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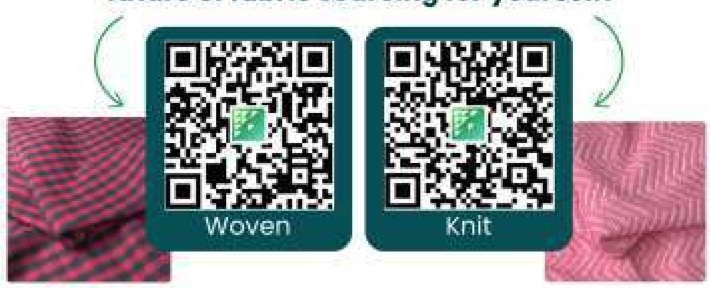

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CONTENTS

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Tel.: 022-35548619, 31725888 • E-mail: taicnt@gmail.com Website: www.textileassociationindia.org

Impact of Industry 4.0 on the Textile Industry in India

The textile industry, often considered the backbone of India's economy, is on the brink of a transformative era. Industry 4.0, defined by technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Robotics, and Big Data, is reshaping how textiles are manufactured, distributed, and consumed.

For the Indian textile sector, this era presents a unique opportunity to enhance productivity, minimize waste, and boost global competitiveness. While deeply rooted in tradition, the industry has immense potential for modernization. IoT-enabled smart factories, for example, allow for real-time monitoring of production processes, minimizing downtime and optimizing energy usage. Similarly, AI-driven analytics empower businesses to predict market trends and create tailored products for an increasingly selective customer base.

One of the most transformative aspects of Industry 4.0 lies in its ability to address persistent challenges in the Indian textile industry, including inconsistent quality, high production costs, and supply chain inefficiencies. Automation and robotics ensure precise production control, reducing defects and enhancing uniformity. Tools like digital twins and predictive maintenance further help minimize machine breakdowns, lowering operational costs.

Yet, the transition to Industry 4.0 is not without hurdles. A large proportion of the Indian textile industry consists of small and medium-sized enterprises (SMEs) that may struggle with the financial and technical requirements of adopting advanced technologies. This gap necessitates collaborative efforts among policymakers, industry leaders, and educational institutions. Government initiatives promoting technological adoption, combined with skill development programs, are essential to ensure SMEs are not excluded from this digital revolution.

Sustainability, an increasingly vital component of modern manufacturing, also finds strong support in Industry 4.0 technologies by optimizing resource utilization and reducing waste. For Indian textile manufacturers, this is an opportunity to strengthen their leadership in sustainable production while meeting international environmental standards.

The future of India's textile industry in the age of Industry 4.0 is both challenging and promising. As Hon. Editor of Journal of the Textile Association, I urge all manufacturers, policymakers, innovators, and academics to collaborate in creating a clear roadmap for this transformation.

By fostering innovation, investing in technology, and nurturing talent, we can ensure the industry retains its rich heritage while becoming a global leader in smart, sustainable manufacturing.

Dr. Aadhar Mandot
Hon. Editor

T. L. PATEL, President

Navigating the Evolving Textile Landscape: Opportunities and Challenges

T. L. PATEL, President

As we navigate the dynamic and ever-evolving textile landscape, it's crucial to recognize both the exciting opportunities and the pressing challenges that lie ahead. Our industry, a cornerstone of global economies, is facing a confluence of factors that demand adaptability, innovation, and a united front.

Embracing Innovation and Sustainability

One of the most significant opportunities lies in embracing innovation and sustainability. Consumers are increasingly demanding eco-friendly and ethically produced products. This presents a unique chance for our industry to showcase its commitment to sustainable practices. By integrating renewable energy sources, adopting circular economy principles, and embracing digital technologies, we can enhance efficiency, reduce our environmental impact, and create products that resonate with conscious consumers.

Leveraging Technology and Digitalization

The rise of technology and digitalization is transforming every aspect of the textile value chain. From automated manufacturing processes and AI-powered design to data-driven supply chain management and personalized customer experiences, these advancements offer immense potential. By embracing these technologies, we can enhance productivity, improve quality, and gain a competitive edge in the global market.

Addressing Global Challenges

However, alongside these opportunities, we face significant challenges. The global economic slowdown, geopolitical uncertainties, and the ever-present threat of disruptions in the supply chain are all factors that demand our attention. Moreover, the increasing competition from emerging economies and the need to adapt to rapidly changing consumer preferences require a proactive and agile approach.

The Role of Collaboration and Collective Action

To effectively address these challenges and capitalize on the emerging opportunities, collaboration and collective action are paramount. Our association plays a vital role in fostering a strong and united industry. We strive to provide a platform for knowledge sharing, facilitate industry-academia collaborations, and advocate for policies that support the growth and sustainability of our sector.

Looking Ahead

The future of the textile industry is bright, but it demands a proactive and collaborative approach. By embracing innovation, leveraging technology, and addressing the challenges head-on, we can ensure the continued growth and prosperity of our industry. I encourage all members to actively engage with our association, share their insights, and contribute to the collective success of our industry

T. L. PATEL
President
The Textile Association (India)

Textile Transformations: Assessing the Impact of GST on MSMEs in Peenya Industrial Area

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Abstract:

Background: The Goods and Services Tax (GST), implemented in India in July 2017, aimed to simplify the tax structure and enhance compliance for businesses. This study evaluates the impact of GST on Micro, Small, and Medium Enterprises (MSMEs) in the textile sector, focusing on those located in the Peenya Industrial Area, which is recognized as a key hub for textile manufacturing and innovation.

Methods: A mixed-methods approach was adopted, integrating quantitative surveys and qualitative interviews with MSME owners. The quantitative surveys focused on measuring changes in compliance costs, operational efficiency, and overall business growth following the implementation of GST. In-depth qualitative interviews were conducted to gather insights into the personal experiences of MSME owners regarding the GST framework.

Results: The findings suggest that while GST has facilitated streamlined tax processes and enhanced compliance among MSMEs, several challenges remain. Notably, increased compliance costs and a widespread lack of awareness regarding GST regulations significantly hinder the ability of MSMEs to fully adapt to the new tax structure. Additionally, many MSMEs reported difficulties in understanding the compliance requirements, which has impacted their operational efficiency.

Conclusion: To maximize the benefits of GST for MSMEs, it is essential to develop targeted support and training programs tailored to the unique challenges faced by these enterprises. Such initiatives will assist businesses in effectively navigating the GST framework, ultimately promoting sustainable growth and resilience within the textile sector.

Keywords: *GST, MSMEs, Peenya Industrial Area, Taxation, Textile Industry*

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1. Introduction

The textile industry is a critical sector in India's economy, playing an indispensable role in providing employment and generating substantial export earnings. Historically, textiles have been a cornerstone of India's economic framework, encompassing a wide range of activities that include fiber production, fabric manufacturing, and garment creation. This industry not only supports millions of livelihoods, particularly in rural areas, but also significantly contributes to the nation's GDP. With a rich heritage and diverse skill sets, the Indian textile sector is renowned globally for its quality and craftsmanship.

In recent years, the introduction of the Goods and Services Tax (GST) in July 2017 marked a significant reform in the Indian taxation system. GST was designed to simplify the complex array of indirect taxes that previously burdened businesses. Before GST, the textile industry was subject to a multitude of taxes at different stages of production and distribution, resulting in a cascading effect that increased the overall tax burden on manufacturers. The implementation of GST aimed to unify these fragmented tax structures under a single umbrella, thereby promoting ease of doing business across various sectors, including textiles.

The transition to GST has profound implications for Micro, Small, and Medium Enterprises (MSMEs), which constitute a significant portion of the textile industry. These enterprises are vital for the sector's growth due to their flexibility, innovation, and contribution to job creation. However, MSMEs often face unique challenges, including limited financial resources, inadequate access to technology, and insufficient understanding of complex regulatory requirements. The introduction of GST presents both opportunities and challenges for these businesses. While GST is expected to reduce compliance burdens in the long term, the immediate effects include increased operational complexities and compliance costs that can disproportionately affect MSMEs.

This research focuses specifically on assessing the implications of GST for MSMEs operating in the Peenya

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Industrial Area, recognized as a significant hub for textile production and innovation. This area is home to a diverse array of textile manufacturers, from traditional handloom units to modern garment factories. The Peenya Industrial Area plays a crucial role in the supply chain of textiles, and its MSMEs contribute significantly to local and national economies.

By investigating the impact of GST on these enterprises, this study aims to highlight the specific challenges they face, such as the increased cost of compliance, limited awareness of GST provisions, and the urgent need for training and support to adapt to the new regulatory environment. Moreover, understanding the effects of GST on these enterprises is vital for identifying potential areas for support and improvement.

The findings of this research will provide valuable insights that can inform policymakers and industry stakeholders about the specific needs of MSMEs in navigating the GST framework. Addressing these needs is essential for enhancing the overall resilience and sustainability of the textile industry in India. In a competitive global market, the ability of MSMEs to effectively adapt to GST will determine not only their survival but also their growth potential.

In summary, the introduction of GST represents a transformative change for the textile industry in India, particularly for MSMEs. As the industry adapts to this new tax regime, ongoing research and support are essential to maximize the benefits of GST while addressing the challenges faced by these enterprises. This study endeavors to contribute to that understanding, paving the way for a more robust and competitive textile sector in India.

2. Materials and Methods

2.1 Research Design

This study employs a mixed-methods research design, integrating both quantitative and qualitative methodologies to provide a comprehensive understanding of the impact of GST on Micro, Small, and Medium Enterprises (MSMEs) within the textile sector [12].

