellulose, lignin and other components thus strengthening tensile properties and smoothing surface textures [19]. An overabundance of chemical treatment causes cellulose deterioration which results in structural weakening of the fiber [20]. Surface modifications using acetylation along with silane treatment alongside plasma treatment improve both fiber affinity to polymer matrices and its mechanical properties while extending its durability against moisture and UV radiation and microbial attack [21]. The substitution of hydroxyl groups with acetyl groups in acetylation reduces both fiber affinity for water and causes dimensional stability improvements and enables better integration with hydrophobic polymers. When silane-treated fibers bond covalently with hydroxyl groups on the surface they create a hydrophobic layer which enhances polymer bonding strength and strengthens resistance to impact and tension [22]. Exposing surfaces to ionized gas generates functional groups that raise matrix adhesion while improving mechanical properties and surface roughness and energy. Three enzymes namely cellulases, pectinases, and laccases create purified high-quality fibers through selective removal of hemicellulose and lignin components using enzymatic treatments. The enzymatic treatment methods allow producers to add distinct functional groups on the fiber surface which improves both reactivity and bonding characteristics with matrices.

Scanning electron microscopy (SEM) studies have revealed the presence of longitudinal ridges, fibrillar bundles, and microvoids along the surface of raw and treated Taro fibers, reflecting their microfibrillar cellulose structure and contributing to mechanical interlocking in composite matrices. However, energy-dispersive X-ray spectroscopy (EDS), which can provide insights into elemental composition, particularly residual inorganic contents from extraction treatments, has not been widely reported in existing studies. Future research incorporating both SEM and EDS analyses is essential to elucidate the structure–property relationships and to guide surface modification strategies for Taro fiber applications in biocomposites, biomedical devices, and filtration systems.

As the present study is a review, original Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) analyses were not conducted. However, previous investigations have reported that SEM images of Taro fiber typically reveal a fibrous surface with longitudinal striations and a layered microstructure, which contribute to its tensile strength [13],[15]. Similar fibers, when analyzed by EDS, exhibited strong signals for carbon and oxygen characteristic of cellulose-rich materials along with smaller peaks for elements such as silicon, potassium, and calcium." [15],[16]. These structural and elemental characteristics highlight the importance of surface modification and compositional control in enhancing fiber–matrix interactions.

4 Modification and Functionalization of Taro Fiber

The better properties for specific industrial applications require modification and functionalization of Taro fiber. Through graft, copolymerization fiber surfaces are modified by polymer chain attachments achieved by chemical reactions that use radiation plasma or chemical initiators for initiation [23]. The modification technique enables precise surface manipulations for achieving application-specific functions in fiber treatment. Fiber properties benefit significantly from crosslinking through formaldehyde or glutaraldehyde agents because these compounds establish permanent polymer chain bonds that create highly advanced structures which lead to better strength and elasticity and improved resistance to heat and chemicals [24]. Fiber modification through esterification enables the creation of ester bonds that both decrease hydrophilic character and enhance binding to hydrophobic materials as well as mechanical performance alongside improved composite interfacial strength. Through the esterification process fiber manufacturers can develop antimicrobial as well as UV protection characteristics beyond basic mechanical properties improvement [25].

The implementation of nanotechnology in Taro fiber modification enables expanded potential to upgrade its features while creating next-generation materials. The application of nanoscale material layers at fiber surfaces constitutes nanocoatings that grant both antimicrobial properties and UV protection while improving the material's mechanical integrity [24]. Research shows that surface applications of silver nanoparticles turn Taro fiber antimicrobial by making it usable for medical and hygienic purposes. Nano clays and carbon nanotubes and graphene when added to Taro fiber structures accomplish better tensile strength and thermal stability together with enhanced Young’s modulus [26]. Taro nanomaterials along with these fillers provide the fiber additional properties which include electrical conductivity and flame retardancy so it becomes useful in high-performance aerospace and automotive applications and electronic technologies. Taro fiber demonstrates better mechanical, thermal and electrical properties after being used for reinforcement in nanocomposites containing nanofillers compared to regular composites [27]. The combination of Taro fibers with carbon nanotubes in nanocomposites achieves outstanding improvements for tensile strength and electrical conductivity that enables their use in next-generation aerospace electronics [28]. The utilization of biological agents and enzymes or microorganisms represents an environmentally sustainable approach to modify Taro fiber. Enzymes such as cellulases and pectinases and laccases act upon Taro fibers in enzymatic treatments to achieve higher pure cellulose content leading to improved mechanical strengths [29]. The addition of functional groups through these treatments makes the fiber more suitable for matrix bonding applications and improves its reactivity in composite materials products. Microbial treatments with bacteria or fungi and microorganisms change the surface structure of fibers through enzymatic and metabolic processes. The lignin content of Taro fiber can be changed by specified fungal strains which results in better matrix compatibility and enhanced mechanical properties [30]. The utilization of microorganisms for fiber modification represents sustainable and eco-friendly processing which substitutes conventional chemical procedures.