2.2 Data Collection

Data were collected over a period from [insert month, year] to [insert month, year] in the Peenya Industrial Area, a significant hub for textile manufacturing in India. The research involved two primary methods of data collection:

- Quantitative Data: Structured surveys were administered to [insert number] MSME owners within the Peenya Industrial Area. The survey included questions designed to gather quantitative data on various aspects, such as compliance costs, operational changes, and overall business performance after the implementation of GST. The survey instrument was validated through a pilot study conducted with a small group of MSME owners to ensure clarity and relevance [13].
- Qualitative Data: Semi-structured interviews were conducted with [insert number] MSME stakeholders, including business owners and managers. These interviews aimed to capture in-depth insights into the challenges and benefits experienced under the GST framework. Open-ended questions allowed respondents to express their views freely, providing rich qualitative data that complemented the quantitative findings [15].

2.3 Data Analysis

Quantitative data collected from the structured surveys were analyzed using statistical methods to assess the impact of GST on Micro, Small, and Medium Enterprises (MSMEs). Software tools such as SPSS and Excel were employed to perform both descriptive and inferential statistical analyses [14]. Descriptive statistics provided an overview of the data, while inferential statistics were utilized to draw conclusions and identify correlations between GST implementation and various performance metrics, such as compliance costs and operational efficiency.

Qualitative data obtained from semi-structured interviews were thematically analyzed, which involved coding the responses to identify recurring themes and significant insights related to the impact of GST on MSMEs [2]. This approach allowed for a deeper understanding of the challenges and benefits experienced by MSME owners in adapting to the GST framework. The combination of both quantitative and qualitative analyses provided a comprehensive view of the effects of GST on the textile sector.

Table 1: Impact of GST on MSMEs

Parameter	Pre-GST Status	Post-GST Status	Percentage Change
Compliance Costs	?50,000 annually	?75,000 annually	+50%
Operational Efficiency	65%	78%	+20%
Business Growth Rate	10%	12%	+2%
Access to Credit	45%	60%	+15%

This table summarizes the changes in key performance metrics for MSMEs in the textile sector before and after the implementation of GST, providing a clear view of the financial and operational impacts.

Table 2: Key Challenges Faced by MSMEs Post-GST

Challenge	Percentage of MSMEs Affected	Description
Increased Compliance Costs	60%	Many MSMEs reported higher costs associated with GST compliance, including accounting and filing expenses.
Lack of Awareness	35%	A significant number of MSMEs lack understanding of GST provisions, leading to compliance issues.
Operational Disruptions	40%	Transitioning to GST created temporary disruptions in business operations, affecting productivity.
Access to Financial Support	30%	Difficulty in securing loans or credit facilities due to new compliance requirements under GST.

This table highlights the primary challenges faced by MSMEs after GST implementation, emphasizing the need for targeted support to mitigate these issues.

Table 3: Benefits Experienced by MSMEs Post-GST

Benefit	Percentage of MSMEs Realizing Benefit	Description
Streamlined Tax Processes	70%	GST has simplified the tax structure, making it easier for MSMEs to comply.
Enhanced Market Competitiveness	60%	Registration under GST has enabled MSMEs to access broader markets and compete effectively.
Improved Credit Access	50%	Many MSMEs report better access to financing due to formalization under GST.
Better Record Keeping	55%	The need for compliance has led MSMEs to adopt better accounting practices.

This table outlines the key benefits that MSMEs have experienced post-GST implementation, indicating improvements in operational capabilities and market positioning.

3. Results and Discussion

3.1 Quantitative Findings

The survey results indicate:

- Compliance Costs: Approximately 60% of respondents reported an increase in compliance costs following GST implementation.
- Operational Efficiency: 20% of MSMEs noted improvements in operational efficiency due to streamlined tax processes.

3.2 Qualitative Insights

Interviews revealed:

- Challenges: Many MSME owners highlighted difficulties in understanding GST regulations, resulting in confusion and increased operational burdens.
- Benefits: Some respondents reported positive changes, such as improved access to credit and reduced competition from unregistered businesses.

4. Conclusions

This research demonstrates that the implementation of Goods and Services Tax (GST) has led to substantial changes in the operations of textile Micro, Small, and Medium Enterprises (MSMEs) in Peenya. While GST has streamlined tax processes and improved compliance for many businesses, significant challenges remain, including increased compliance costs and a lack of awareness regarding GST regulations. These findings highlight the critical need for ongoing support from government and financial institutions to help MSMEs navigate the complexities of the GST framework. Strategic initiatives, such as targeted training programs and the simplification of compliance procedures, are vital for enhancing the resilience and growth of MSMEs in the textile sector. Addressing these challenges will not only improve business performance but also contribute to the overall sustainability of the textile industry in India.

5. Acknowledgments

We would like to express our sincere gratitude to the Micro, Small, and Medium Enterprises (MSMEs) in the Peenya Industrial Area for their invaluable insights and participation in this study. We also acknowledge the support of our research team and funding from the Department of Commerce, Vivekananda College of Arts and Science for Women, and the Peenya Industrial Association for making this research possible.

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■ ■ ■

Circular Fashion Revolution: Sustainable Fashion through Up-cycling and Traditional Textiles

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Abstract:

Background:

The fashion industry is under increasing pressure to adopt sustainable practices. Ranked as the second most polluting sector globally, after oil industry, the textile industry has a significant environmental impact. This situation has been exacerbated by the fast fashion phenomenon, which thrives on the constant creation, promotion, and disposal of trends over the last two decades.

Methods: To highlight the wastefulness of the textile and clothing industry, we will briefly examine the adverse effects of fast fashion. Furthermore, we will investigate how the industry can shift from a linear economy to a circular one by incorporating traditional textiles and emphasizing reuse and recycling. Therefore, this research employed mixed method approach both qualitative and quantitative. It utilized convenience sampling to survey 50 fashion industry respondents and personal interviews with 5 key fashion stakeholders.

Results: The objective of this research is to examine and analyze the application of circular fashion principles through upcycling and traditional textiles, aiming to transform the fashion industry into a more sustainable and environmentally conscious sector. The results indicate that integrating circular fashion practices is vital for reducing the industry's environmental footprint and meeting the demand for sustainable consumer options.

Conclusion: Circular fashion aims to minimize waste and prolong the lifespan of products, with upcycling involving the repurposing of waste materials into new items. Traditional textiles not only offer cultural richness but also present opportunities for sustainability. Collaboration among stakeholders is vital for achieving long-term sustainability.

Keywords : *Circular fashion, environmentally, sustainable practices, traditional textiles, up-cycling*

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1. Introduction

The fashion and textile sector stands out as one of the most environmentally harmful industries worldwide, largely because of its extensive production volume. Textile production demands vast amounts of land for cultivation and utilizes substantial quantities of water, energy, chemicals, and various resources. Regrettably, this frequently leads to unaddressed pollution, causing adverse effects on the environment, economy, and society. The fashion industry accounts for around 10 percent of total global carbon emissions and 20 percent of global wastewater. Additionally, it produces an alarming 92 million tons of textile waste annually, with projections indicating a potential increase of nearly 60 percent by 2030 if proactive measures are not implemented. Consequently, it is evident that the fashion industry is far from being environmentally friendly.

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The current methods of clothing production have significant environmental consequences. The fashion industry thrives on creating, promoting, and discarding fashion trends [1]. In the past two decades, the pace of fashion has accelerated, giving rise to the concept of fast fashion. This phenomenon revolves around rapidly changing trends, excessive consumption, and low-quality garments that prompt consumers to purchase more frequently due to their affordability. However, these clothes are often discarded after just one season, exacerbating the issue of waste in the industry.

To combat the negative environmental impact caused by fast fashion, there are numerous solutions that can be implemented. This includes reducing water consumption, utilizing sustainable materials, and encouraging collaboration among various industries to promote a circular economy. Such an approach is essential for the textile and clothing industry to address the challenges it currently faces and to ensure its viability in an era of stringent environmental regulations. The goal is to maximize resource utilization while minimizing waste and emissions, all while maintaining profitability without harming the environment.

To highlight the wastefulness of the textile and clothing industry, this study will first assess the detrimental impacts of fast fashion. It will then investigate how the industry can transition from its current linear model to a circular economy by incorporating traditional textiles and emphasizing practices of reuse and recycling. The article will conclude with a thorough summary of the key issues addressed.

The primary objective of this study is to explore and analyse the implementation of circular fashion principles via upcycling and the use of traditional textiles, with the goal of transforming the fashion industry into a more sustainable and environmentally responsible sector. This research aims to understand how these practices can effectively reduce waste, preserve cultural heritage, and generate new economic opportunities, ultimately contributing to a more sustainable fashion ecosystem and fostering a circular economy.

1.1 State of clothing and textile industry

The textile industry is recognized as the second most polluting sector globally, following the oil industry. It is responsible for approximately 1.2 billion tons of greenhouse gas emissions, which exceed the combined emissions from international aviation and maritime shipping [2]. Projections indicate that by the year 2050, the fashion industry may account for as much as 25% of the world's carbon budget. In addition to these considerable carbon emissions, the industry contributes to ocean pollution through the release of microplastics [3]. The entire supply chain, encompassing the production and distribution of crops, fibers, and garments, results in air, water, and soil contamination. This situation emphasizes the critical concerns surrounding water consumption and pollution associated with textile wet processing operations, such as dyeing, finishing, and sizing. Consequently, these factors present significant challenges to sustainability within the industry [4].

1.2 Fast fashion

Recently, there has been a rise in "fast fashion," which refers to the production of cheap and trendy clothing that imitates high-end culture and celebrity ideas. These low-quality garments are sold at affordable prices, targeting low-income earners. Hence, fast fashion promotes mass consumption through low prices, but it also generates a significant amount of waste [5].

1.3 Circular Economy

The existing clothing system predominantly functions in a linear fashion, encompassing manufacturing, distribution, and consumption in a sequential manner. A substantial proportion of the fibers employed in garment production is sourced from non-renewable resources, particularly fossil fuels, which significantly contribute to environmental pollution. Typically, these garments are worn for a limited duration before being disposed of, either in landfills or through incineration. To effectively address these challenges, it is essential to transition from a linear economy to a circular economy. The circular economy is anchored by three fundamental principles: reduce, reuse, and recycle. These principles are intrinsically linked to traditional waste management strategies and aim to minimize waste, conserve resources, and promote sustainability within the fashion industry. (Fig.1).

Figure 1: Linear Economy Vs Circular Economy

1.4 Sustainable fashion

In the fashion industry, sustainability has become an increasingly important concern. One effective strategy to achieve sustainability involves the use of durable and long-lasting materials during the manufacturing process. However, this approach may not resonate with consumer preferences, as many individuals tend to replace their clothing according to seasonal trends and specific occasions. To effectively address the environmental impact of fast fashion and establish a competitive edge in a rapidly growing market, it is essential to embrace circular economy practices. These approaches aim to minimize the negative effects of the fashion industry on sustainability while promoting responsible consumption and production [6].

Therefore, here are a few examples of sustainable and eco-friendly approaches that can be implemented:

1.4.1 Sustainable and eco materials: Textiles are produced from renewable or sustainably cultivated raw materials that are non-toxic and free from pesticides. This emphasizes a preference for durable fibers such as linen, hemp, and bamboo.

1.4.2 Human rights: Numerous retailers have begun utilizing fair trade certification and membership as a means to demonstrate that equitable compensation has been provided to the producers of raw materials.

1.4.3 Environment friendly manufacturing: The garment industry has been compelled to adopt various eco labels and management systems, such as ISO Standards and OEKO-TEX, due to the combination of regulations, standards, and a growing consciousness regarding the use of less toxic and sustainable products

1.4.4 Local production: In order to mitigate the growing trend of globalization within the fashion sector and its subsequent social and environmental repercussions, manufacturers are shifting towards local production networks. This approach not only brings about various benefits but also enhances transparency and quality control throughout the supply chain.

1.4.5 Environment-friendly garment care: Numerous retailers are actively engaging with environmentally conscious consumers to deepen their understanding of harmful environmental effects linked to garment usage and maintenance.

1.5 Indian traditional textiles and sustainable fashion

India possesses a profound historical legacy in the use of traditional textile garments and techniques, such as handloom weaving and natural dyeing. These practices are not only environmentally sustainable but also exert a significantly reduced impact on the ecosystem when contrasted with industrial methods. As a result, the rich variety of traditional textile garments and techniques from various Indian states can be harnessed to transform worn garments into innovative new products through effective recycling and upcycling methods. Embracing these practices not only preserves cultural heritage but also contributes to a more sustainable future.

The textile and clothing industry in India reflects a rich tapestry of improvisation, philosophy, artisanal skills, and a shared commitment to optimizing limited resources. Recycling and upcycling handmade garments are deeply embedded in India's heritage, making substantial contributions to the reduction of greenhouse gas emissions.

Each Indian state features its own unique textiles, characterized by distinct processes, designs, and patterns. Historically, these fabrics have been created using locally sourced materials, showcasing regional craftsmanship and sustainability. When transformed into garments, they were carefully tailored to cater to individuals of all ages and sometimes even passed down through generations. Moreover, these outfits were designed with consideration for the local climate. Notably, these garments were renowned for their long life-cycle, emphasizing reuse and recycling. Even after their initial purpose was fulfilled, they were creatively upcycled into practical items.

Aligning the sustainable techniques mentioned earlier with the traditional textiles of India involves recognizing the eco-friendly attributes deeply ingrained in India's textile legacy and combining them with modern sustainable principles. The subsequent details how each sustainable technique can be incorporated:

1.5.1 Sustainable and Environmentally Friendly Materials

1. Khadi: A fabric that is hand-spun and hand-woven, traditionally made from cotton but also from silk and wool, known for its durability and minimal environmental impact.

2. Organic Cotton: Grown without synthetic pesticides and fertilizers, commonly used in traditional Indian clothing.

3. Eri and Ahimsa Silk: Silk produced without harming silkworms, aiding in the conservation of biodiversity.

1.5.2 Human Rights

Craft Revival Initiatives: Projects focused on reviving traditional crafts often prioritize improving the livelihoods of artisans.

1.5.3 Eco-friendly Manufacturing of Traditional Indian Textiles

1.5.3.1 Organic/Natural Dyes

Traditional textiles frequently incorporate organic dyes sourced from plants, minerals, and insects, which are both non-toxic and biodegradable.

1.5.3.2 Artisanal Weaving

Weaving looms, which are manually operated tools employed to create a diverse array of designs and fabrics in various sizes, represent a tradition upheld by numerous communities throughout India. The hand-weaving process not only reduces energy consumption but also results in a low carbon footprint, thereby promoting sustainable manufacturing practices.

1.5.4 Local Production

Rural-Based Production: Many traditional textiles are crafted in rural areas, supporting local economies and preserving cultural heritage.

1.5.4.1 Local Markets

Selling textiles in nearby markets reduces the carbon footprint associated with transportation.

1.5.5 Environment friendly clothing care

1.5.5.1 Durable Fabrics

Khadi and handloom fabrics, known for their longevity, reduce the need for frequent replacements.

1.5.5.2 Simple Maintenance Tips

Many traditional textiles require easy, eco-friendly care methods such as hand washing and air drying.

1.6 Traditional Indian Textile Techniques

India has a wide array of traditional textile techniques that are used to recycle textile waste in different regions. Hence, traditional Indian textile techniques are instrumental in transforming textile waste into marketable products. As the population continues to grow, the issue of clothing waste has become increasingly significant. In various Indian states, numerous methods exist for repurposing old fabric and recycling textile waste, employing a range of surface embellishment techniques to produce innovative new products [7]. Some examples include:

Sujani embroidery, hailing from Bihar, showcases floral motifs on quilts, Panja dhurrie, or durrie, is a vibrant, flat-woven rug common in North India. Kasuti embroidery from Karnataka uses various stitches to depict nature and mythology, Patchwork creatively combines different fabrics promoting sustainability, Chakhlo represents traditional stuffed puppet art, contributing to India's rich textile heritage.

These crafts highlight the skill of artisans and the importance of preserving cultural heritage.

To promote sustainable growth in the textile industry strategies like reducing, reusing and recycling are essential for transforming textile wastse into valuable products. Traditional Indian crafts are vital in this effortas artisons skilfully repurpose used garments to create a variety of valuable items [8].

India's traditional textiles have gained global recognition for their outstanding quality. The Indian subcontinent is celebrated for its extensive artistic and cultural legacy. Historical records indicate that as far back as 2500 BCE, Indian crafts and textiles were exchanged with civilizations such as China, Mesopotamia and Egypt, originating from the Mohenjo-Daro and Harappan cultures. These textiles were produced using a variety of fabrics and techniques, including knitting, weaving, and decorative surface treatments. Methods like dyeing, printing, and embroidery enriched their visual appeal, incorporating designs inspired by the local environment, flora, and cultural elements. Preserving these traditional skills is crucial for sustaining the distinctive identity of local communities [9].

Textile recycling is crucial and important in ensuring the longevity of textiles. Improper disposal of textile materials can release harmful gases into the environment over many years. Recycling clothes provides a sustainable solution to this issue. There are various ways to repurpose and reuse recyclable clothing [10].

The materials utilized in the production of goods present five distinct methods for product recovery: repair, reuse, refurbishment, remanufacturing, and recycling [11]. As a result, artisanal products made from high-quality recycled materials enhance the longevity of the product [12].

1.7 Sustainable Craftsmanship: Upcycling Clothing into New Products

Upcycling, which involves giving an old, abandoned item a completely new life, is a fashion statement in and of itself. In India, the well-known adage "One man's trash is another man's treasure" is taken far too seriously.

1.7.1 Making Rugs and Quilts

Chindi rugs: Chindi rugs exemplify the innovative reuse of textile waste. Predominantly found in Maharashtra and Gujarat, these rugs are crafted by braiding or weaving strips of leftover fabric scraps, resulting in vibrant and multi-textured pieces. Renowned for their durability, Chindi rugs possess a distinctive character, ensuring that each rug is unique.

Ralli quilts: Typically seen adorning village beds in Sindh and Punjab, Ralli quilts are made by stitching together small patches of brightly colored fabric in a collage-like fashion. Various techniques, including patchwork, applique, and embroidery, are employed to create geometric patterns that frequently feature traditional motifs.

Kaithoon: Hailing from Rajasthan, Kaithoon is a traditional patchwork method primarily used to produce intricately designed quilts known as 'Gudri'. These quilts are made by sewing together fabric pieces, often sourced from old sarees and garments. Gudri quilts are cherished heirlooms, passed down through generations, encapsulating memories and cultural traditions within their fabric.

Pipli work: This brilliant appliqué method is used in Odissi artwork to create ornamental patterns by sewing colorful patches of fabric onto a base cloth. Wall hangings, canopies, traditional umbrellas, and even ceremonial decorations are frequently made using this technique. A significant cultural icon, pipli work is frequently shown at temples and at festivals. The cloth cover of the three chariots that the Puri temple's deities ride in each year during the Ratha Yatra is where the appliqué work is most noticeable.

Kantha: Kantha embroidery is a visible mending technique used in Bangladesh and West Bengal that entails piecing together worn-out textiles using straightforward running stitches. This method is frequently used to reinforce deteriorated fabric, extending the life of the garment. Women used to make quilts, bedspreads, and even clothes out of discarded sarees and dhotis by sewing them together and layering them. The simplicity of Kantha is what makes it so beautiful; the intricate patterns created by the repeated stitching give the fabric texture and vitality [13].

In order to produce several layers, homemakers recycle fabric waste and outdated fabrics to make quilts. Another technique for reusing textiles that makes use of clothing's adaptability is appliqué [14]. These methods and fabrics are extremely significant because they allow rural communities to express their culturally inspired images while also providing a source of revenue.