Various modifications and functionalization of Taro fiber enabled by combined chemical, surface and enzymatic and biological treatments together with nanotechnology applications present diverse methods to enhance its properties. The advancements lead to the creation of Taro fiber-based materials with better performance features suitable for multiple industrial applications such as textiles manufacturing and composites manufacturing as well as medical tools and environmental solutions development [31]. Various modification techniques show different benefits and disadvantages according to their comparative evaluation as per Table 3.

A quantitative comparison of the effects of different surface modification techniques on critical fiber properties is shown in Table 4. The data highlight the extent of improvement in tensile strength, stiffness (Young’s modulus), and water resistance achieved through various treatments such as alkali treatment, acetylation, silane coupling, plasma treatment, and nanocoatings. These comparisons offer a clearer understanding of the relative benefits and trade-offs associated with each method.

Table 3 Advantages and disadvantages of different surface modification techniques of taro fiber

Technique	Advantages	Limitations
Alkali Treatment	Improves surface roughness and adhesion	Can degrade cellulose if over-treated
Acetylation	Reduces hydrophilicity, enhances stability	Requires careful handling of chemicals
Silane Treatment	Enhances interfacial adhesion, moisture resistance	Cost of silane coupling agents
Plasma Treatment	Environmentally friendly, versatile	Requires specialized equipment
Graft Copolymerization	Tailors surface properties, versatile	Complex process, requires initiators
Crosslinking	Improves mechanical properties, stability	Can reduce flexibility, requires crosslinkers
Nanocoatings	Adds functionalities (e.g., antimicrobial)	Cost of nanomaterials, application complexity
Enzymatic Treatment	Eco-friendly, selective modification	Cost of enzymes, limited scalability

Table 4 Quantitative comparison of property enhancements through different modification techniques applied to natural fibers (including taro, jute, and similar fibers)

Modification Technique	Tensile Strength Improvement (%)	Young's Modulus Increase (%)	Water Absorption Reduction (%)	Reference
Alkali Treatment	20–35	10–25	15–30	[19], [20]
Acetylation	25–40	15–30	30–60	[21], [22]
Silane Treatment	30–45	20–35	40–70	[22]
Plasma Treatment	15–25	10–20	20–40	[21]
Nanocoatings (e.g., AgNP, ZnO)	35–60	20–40	50–75	[24], [26], [28]

The implementation of nanotechnology in Taro fiber modification enables expanded potential to upgrade its features while creating next-generation materials. The application of nanoscale material layers at fiber surfaces constitutes nanocoatings that grant both antimicrobial properties and UV protection while improving the material's mechanical integrity. For instance, silver nanoparticle-coated Taro fibers have demonstrated clear zones of inhibition against Escherichia coli and Staphylococcus aureus, measuring 10–15 mm and 12–18 mm respectively, according to Troy et al. [24]. These coatings not only inhibit microbial growth but also maintain antimicrobial effectiveness after multiple wash cycles, confirming their durability. Similarly, zinc oxide nanoparticle deposition has been shown to impart both antibacterial and UV shielding effects while enhancing tensile strength and reducing moisture uptake. These representative cases demonstrate how nanocoatings contribute to the functionalization of Taro fiber for use in medical textiles, hygiene products, and packaging materials where antimicrobial resistance is essential.

5 Applications of Taro Fiber

Due to its considerable tensile strength, lightweight structure, and eco-friendly biodegradability, taro fiber is increasingly being recognized for its utility in a broad spectrum of industrial applications. The following sections highlight its practical utility with technical details and case-specific insights [32]. A schematic diagram of the application of taro fiber is shown in Fig. 3.