The obsolescence of fashion products is not solely due to material factors, but also influenced by shifts in consumer behavior and social dynamics. The future of India's textile and fashion industries will surely be impacted if recycling procedures for scrap fabric are not used in the industry, both on a small and large scale. Raising awareness among young textile craftsmen is essential to preserving and advancing traditional craft processes for future generations. This can be accomplished by highlighting the benefits of these methods and setting up training sessions and workshops, which will be assisted by the Indian government's textile ministry.

However, as the global sustainability movement picks up steam, contemporary Indian designers and companies are adopting upcycling more and more, drawing inspiration from old methods while creating new styles for the modern era. As a result, the Indian fashion industry has accepted the practice of recovering textile waste to prolong the life cycle of its products. In the current fashion scene below is India's conscientious brand reinventing upcycling in the following way:

Label Ka-Sha - At Label Ka-Sha- Fabric waste is repurposed at the source at Label Ka-Sha. During the cutting and stitching procedure, up to sixteen percent of the fabric can usually be thrown away. In order to address this, Ka-Sha started the "Heart to Haat" campaign, which recycles fabric waste into a range of goods, including as bags, macramé, stuffed animals, patchwork, shoes, and embroidery. To ensure that the least amount of trash is produced, the business also works with friends and other designers in the field to gather more leftover fabric.

2. Materials and Methods

2.1 Research objectives

The primary objective is to explore the potential of incorporating circular fashion principles, such as upcycling, reuse, and the utilization of traditional textiles, to promote sustainability and revolutionize the fashion sector.

- To investigate how traditional Indian garments and traditional textiles can contribute to circular fashion.
- To explore how the ethos of traditional crafts can slow down fast fashion and contribute to a sustainable fashion system.
- To assess the impact of integrating traditional knowledge on fashion and textiles into contemporary fashion design to achieve true sustainability.
- To evaluate the cultural tradition of extending the life span of clothing through reuse and repair in Indian customs.
- To investigate the prevailing beliefs regarding repurposing left over materials and its acknowledged significance for promoting sustainability.
- Analyse the shared awareness of the need to reduce pollutant burdens through waste reduction, reuse and recycling.

These objectives provide a structured framework for investigating the potential of integrating upcycling and traditional textiles into circular fashion to drive sustainability and transformation in the fashion industry.

2.3 Research methodology

This research study utilizes a combination of qualitative and quantitative methods. The secondary research involved a thorough examination of reports, books, research articles, and online sources to gather insights. Primary data collection consisted of a structured survey administered to 50 respondents from the fashion industry, followed by personal interviews with 5 key stakeholders.

2.4 Sampling method and sample size

This study employed purposive sampling to gather data. A total of 55 respondents from the fashion industry were selected, along with personal online interviews conducted with 5 fashion stakeholders. The sample of 55 comprised fashion faculty, designers, and fashion/textile students from Jaipur, ensuring that the participants had relevant knowledge and experience in sustainable fashion. This carefully chosen sample facilitated in-depth discussions, which enriched the insights necessary for understanding the complexities of the circular fashion movement within the broader context of sustainable fashion.

2.5 Ethical considerations and limitations

Ethical considerations such as informed consent, confidentiality, and adherence to ethical guidelines were taken into account throughout the research process. The study also recognizes limitations, such as the inability to study the entire population and time constraints.

3. Results and discussion

An online survey was conducted with 50 respondents and they were asked questions related to each of the four research objectives. The gender distribution is fairly balanced, with 52% females and 48% males, showing a slight female majority. This balance ensures that the results are not biased towards one gender, making them applicable to both male and female perspectives.

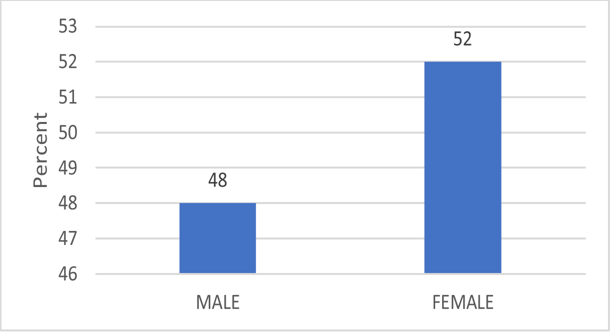

Figure 2: Gender

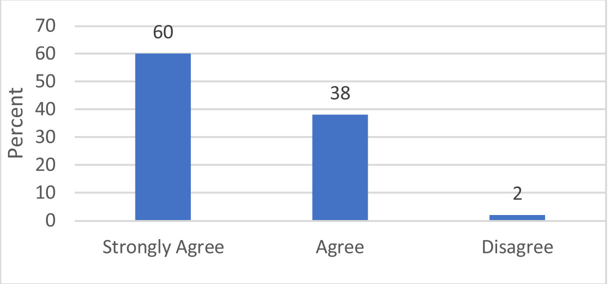

Figure 3: Traditional textiles or traditional couture existed long before the establishment of the fashion systems

A large majority (98%) of participants, with 38% and 60% either agreeing or strongly agreeing, believe that traditional textiles existed before modern fashion systems. This indicates a high level of awareness and acknowledgment of the historical roots and enduring nature of traditional textiles. A very small minority (2%) disagrees, showing almost universal recognition of this fact.

All respondents (100%) either strongly agree or agree (54% and 46%) that traditional Indian garments like Saris and Dhotis follow a zero-waste design principle. This unanimous agreement highlights the strong connection perceived between traditional Indian clothing design and sustainable practices, emphasizing the importance and effectiveness of these traditional methods in sustainability.

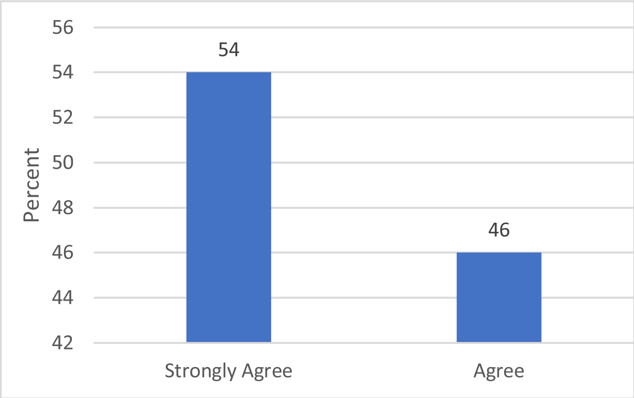

Figure 4: Traditional Indian garments such as the saries and the dhoties follow a zero waste pattern making principle. This is sustainable by design

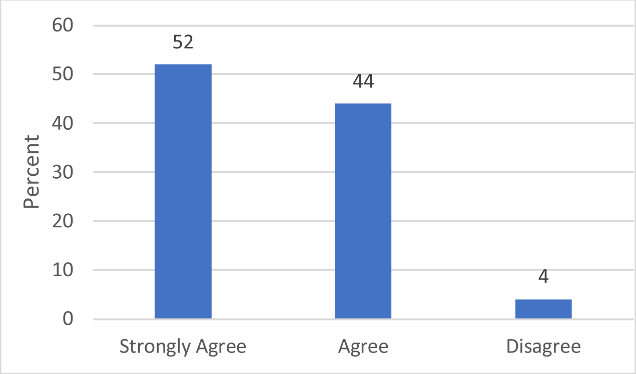

Figure 5: Imbibing the true ethos of craft can become road map to slowing fast fashion

The vast majority (96%) of participants believe that embracing the authentic essence of traditional craftsmanship can help slow down the rapid pace of the fast fashion industry. This indicates strong support for traditional craft as a viable solution to combat the fast production cycles associated with fast fashion. The small dissenting fraction (4%) suggests some scepticism, although minimal.

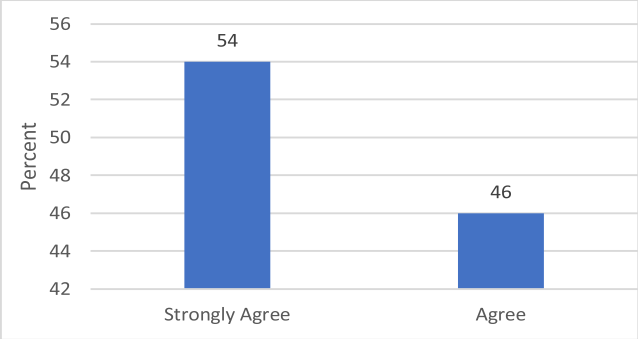

Figure 6: Traditional textiles sector is eco-friendly and effectively deals with environmental sustainability

All respondents (100%) unanimously agree or strongly agree that the traditional textiles sector is environmentally friendly and effectively addresses sustainability issues. This consensus highlights the sector's perceived environmental benefits and its efficiency in tackling sustainability challenges.

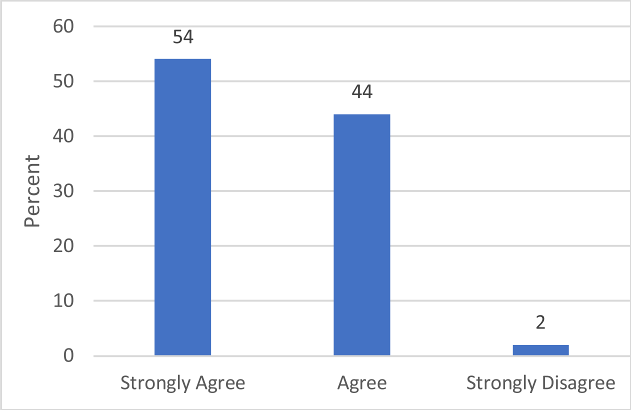

Figure 7: Sustainable fashion can be truly created if traditional knowledge on fashion & textile is integrated into contemporary fashion

A significant majority (98%) of participants firmly believe that incorporating traditional wisdom into modern fashion can lead to genuinely sustainable fashion. This strong support indicates a desire to merge traditional and contemporary methods in order to achieve sustainability. A small percentage (2%) of strong disagreement suggests a minor level of opposition, possibly due to differing opinions on the practicality or importance of such integration.