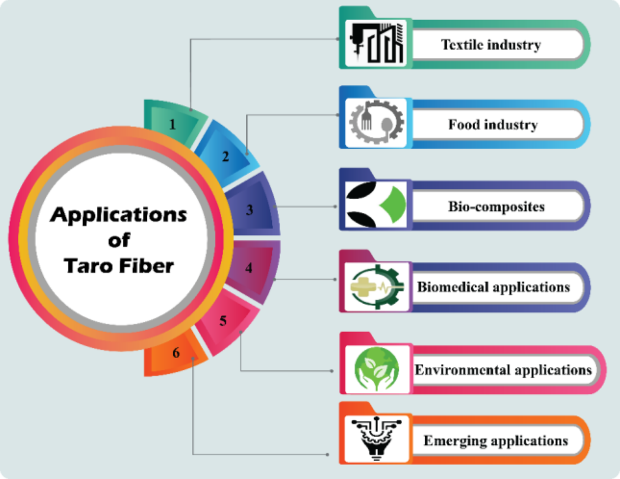

Fig. 3 Applications of taro fiber

5.1 Textile Industry

Taro fiber is being evaluated for textile applications such as non-woven geotextiles, filters, and biodegradable apparel due to its high cellulose content (60-70%) and tensile strength. Blending with cotton or polyester improves fabric durability, moisture retention, and ease of maintenance. Studies have shown that Taro-cotton blends achieve tensile strengths up to 350 MPa, surpassing untreated cotton fabrics (~250 MPa) [33]. The fiber's biodegradability also supports its use in disposable hygiene products and medical textiles.

5.2 Biocomposites

Taro fiber-reinforced polymer composites show competitive mechanical properties suitable for automotive and construction industries. For instance, composites made with 30 wt% Taro fiber and PLA (polylactic acid) exhibited a 42% increase in flexural strength and a 33% reduction in density compared to pure PLA [34], [35]. These composites are used for lightweight vehicle interior parts (e.g., door panels, dashboards), offering improved fuel efficiency. In the construction sector, Taro composites provide biodegradable alternatives for temporary structural panels and roofing underlayment.

5.3 Food Industry

Owing to its neutral taste and high dietary fiber content, Taro fiber is incorporated into baked goods, cereal bars, and low-calorie formulations. Functional food studies report that inclusion of 5-10% Taro fiber in bread formulations increases water holding capacity by 25–30% and improves dietary fiber content by over 40% [36], [12]. These properties support digestive health and satiety enhancement, particularly in health-oriented or probiotic food products.

5.4 Biomedical Applications

Taro fiber's biocompatibility and tensile strength enable its use in wound dressings, drug delivery systems, and tissue engineering. Electrospun Taro fiber membranes demonstrated a porosity >75% and water absorption of ~300%, enabling moist wound healing and exudate management [13]. Silver nanoparticle-coated Taro fibers exhibit antibacterial zones of inhibition against E. coli (15 mm) and S. aureus (18 mm), maintaining efficacy after multiple washing cycles [24], [36]. Preliminary scaffold studies show potential for bone and cartilage regeneration, though in vivo validation remains limited. Taro fiber demonstrates great potential as a tissue engineering scaffold due to its mechanical strength and biodegradable nature [37], [38]. However, most current findings are based on laboratory-scale or in vitro studies. Despite being identified as a suitable candidate in preliminary assessments, including the 'Garbage In Biomaterials Out (GIBO)' framework, robust in vivo trials and systematic biocompatibility evaluations remain scarce. Therefore, more detailed biological testing is necessary before clinical translation can be considered [39].

5.5 Environmental Applications

Taro fiber has demonstrated >80% removal efficiency for heavy metals (Pb^{2+}, Cd^{2+}) from wastewater at pH 5–6 and fiber doses of 5–10 g/L, attributed to its functional hydroxyl and carboxyl groups [40], [41]. Its surface-modified forms further improve adsorption efficiency. Taro fiber is also used in biodegradable packaging e.g., molded trays, agricultural mulch films with a 3–6-month degradation window under composting conditions, reducing plastic pollution.