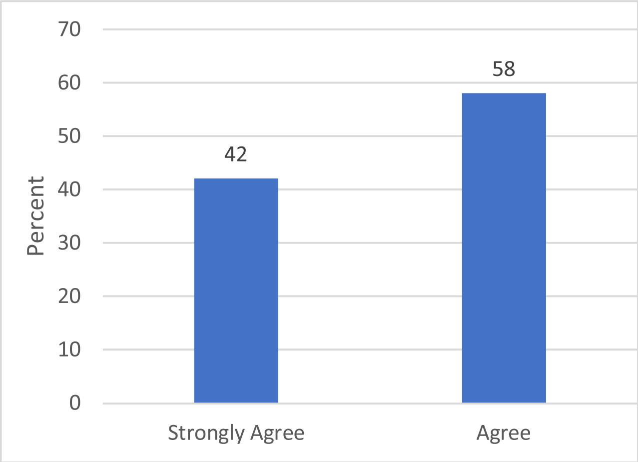

Figure 8: It is part of the Indian lifestyle to prolong the life of Garment through Reuse and Repair

All participants (42% and 58%) strongly agree or agree that extending the lifespan of clothing through reuse and repair is a fundamental aspect of the Indian way of life. This showcases a strong cultural norm of sustainability in garment usage, highlighting a deeply ingrained tradition of maximizing the utility of apparel.

The majority of respondents (76%) strongly believe or believe in the significance of upcycling leftover materials, emphasizing a widespread recognition of upcycling's role in

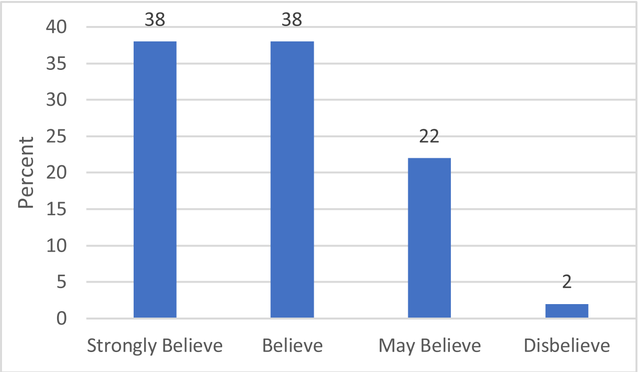

Figure 9: It is crucial to up cycle leftover yardage, fabric scraps, yarn, and other materials

sustainability. However, there is a noticeable minority (22% and 2%) who are either unsure or do not believe, indicating a need for further education and awareness.

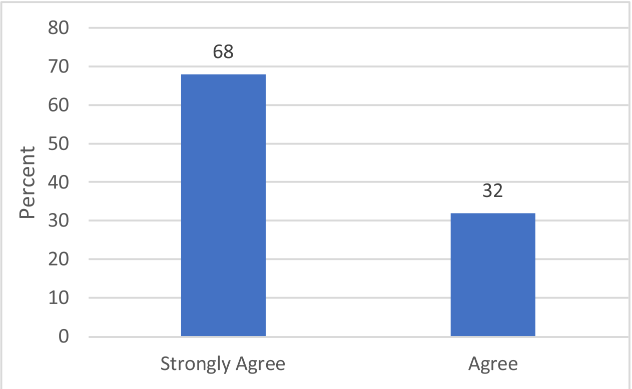

Figure 10: Upcycling/recycling has highly beneficial effect on sustainable fashion

Every respondent (100%) concurs that upcycling/recycling greatly benefits sustainable fashion. This unanimous consensus highlights a widespread agreement on the positive influence of upcycling and recycling practices on the sustainability of the fashion sector.

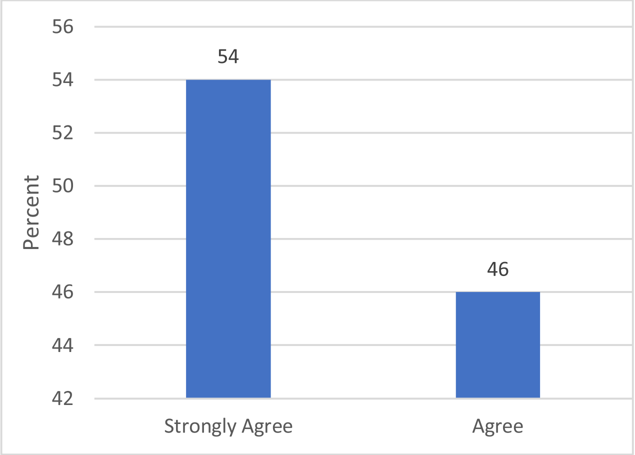

Figure 11: Reduce Economic & Environment pollutant burden which has led to the awareness of reuse and re cycling

All survey participants (54% and 46%) strongly agree and agree on the necessity to lessen economic and environmental burdens caused by pollutants through waste reduction, reuse, and recycling. This unanimous agreement underscores a collective awareness and recognition of the significance of these sustainable practices in reducing environmental impact.

Focus group interview was conducted with the objective of gathering perspectives from different individuals involved in the fashion industry regarding the incorporation of circular fashion practices, with a specific emphasis on upcycling and the utilization of traditional textiles to foster sustainability. The outcome of the focus group indicated a unanimous agreement that integrating circular fashion through upcycling and traditional textiles is not only feasible but also crucial for the industry's future. The participants demonstrated a shared dedication to advancing these practices and emphasized the need for ongoing discussions and cooperation among all stakeholders to facilitate the transition towards a more sustainable fashion industry.

Hence, Crafts, particularly textile crafts, have a higher likelihood of influencing the practical value of consumption among fashion consumers and establishing a positive emotional connection to the product. This emotional attachment leads to prolonged product lifespan through increased usage, thereby aligning consumption with sustainability. The narratives surrounding the origin, heritage, and handmade nature of the product further contribute to the consumer's emotional attachment. Additionally, consumers are aware that their purchase supports livelihood generation for others, enhancing their emotional connection. Craft, therefore, serves as a bridge between contemporary and traditional elements and offers sustainable solutions through slow fashion strategies.

Consequently, prioritizing the circularization of production and utilization processes is crucial in preserving our planet, its environment, and minimizing the depletion of natural resources caused by fast fashion and consumerism.

4. Conclusion

This study underscores the significant role of traditional Indian practices and circular fashion principles in promoting sustainability within the fashion sector. Consequently, the objectives of the emerging circular fashion model aim to shift the linear economy towards more sustainable frameworks. These objectives can be categorized into four key elements of the clothing system: (1) materials, (2) production, (3) usage, and (4) post-usage. The analysis suggests that traditional textiles possess lasting qualities that can support the slow fashion movement. The recycling and upcycling techniques historically utilized in various regions of India play a vital role in ensuring a sustainable future for the Indian textile industry. These practices not only extend the lifespan of products but also generate employment opportunities for millions. By embracing these methods, a clear pathway is established to steer the industry towards enhanced sustainability and environmental responsibility.

5. Acknowledgement

I would like to express my sincere gratitude to my supervisor for his invaluable guidance and support throughout this research. I would also like to thank the fashion industry professionals and artisans who shared their knowledge and experiences. I hope that this work will inspire and contribute to the ongoing conversation about sustainable fashion practices.

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A Study on Antibacterial Finish on Bamboo Fabric using Plant Extract

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Abstract :

Purpose: In response to the rising global interest in natural remedies and the need for sustainable textile practices, this study investigates the potential of medicinal plant extracts as eco-friendly antibacterial finishes for bamboo fabric. The purpose is to explore the utilization of plant extracts not only as natural dyes but also as effective antibacterial agents, aiming to enhance the eco-friendliness and antimicrobial properties of bamboo textiles.

Design/Methodology/Approach: The study employs a comprehensive approach by first assessing the phytochemical composition of Basella alba, Jacaranda mimosifolia D. Don, and Moringa oleifera Lam. Extracts from these medicinal plants are obtained using acetate, methanol, and petroleum ether solvents. Antibacterial activity is evaluated using the EN ISO 20645 test method against Escherichia coli and Staphylococcus aureus. Fabric finishing is conducted by treating bamboo fabric with a solution comprising 1% medicinal plant extracts, 1% acrylic binder, and 0.5% wetting agent, followed by standard finishing techniques.

Findings: The plant extracts contain bioactive substances such alkaloids, flavonoids, terpenoids, phenols, and tannins, according to the phytochemical analysis. When it comes to test microorganisms, methanol extracts have the strongest antibacterial activity. Their inhibitory zones span roughly 16 to 20 mm. Treated bamboo fabric samples demonstrate significant antibacterial efficacy, with inhibitory zones measuring approximately 24 to 28 mm against Escherichia coli and Staphylococcus aureus.

Originality: This study contributes to the area by showing the potential of medicinal plant extracts as both natural dyes and efficient antibacterial treatments for bamboo fabric. The eco-friendly approach to fabric finishing is consistent with the rising need for sustainable textile techniques. Furthermore, including plant extracts into fabric treatments provides a unique method for improving antibacterial capabilities while maintaining environmental sustainability.

Conclusion: The findings highlight the efficacy of medicinal plant extracts to enhance the antibacterial properties to bamboo fabric and bringing up possibilities for the development of environmentally friendly and antimicrobial textiles for wide range of applications.

Keywords: *Antibacterial agent, Bamboo fabric, Basella alba, Jacaranda mimosifolia, Moringa oleifera Lam.*

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1. Introduction

Natural dyes are widely available in India and its subcontinent, with a significant potential for generating a wide spectrum of skin tones while being eco-friendly [1]. A growing understanding of the non-toxic and non-allergic qualities of natural colors, as well as the allergic and toxic effects of some synthetic dyes [2]. In recent times, consumer and textile manufacturers have expressed an interest in natural dyes, citing their manufacturer product need to claim biodegradability, eco-compatibility, therapeutic efficacy, as well as the antibacterial and UV protecting properties [3]. Textiles have long been recognized as a growing substrate for microorganisms, including fungi and bacteria. These bacteria are ubiquitous in the environment. Microbial growth on textiles can have adverse effects on both the fabric and the individual using it. The repercussions consist of the development of unpleasant odors, stains, and discoloration in the fabric, a decrease in fabric durability, and a higher likelihood of contamination. Therefore, it is highly important to inhibit the proliferation of microorganisms on fabrics while they are being used or stored.

Consumers' need for clean clothing has produced a significant demand for antimicrobial textile. Biocidal antimicrobial agents are those that kill bacteria and hinder the

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development of microorganisms, hence preventing odor generation. They are also known as biostatic agents [4, 5]. As a result, it is vital to discover antimicrobial agents with the least impact on human health and the environment. Plant-based antimicrobial substances are more ecologically friendly, safe, and non-toxic than synthetic chemicals, and they suppress bacterial infections. Most botanical extracts consist of bioactive chemicals. One of the most ancient medicine practices with fundamental principle which are developed in India, called as Ayurveda. In India, there are several plants species with medicinal properties [6]. Basella alba is a fast grown leafy vegetable plant with excellent medicinal properties which is cultivated worldwide [7]. The Basellaceae family includes Basella alba. Wine spinach, Malabar spinach, Indian spinach, and Ceylon spinach are some other names for it. The plant's aerial parts, including its leaves and stem, are utilized as edible plants or vegetables in various parts of the world.

The flavorful leaves and stems are used as a vegetable in soups, salads, stir-fries, and as a pot herb in stews [8].B. alba leaves have a greater concentration of terpenoid and alkaloid compounds [9, 10], it is useful in the management of inflammatory diseases like diabetes mellitus, atherosclerosis, stroke, Alzheimer's disease, and heart disease. In Africa, Asia, and the West Indies, spreads widely and grows approximately 5 to 10 meters tall, leave range from 4 to 10 cm in length [11, 12]. Jacaranda mimosifolia is Pioneer tree, belong to Bignoniceae family. J.mimisifolia grows in tropical region and subtropics of the world [13]. J.mimosifolia is cluster of beautiful foliage blue tubular flowers which commonly known as blue trumpet tree [14].Jacaranda mimosifolia showed presence of alkaloids, flavonoids, phenols, saponins and tannins [15]. J.mimosifolia barks has been used in treatment of wound and skin ailments, hypertension, blood purification, eczema, fungal infections and traditional healers [16, 17]. Moringa oleifera Lam. is evergreen or deciduous tree, fast growing upto 10 to 12m height. It is alternatively referred to as the miracle tree, drumstick, tree for life, and horse radish tree [18]. Moringa is a deciduous herb that belongs to the Moringaceae family. It is native to the sub-Himalayan regions of India, Pakistan, Afghanistan, and Bangladesh [19, 20]. It is known for its nutritional properties. The crude methanolic extract of moringa leaves was shown to include phytochemicals such as alkaloids, flavonoids, tannins, polysaccharides, and saponins [21]. M. oleifera is frequently employed in Ayurvedic medicine to address cancer, malaria, typhoid fever, and joint pain [22]. Additionally, it provides assistance to mothers who are breastfeeding and enhances the production of milk after childbirth [23]. Literature demonstrates that these three medicinal plants are utilized in both traditional and modern therapy settings [24, 25 & 26]. The objective of this study is to evaluate the phytochemical composition and antibacterial properties of the extracts. The antibacterial properties of extracts from Basella alba, Jacaranda mimosifolia D. Don, and Moringa oleifera Lam. were tested on bamboo fabric.

2. Review of Literature

In the review article "Antibacterial Potential of Bamboo Extracts: A Comprehensive Review" [27], the authors provide a thorough examination of the antibacterial properties of bamboo extracts. They elucidate the efficacy of bamboo extracts against a broad spectrum of bacterial strains and delve into the underlying mechanisms contributing to their antibacterial activity. By analyzing the presence of bioactive compounds within bamboo extracts and their interactions with bacterial cells, the authors shed light on the multifaceted nature of bamboo's antibacterial potential. Furthermore, they explore potential applications of bamboo extracts across diverse domains, including medicine, personal care, and environmental health, underscoring the versatility and significance of bamboo as a natural antibacterial agent.

In the study "Exploring Medicinal Plants for Antibacterial Activity: A Systematic Review" [28], researchers systematically assess the antibacterial activity of various medicinal plants, including bamboo, synthesizing findings from multiple studies. Through this comprehensive analysis, the authors underscore the effectiveness of plant-derived compounds against pathogenic bacteria and elucidate their mechanisms of action. Moreover, they emphasize the importance of plant-based antibacterial agents as viable alternatives to conventional antibiotics, particularly in the context of combating antibiotic resistance. This systematic review contributes valuable insights into the potential of plant-derived compounds, including those derived from bamboo, in addressing global health challenges associated with bacterial infections.

Similarly, in the review article "A Review of Plant-Derived Compounds with Antibacterial Properties for Biomedical Applications" [29], the authors offer a comprehensive overview of plant-derived compounds with antibacterial properties and their biomedical significance. By examining the diverse array of plant sources and their bioactive constituents, the authors underscore the rich reservoir of antibacterial agents present in nature, including those found in bamboo. Through a critical evaluation of existing literature, they highlight the potential biomedical applications of plant-derived antibacterial compounds, ranging from pharmaceuticals to personal care products. Overall, this review underscores the importance of harnessing the antibacterial potential of plants, such as bamboo, for the development of novel therapeutic interventions and biomedical innovations.

2.1 Research Gap

An area of research that has not been extensively studied in the realm of antibacterial capabilities of bamboo is the investigation of synergistic interactions among its bioactive chemicals. This gap was pointed out by [30]. Although there have been studies on the antibacterial effects of some chemicals, such as flavonoids or phenolic acids, there is a lack of study on how these compounds interact with each other and with bacterial targets to either enhance or inhibit antibacterial activity. [31] Similarly acknowledged this lack of understanding in their examination of antibacterial compounds originating from plants. Examining the combined impact of several bioactive components present in bamboo extracts could yield significant knowledge for enhancing antibacterial compositions and devising more potent remedies for bacterial illnesses. This research should also investigate the potential influence of these products on the development of microbial resistance, as indicated by the findings of [32]. By exploring new possibilities, we could potentially able to make contributions to the development of novel antibacterial properties to textiles produced from plant extracts. These textiles are would possess higher medicinal properties and be more ecologically friendly.

3. Materials and Methods

3.1 Materials

Basella alba, Jacaranda mimosifolia D. Don, and Moringa oleifera Lam. were sourced from several places in the hilly area of Salem, Tamil Nadu, for the study. The plant specimens were identified and verified by the Botanical Survey of India, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. Plants were chosen for their therapeutic and pharmacological characteristics as described in the literature. The taxonomy of the chosen plants listed in Table 1 is shown alongside their corresponding photos in Figure 1. The medicinal herbs are labelled as a, b, and c. The fabric material used in this study is a 180 GSM bamboo fabric with a dobby weave. Figure 2 shows the corresponding image.

Table 1: Taxonomical of medicinal plants

Order	Family	Genus	Species	Common name
Caryophyllales	*Basellaceae* Raf.	*Basella* L.	*Basella alba*	Indian spinach
Scrophulariales	*Bignoniceae*	*Jacaranda* Juss.	*Jacaranda mimosifolia* D. Don	Pioneer tree
Capparales	*Moringaceae* Martinov	*Moringa* Adans.	*Moringaoleifera* Lam.	Drumstick tree

Figure 1: Basella alba (a), Jacaranda mimosifolia D. Don (b), Moringa oleifera Lam. (c)

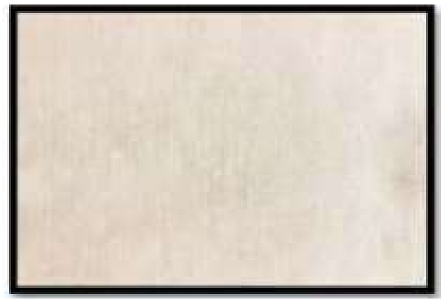

Figure 2: Bamboo Fabric

3.2 Methodology

3.2.1 Solvent methanol extraction

The plant's leaves underwent a process of purification with distilled water, followed by exposure to a temperature of 50°C in an oven for around three hours. Subsequently, they were fragmented into tiny particles and further pulverized into a fine powder utilizing a commercial grinder. The Soxhlet device is a conventional extraction technique that utilizes an infusion-based method. For the extraction process, 100mg of powdered material was poured into a thimble and then extracted in a Soxhlet extractor using multiple solvents. The bag was placed into the gadget. During the extraction process, the methanol solvent was heated, causing it to evaporate and collect in a separate compartment called a thimble. It was then condensed and released into the condenser, which is placed on top. This process is iterated until the syphon arm completely transfers the liquid into the bottom flask, and then it recommences. The collected liquids were concentrated and desiccated at reduced pressure. The desiccated extracts were preserved in sterilized tiny containers at a temperature of 4ºC for future utilization [33].

4. Phytochemical screening of extract

4.1 Presence of Alkaloids [34]

4.1.1 Mayer's test

To detect the presence of alkaloids, gently add drops of Mayer's reagent to 2 ml of extract using the test tube's side. A white or creamy precipitate will appear.