5.6 Emerging Applications

Recent studies explore Taro fiber in smart textiles, 3D printing, and energy storage. Taro-derived carbon fibers used in supercapacitor electrodes exhibit specific capacitances of ~160 F/g and maintain >90% performance over 1000 charge-discharge cycles [40]. In flexible biosensors, Taro fiber composites have enabled real-time monitoring of body motion and vital signs due to their flexibility and biointegration capabilities.

6 Challenges and Limitations

Various obstacles stand in the way of Taro fiber becoming a widespread sustainable material because of its implementation barriers. Several technical economic and environmental barriers must be solved for Taro fiber to successfully enter different industries [42]. This section conducts a comprehensive breakdown of these difficulties using research findings and case research. Fig. 4 illustrates the challenges and limitations of the widespread use of the application of taro fiber.

6.1 Technical Challenges

The major technical difficulties encountered with Taro fiber production include practical scalability, fiber uniformity, processing efficiency, and mechanical performance. A primary limitation for industrial application lies in the inability of current extraction methods especially enzymatic and manual approaches to meet industrial throughput demands. For instance, conventional enzymatic retting, while environmentally benign, yields only 4-6 kg of fiber per 100 kg of raw petioles over 3-5 days, limiting daily output and increasing production time. Mechanical decortication, though faster, requires further refinement to preserve fiber integrity. Pilot-scale studies suggest that modified decorticators can process approximately 200-300 kg of raw material per hour, yet this remains insufficient against projected industrial requirements exceeding 1-2 tons of processed fiber per day for applications in textiles or packaging sectors. Therefore, integration of hybrid extraction systems combining chemical pretreatment with mechanized decortication could improve throughput efficiency while balancing fiber quality [43], [44]. However, standard protocols and validated pilot-scale data remain limited in published literature. Future studies should explore continuous-flow or modular extraction units capable of scaling up without compromising environmental and economic performance.

Fig. 4 Challenges and Limitations of widespread use of taro fiber

6.2 Economic Viability

For Taro fiber to gain widespread industrial adoption the economic factors require improvement because synthetic materials currently have stronger market competitiveness. Uses of enzymatic treatment and nanotechnology during extraction and processing lead to elevated costs because they require dedicated specialized equipment and special materials [45]. Cost-effective processing methods need development for lowering costs and increasing affordability. The commercial performance of Taro fiber suffers due to competition from synthetic materials because polyester and nylon remain dominant market leaders through their economic advantage and reliable characteristics. The competitive advantage of Taro fiber depends heavily on showing its economic benefits through sustainability alongside ability to degrade naturally. Market penetration requires Taro fiber stakeholders to construct a reliable supply network through business alliances with producers and implement educational programs to show product advantages to customers. The implementation of government-based sustainable material policies and incentives would promote additional adoption of Tarophylla fiber. The development of large-scale production operations is crucial because it enables cost reduction in each unit while making Taro fiber economically feasible. Widespread acceptance of Taro fiber requires large-scale investment into infrastructure and technological development together with research and development work aimed at reducing production costs.

6.3 Environmental Concerns

The sustainability of Taro fiber faces challenges during its large-scale production because extraction methods need further environmental consideration to maintain its positive attributes. Sustainable cultivation practices including crop rotation and intercropping and organic farming systems prevent three major environmental problems: soil degradation along with biodiversity decline and enhanced pest and disease exposure because of cultivating single crops. Taro plants consume appreciable water resources that tax water supplies in water-scarce regions so farmers need to develop efficient water usage systems along with treated wastewater collection as an alternative water source [46]. Water pollution happens when improper management of sodium hydroxide during extraction leads to water contamination as a result of traditional alkali treatments so researchers pursue greener methods such as enzymatic processes and green chemistry principles. Proper waste management solutions exist for the plant waste and by-products resulting from Taro fiber extraction including composting and animal feed usage and bioenergy conversion. A comprehensive examination of Taro fiber emissions throughout production requires evaluation of total energy usage and chemical use with transportation implications [47]. The assessment and reduction of environmental impact from Taro fiber production becomes achievable through life cycle assessments (LCAs) for complete sustainability purposes [48]. While a comprehensive life cycle assessment (LCA) of taro fiber remains underexplored, preliminary comparisons with established natural fibers such as jute offer useful insights. Jute, a widely studied bast fiber, typically shows favorable LCA metrics due to its low water and chemical input requirements during cultivation and processing. In contrast, taro cultivation may demand higher water usage depending on agroecological conditions, and its chemical retting processes particularly alkali treatments can introduce environmental risks if not managed sustainably. However, taro fiber also presents unique environmental advantages. It is often sourced from agricultural residues (e.g., petioles and corms), thereby utilizing what would otherwise be waste biomass. This waste valorization reduces the need for dedicated fiber cultivation, potentially lowering land use and associated emissions. Furthermore, enzymatic and biological extraction methods under development for taro fiber offer promise for reducing chemical use and energy intensity, aligning it with or even improving upon jute's environmental profile. Future research should incorporate detailed LCA studies to quantify these differences across cultivation, processing, transportation, and end-of-life phases. Such assessments will be vital to positioning taro fiber within sustainable material frameworks alongside more established fibers.