4.2 Presence of Flavonoids Test [35]

4.2.1 Alkaline reagent Test

There is no text provided. A total of 5 mL of extract was mixed with 2 mL of distilled water, followed by the addition of 0.15 mL of a 5% $NaNO_2$ solution. After a duration of six minutes, a volume of 0.15 mL of a solution containing 10% aluminum chloride was introduced and left undisturbed for an additional six minutes. Subsequently, a volume of 2 mL of a solution containing 4% sodium hydroxide was added to the combination. The mixture was rapidly diluted with distilled water and then left to incubate at room temperature for 15 minutes. The presence of flavonoids is indicated by the appearance of a pink hue.

4.3 Presence of Terpenoids Test [36]

4.3.1 Salkowski Test

$C_4H_6O_3$ and concentrated H_2SO_4 were introduced into a 2ml sample of plant material extract. The presence of terpenoids causes the formation of blue-green rings in the formula.

4.4 Presence of Phenolic Test [37]

4.4.1 Ferric chloride Test

Combine 1ml of the extract with 5ml of distilled water in a test tube for the phenol test. The solution exhibited strong oscillations and displayed a consistent, enduring foam. When three drops of phenol are mixed with froth and vigorously shaken, they produce a lasting blue colour.

4.5 Presence of Tannin Test [38]

4.5.1 Ferric chloride Test:

10 milliliters of distilled water mixed with 1 milliliter of extract. Combining 2 ml of filtrate with 2 ml of $FeCl_3$ after filtering the mixture. A blue-black precipitate formed, indicating the presence of tannins.

5. Antibacterial screening of plants extractions treated on bamboo fabric

5.1 Assessment of Antibacterial activity (EN ISO 20645)

Over the past few decades, there has been an increasing worldwide fascination with various herbal plants due to their inherent antibacterial capabilities [39]. Pathogenic diseases caused by bacteria, viruses, fungi, and parasites continue to pose a significant threat [40]. Ensuring a hygienic living environment is crucial for effectively controlling germs [41]. The plant crude extract was prepared from three samples and tested for antibacterial activity using the EN ISO 20645 test method. The test specimens, in the form of swatches, were precisely cut into pieces with a diameter of 20mm. These pieces were then subjected to testing using two standard bacterial cultures. Both test microorganisms maintained in nutrient agar slants. Both test bacteria were cultivated on Nutrient Agar slants in a microbiology laboratory. Table 2 displays the media composition of Nutrient broth and Mueller-Histon agar composition [42]. The inoculation broth tubes were incubated at 37 degrees Celsius for 12 to 24 hours until bacterial growth became turbid. Each test bacterial culture (Escherichia coli and Staphylococcus aureus) was placed onto the Mueller-Hinton agar (MHA) plate and the central region of the petri dish using a sterile 4mm inoculating loop by swabbing the surface.

Every test organism was given a separate Mueller-Hinton agar plate within a sterile area. Following the collection of test microorganisms, the test fabric swatches (including treated and untreated control fabrics) were placed on opposite sides of the MHA plates. The identical procedure was applied to all test samples. The plates containing test swatches were placed in a regular incubator and kept at a temperature of 37°C for a duration of 12 to 24 hours. After the specified incubation period, all test plates were examined for a clearly visible area where the growth of microorganisms was prevented around the treated textiles. The diameter of the zone of inhibition surrounding each fabric sample was quantified in millimeters (mm) and then recorded.

Table 2: Nutrient Broth and Mueller-Hinton agar Composition

	Media Composition	g/L
Nutrient Broth Composition	Peptone	5.0
	Yeast extract	5.0
	Beef extract	3.0
	Sodium chloride	5.0
	pH	7.0 ± 0.2
	Distilled water	1000ml
	Media Composition	**g/L**
Mueller-Hinton agar Composition	Acid hydrolysate of Casein	17.5
	Starch	1.5
	Agar	20.0
	Sodium chloride	5.0
	pH	7.0 ± 0.2
	Distilled water	1000ml

5.2 Method of finishing on fabric

The chosen fabric material was immersed in a standard solution of fresh water for a duration of 20 minutes. The laundered fabrics underwent a thorough rinsing process in flowing water to remove any surface dirt and pollutants. All of the material was delicately compressed by hand and air-dried at ambient temperature. A 1% (10g/L) solution of sodium lauryl sulphate, a non-ionic detergent, was employed to remove any surplus starchy components from the surface of the fabric. Padding was done with 80% wet pick up, at neutral pH, and at room temperature using a solution that contained 1% extract, 1% crosslinking agent (citric acid), and 0.5% wetting agent. After that, it was dried for five minutes at 80°C and cured for two minutes at 120°C. The samples underwent UV disinfection in a controlled airflow chamber for a duration of 30 minutes, followed by storage in a sterile environment for subsequent investigation. Figure 3 contains the relevant photographs of the treated fabric that was retrieved.

a b c

Figure 3: Plant extractions treated on bamboo fabric

6. Results and discussion

Table 3 displays the results of the phytochemical analysis conducted on Basella alba, Jacaranda Mimosifolia D. Don, and Moringa oleifera Lam. Plants possess bioactive compounds such as alkaloids, terpenoids, steroids, phenols, and flavonoids. Basella alba extracts contain alkaloids, flavonoids, terpenoids, and tannin. Flavonoids and phenols were detected in the extracts of Jacaranda mimosifolia. Alkaloids, flavonoids, and phenols were detected in extracts of Moringa oleifera Lam, suggesting the existence of bioactive constituents that exhibit medicinal plant properties.

Table 3: Results of phytochemical screening test

Compound	*Test*	*Basella alba*	*Jacaranda mimosifolia* D. Don	*Moringa oleifera* Lam.
Alkaloids	*Mayer's test*	+	-	+
Flavonoids	*Alkaline reagent Test*	+	+	+
Terpenoids	*Salkowski Test*	+	-	-
Phenol	*Ferric chloride Test*	-	+	+
Tannin	*Ferric chloride Test*	+	-	-

*+ = positive to color test, *- = negative to color test

6.1 Antibacterial assay

The antibacterial characteristics of the methanol extract of the plants were tested, and it was found to have the highest antibacterial activity against Escherichia coli and Staphylococcus aureus compared to the other two solvent extracts. Extracts from Basella alba showed inhibitory zones measuring approximately 20mm and 16mm against Escherichia coli and Staphylococcus aureus, respectively. Extracts from J. Mimosifolia displayed inhibitory zones of about 19mm and 18mm against the same bacteria. M. oleifera extracts demonstrated inhibitory zones of approximately 18mm and 15mm against Escherichia coli and Staphylococcus aureus, respectively. These results are shown in Table 4, Figure 4 and 5 were present the outcomes of the antibacterial screening test conducted on the raw extract of several plants against the examined microorganism. The solvent extract derived from the medicinal plant shown significant efficacy against Escherichia coli and Staphylococcus aureus. The antibacterial capabilities of medicinal plants are most potent in the methanolic extract, surpassing the effectiveness of acetone and ethanol. The study provides evidence that the plant leaves possess antibacterial properties.

Table 4: Antibacterial Screening of Basella alba, J. Mimosifolia and M. oleifera against Escherichia coli and S. aureus

Medicinal plants	Zone of Inhibition against *E. coli* (in mm)			Zone of Inhibition against *S. aureus* (in mm)		
	Petroleum ether (PE)	Methanol (M)	Acetone (A)	Petroleum ether (PE)	Methanol (M)	Acetone (A)
Basella alba	11	20	0	12	16	0
J. Mimosifolia	0	19	13	0	18	10
M. oleifera	14	18	0	12	15	0

The reason for the effective antibacterial activity of herbal extract was keen to identify from the literature source available. The relevance of phytochemical components and other biological substances of Basella alba, J. mimosifolia and M. oleifera that are attributing to antibacterial abilities, antioxidant properties, anticancer properties, etc. were noted in several studies.

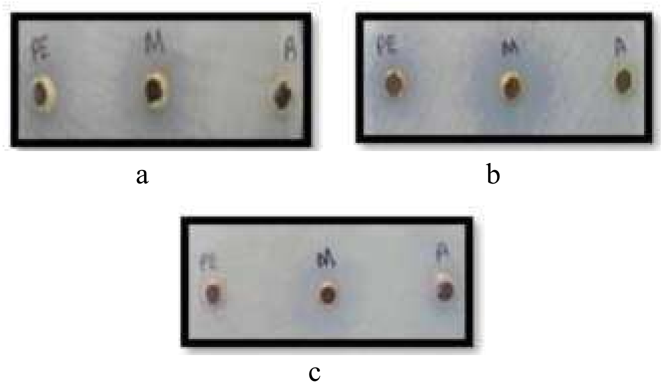

Figure 4. Antibacterial Screening of individual plants against Escherichia coli

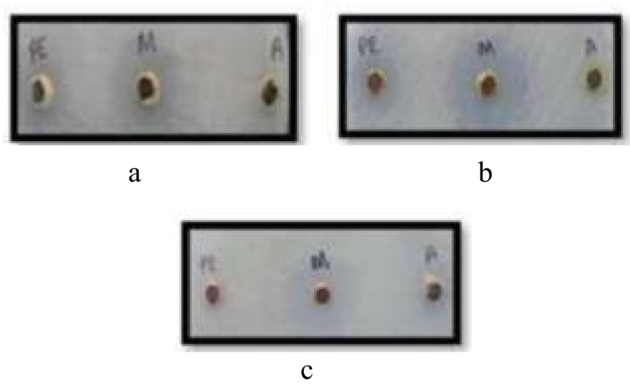

Figure 5: Antibacterial screening of individual plants against Staphylococcus aureus

The study showed a substantial reduction in the growth of both Gram-Negative and Gram-Positive bacteria, resulting in the development of dependable, economical plant products and potential ingredients for wide-ranging antibacterial drugs. The researchers identified several secondary metabolites, including as tannins, terpenoids, alkaloids, and flavonoids, all of which had strong antibacterial properties.