6.4 Social and Regulatory Challenges

The implementation of Taro fiber confronts obstacles from both social standards and governmental regulatory agencies which need to be resolved. Public relations efforts which include workshops and student outreach can help educate Taro fiber benefits to all member groups including customers and industrial producers and regulators. The promotion of sustainable materials depends on governmental policies and regulations because supportive measures such as sustainable farming practice subsidies and biodegradable material incentives and restrictions against synthetic fibers contribute to adoption [49]. To guarantee consistent performance and quality and attract more customers standardization protocols must be developed for Taro fiber cultivation and extraction and processing.

7 Future Perspectives and Research Directions

Taro fiber has established itself as a leading sustainable materials choice because increasing market needs underline its bright future potential. Since it possesses specific properties along with renewable and biodegradable nature the material shows potential use in multiple applications. The complete utilization of Taro fiber requires solving current problems and developing innovative solutions to maximize its potential uses. The upcoming research discusses Taro fiber development by studying sustainable manufacturing practices together with sophisticated functionalization approaches as well as interdisciplinary collaborations and possible commercial uses [50].

7.1 Sustainable Production

The future development of Taro fiber depends on sustainable production processes which demand environmentally sustainable and economically feasible methods throughout cultivation extraction and processing. The sustainable cultivation methods should include organic farming and crop rotation with intercropping techniques because they protect soil health and biodiversity and water conservation requires efficient irrigation and alternative water sources including treated wastewater [51]. Green extraction techniques that combine enzymatic treatment with microbial treatment along with green chemistry approaches provide nature-friendly alternatives to chemical extraction methods which enhance both fiber quality standards and their consistency level. While the production of Taro fiber continues its development waste valorization techniques such as composting along with agricultural waste animal feed usage and bioenergy generation reduce waste while adding value to operations which strengthens the Taro fiber business success.

7.2 Advanced Functionalization

The application scope of Taro fiber has expanded because of advanced functionalization techniques that enable specific modifications at the molecular and nanoscale levels to enhance its properties. The integration of nanotechnology with Taro fiber modification creates innovation possibilities which include attaching Nano coatings to achieve antimicrobial alongside UV-resistant and flame-retardant properties while nanofillers including carbon nanotubes and graphene enhance mechanical and thermal properties together with electrical properties in Taro fiber-based composites. Researchers have identified the development of responsive multicomponent Taro fibers through environmental stimulus responses as a promising research field leading to applications such as vital sign and pollution monitoring using sensory Taro fibers and drug-delivering biomedical fiber systems. Surface modifications utilizing plasma treatment and chemical grafting and biofunctionalization enable technicians to enhance Taro fiber performance in various applications by improving surface adhesion and compatibility along with performance capabilities through specific functional group or polymer addition to the fiber surface [52].

7.3 Interdisciplinary Research

Research that combines multiple disciplines becomes essential to solve complicated technical barriers with Taro fiber components and achieve maximum utility. Crossover initiatives between material science and biotechnology and environmental science and additional branches will quicken technology development for Taro fiber applications [53]. Material science and engineering research involves work on developing novel composite materials alongside finding advanced modification approaches as well as processing techniques for Taro fiber such as using hybrid composite structures with natural and synthetic fibers to improve performance. Through biotechnology researchers can develop Taro plants genetically and optimize microbial treatments for sustainable fiber extraction by improving fiber properties such as cellulose levels and mechanical strength. By applying life cycle assessment methodology to Taro fiber manufacturing processes research teams can measure production-related environment stressors and search for uses in environmental cleanup operations [54].

7.4 Integration with Circular Economy

The use of Taro fiber within circular economies shows potential for sustainable resource management which enables waste minimization and the establishment of looped system operations. The key development for Taro fiber production needs to focus on productive loops that make end-of-life materials easy to recycle or compost such as packaging materials made from Taro fiber which naturally decompose and reduce waste and environmental impact [55]. Sustainability gains momentum through waste-to-resource strategies because these approaches convert Taro fiber extraction waste into usable bioenergy and raw products and generate dual revenue streams through waste reduction efforts. The sustainable development of Taro fiber production requires a responsible raw material supply chain system together with reduced environmental effects at manufacturing stages and ethical treatment of workers. Community participation together with stakeholder involvement creates dual social and economic advantages which maintains the sustainable production of Taro fiber over time.

7.5 Market Potential and Commercialization

The market value for commercial Taro-fiber products appears substantial since they satisfy demands for sustainable and eco-safe materials. The textile industry demonstrates potential for Taro fiber biodegradable material production that includes innovative smart functional fabrics with growth potential for the market. Putting eco-labels and certifications in place creates conditions for consumers to trust products more and boosts their purchasing willingness. Taro fiber shows major business potential in automotive and construction sectors as well as packaging markets through the development of advanced materials which display improved performance characteristics combined with better mechanical and thermal and environmental abilities [56]. Industry partnerships between manufacturers and stakeholders will help Taro fiber gain better integration within supply chain operations. The biomedical sector continues to develop wound dressings and drug delivery systems and tissue engineering products made from Taro fiber because market expansion depends on successful innovation and appropriate regulatory approvals. The market potential for Taro fiber as a water filtration technology and eco-friendly packaging solution grows because manufacturers have now found economical production methods to implement further scale-up. Marketing efforts targeting consumer understanding will boost adoption in these fields.

7.6 Policy and Regulatory Support

The market value for commercial Taro-fiber products appears substantial since they satisfy demands for sustainable and eco-safe materials. The textile industry demonstrates potential for Taro fiber biodegradable material production that includes innovative smart functional fabrics with growth potential for the market. Putting eco-labels and certifications in place creates conditions for consumers to trust products more and boosts their purchasing willingness. Taro fiber shows major business potential in automotive and construction sectors as well as packaging markets through the development of advanced materials which display improved performance characteristics combined with better mechanical and thermal and environmental abilities [57]. Industry partnerships between manufacturers and stakeholders will help Taro fiber gain better integration within supply chain operations. The biomedical sector continues to develop wound dressings and drug delivery systems and tissue engineering products made from Taro fiber because market expansion depends on successful innovation and appropriate regulatory approvals [58]. The market potential for Taro fiber as a water filtration technology and eco-friendly packaging solution grows because manufacturers have now found economical production methods to implement further scale-up. Marketing efforts targeting consumer understanding will boost adoption in these fields.

8 Conclusion

Taro fiber, derived from *Colocasia esculenta*, has emerged as a sustainable and biodegradable alternative to conventional fibers due to its high cellulose content, low density, and competitive tensile strength (200–400 MPa), enabling applications across textiles, biocomposites, biomedical devices, food, environmental remediation, and emerging sectors like energy storage and smart textiles. Advances in extraction methods such as enzymatic retting, chemical treatments, and mechanical decortication—have improved fiber quality and scalability, while surface modifications and nanotechnology have enhanced its mechanical, antimicrobial, and compatibility properties. However, widespread adoption faces several challenges, including limited scalability of eco-friendly extraction techniques, high production costs, environmental concerns related to water use and chemical waste, and insufficient standardization, lifecycle assessment, and biocompatibility data. Future progress requires integrated efforts toward green hybrid extraction systems, advanced functionalization, circular economy practices, and cross-disciplinary research in materials science, biotechnology, and environmental engineering. Additionally, government policies, market incentives, and public education will play vital roles in promoting commercialization and regulatory acceptance. Taro fiber represents a promising natural solution for advancing sustainable materials and addressing environmental and resource-related challenges.

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Conflict of Interest

All authors state that there is no conflict of interest.

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