6.2 Antibacterial activity of plant extract treated on bamboo fabrics

The plant extracts applied to fabric samples exhibited significant antibacterial inhibitory zones as detailed in Table 5. Examined samples of treated fabric (F) and untreated fabric (UF) for microbial presence. The Basella alba extract applied to bamboo fabric exhibited inhibitory zones measuring approximately 26mm and 25mm against Escherichia coli and Staphylococcus aureus, respectively. The fabric treated with Jacaranda mimosifolia D. Don extract exhibited inhibitory zones measuring around 26mm and 24mm, while the fabric treated with Moringa oleifera Lam. showed antibacterial activity with zones of 28mm and 25mm against the test microorganisms.

Table 5: Antibacterial activity of plants extraction treated on bamboo fabric

Selected Medicinal plants	Zone of Inhibition (in mm)	
	Escherichia coli	***Staphylococcus aureus***
Basella alba	26	25
Jacaranda mimosifolia D. Don	26	24
Moringa oleifera Lam.	28	25

At a societal level, the investigation into utilizing medicinal plant extracts as natural dyes and antibacterial agents on bamboo cloth offers a sustainable solution to the environmental concerns associated with synthetic dyes. By promoting eco-friendly textile production methods, the research contributes to reducing chemical pollution and environmental degradation, aligning with global efforts towards sustainability. Furthermore, the development of antimicrobial bamboo fabrics addresses consumer demands for safer and healthier textile options, potentially mitigating the risk of bacterial infections and improving overall well-being. For the research community, this study represents a valuable contribution to the field of textile science and pharmacology. By analyzing the phytochemical composition and antimicrobial properties of medicinal plant extracts on bamboo fabric, researchers gain insights into novel applications of natural compounds in textile production. This interdisciplinary approach fosters collaboration between textile scientists, pharmacologists, and microbiologists, leading to a deeper understanding of the potential therapeutic benefits of medicinal plants in textile applications. Additionally, the study opens up avenues for further research into biomedical textiles and antimicrobial fabrics, driving innovation and knowledge advancement in these fields. Within academia, the findings of this research enrich the existing body of knowledge on natural dyeing techniques and sustainable textile production methods. By documenting the phytochemical analysis, antioxidant properties, and antibacterial effects of medicinal plant extracts on bamboo fabric, the study contributes to academic discourse on environmentally friendly textile innovations. Moreover, it underscores the importance of interdisciplinary research approaches in addressing complex societal challenges, such as environmental sustainability and public health. As such, the research serves as a catalyst for future studies exploring the intersection of textile science, pharmacology, and microbiology, ultimately driving progress and innovation in these interconnected fields.

7. Conclusion

The study focuses on the rise of natural dyeing in the textile sector and evaluates the antibacterial properties of medicinal plants such Basella alba, Jacaranda mimosifolia D. Don, and Moringa oleifera Lam. These plant extracts are applied to bamboo fabric. Basella alba leaves were found to contain alkaloids, flavonoids, terpenoids, and tannins through phytochemical examination. Flavonoids and phenols were identified in the foliage of Jacaranda mimosifolia D. Don. The leaves of Moringa oleifera Lam were discovered to contain alkaloids, flavonoids, and phenols. The medicinal plants demonstrate significant antibacterial activity against Escherichia coli and Staphylococcus aureus. The study suggests that cloth, which has been treated with plant extract, has the potential to be transformed into biomedical and home textile goods that are standardized, safe, and cost-effective.

7.1 Limitation of the study

The limitations of this study encompass several aspects. Firstly, the research has a narrow focus on only three specific medicinal plants (Basella alba, Jacaranda mimosifolia D. Don, and Moringa oleifera Lam.), which may not fully represent the diversity of plant-based natural dyes and antibacterial agents available in nature. Consequently, the findings may not be generalizable to other medicinal plants with potentially different chemical compositions and properties. Secondly, the study's reliance on a limited range of solvents (acetate, methanol, and petroleum ether) for extracting bioactive compounds from the medicinal plant leaves may have overlooked alternative extraction methods that could yield different results. By investigating alternative solvents or extraction methods, a more thorough comprehension of the bioactive chemicals found in plants and their potential uses in textile manufacturing could be achieved. In addition, the study evaluated the antioxidant and antibacterial characteristics of the medicinal plant extracts against specific microorganisms (Escherichia coli, Staphylococcus aureus, Candida albicans, and Candida tropicalis). However, it did not examine their effectiveness against a wider range of pathogens or take into account potential differences in antimicrobial activity depending on geographical location, plant growth conditions, or seasonal variations. Finally, the study's findings and conclusions are based on laboratory experiments and may not fully reflect real-world conditions or practical challenges associated with scaling up the production of antimicrobial bamboo fabrics using medicinal plant extracts. Further research involving pilot-scale production and field trials would be necessary to assess the feasibility, scalability, and economic viability of implementing such processes in industrial textile manufacturing.

7.2 Conflict of interest

No conflict of interest

7.3 Funding source

Authors report no financial support from any funding agency or institution

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Significance and Factors Contributing to the Popularity of the Indian Carpet Industry

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Abstract

Carpet art holds a unique and significant place in the material culture of all Central Asian peoples, reflecting centuries of tradition, skill, and aesthetic values deeply embedded in the region's history. Carpet weaving in Central Asia dates back thousands of years and is deeply intertwined with the nomadic and semi-nomadic lifestyles of the region's peoples. Historical evidence suggests that carpet-making began as early as the Bronze Age, evolving through interactions with various cultures and empires, including the Persian, Mongol, and Ottoman empires. Each Central Asian nation, from Turkmenistan and Uzbekistan to Kazakhstan, Kyrgyzstan, and Tajikistan, boasts distinctive carpet styles that serve as cultural identifiers. These carpets are not merely decorative items but carry profound symbolic meanings, encapsulating stories, beliefs, and traditions passed down through generations. The editorial aims to provide a detailed description of Indian Handmade carpets. It indicates the technical, patterned, and decorative attributes of the Indian carpets. The paper provides an overview of the significance of Carpets historically and in the new times. Carpets are believed to be integral to important life events such as weddings, funerals, and festivals. Carpets are often given as dowries, symbolizing the weaver's skill and the family's status. They also serve as a form of communication and expression, with each piece encapsulating the weaver's identity and the community's collective memory.

Keywords: *Carpet, cultural identifiers, cultural identifiers, Indian, significance, weaving*

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1. Introduction

Carpet art holds a unique and distinguished place in the material culture of all Central Asian peoples. It is a distinct category of applied craftsmanship with its own rich customs and traditions, rooted in a centuries-old history of carpet weaving. Throughout history, carpets have not only served as important symbols of status but also as valuable assets for survival and prosperity. Even today, in many rural households, well-being is often measured by the ownership of carpets and kilims. For households recovering from years of asset depletion, the first sign of rebuilding wealth is often the acquisition of a carpet, even if it is a machine-made Iranian one.

In the international market, carpets hold a complex value system. For some, their worth is more artistic, appreciated as works of art with aesthetic appeal. This artistic value can sometimes conflict with their functional use or be viewed as an investment. However, investing in carpets can be challenging, as they do not offer an annual return, take time to appreciate in value enough to offset transaction costs, and may lose value with use.

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The Persian style of carpet weaving originated in Iran, historically known as Persia. The earliest documented evidence of Persian carpets appears in Chinese texts from the Sassanid dynasty (224-641 AD). During the Islamic era, Persia remained a major center of carpet production, continuing its global renown into the 8th century A.D. Historical records mention that every year, up to 600 carpets were sent as tribute to the caliphs' courts in Baghdad from regions such as Azerbaijan, Tabarestan, Khorasan, Sistan, and Bukhara, all part of Iran [1].

In contemporary times, the popularity of Indian carpets can be attributed to a multitude of factors. Key among them are the exceptional craftsmanship and the use of high-quality natural materials, which together ensure durability and aesthetic appeal. The industry's ability to adapt traditional techniques to modern tastes and the growing demand for artisanal and handcrafted goods in international markets have further amplified its reach [2]. Additionally, the industry's robust export strategies, coupled with effective marketing and branding initiatives, have played a crucial role in enhancing its global footprint.

This paper aims to systematically examine these factors, providing insights into the socio-economic and cultural dynamics that have influenced the growth and international acclaim of the Indian carpet industry. Through a comprehensive analysis of historical trends, market drivers, and consumer preferences, this study seeks to offer a nuanced understanding of why Indian carpets continue to captivate and sustain global interest.

2. Literature review

India is the biggest fabricator and exporter of hand-knotted carpets when we talk about value and volume but 90% of the carpets made in India are exported. There is a huge demand for Indian carpets globally because of outstanding design, appealing colours, and excellence. The wool fabricated in the north-west territory of the nation is most appropriate for carpet manufacturing as it provides excellent pile coverage, hand, and resiliency to carpet [3].

Indian carpets and rugs have been traced back to as early as 985 CE, with evidence suggesting that Mahabalipuram was one of the oldest production centers in the country. In the 16th century, Mughal Emperor Babar (1526-30) imported carpets from Turkey and Persia, which helped establish the art of carpet weaving in India. This tradition, introduced by the Mughals, continued to flourish and spread throughout the region. Mughal emperors frequently commissioned skilled artisans to create magnificent carpets for their palaces and courts [4]

A country with a populace possessing both skill and inclination toward crafts holds substantial potential for growth. Participation in such activities not only generates employment but also fosters socio-economic advancement. The handmade carpet industry exemplifies this potential for socio-economic growth, not only for individual nations but also on a global scale. The carpet industry as a prime example of leveraging India's comparative advantage, particularly its abundant labor force [5].

What began as a cottage industry has evolved into a robust manufacturing sector and a significant export earner for India. Through coordinated efforts by bodies like the Carpet Export Promotion Council (CEPC) and government authorities, the challenges faced by manufacturers and exporters in this sector can be addressed, leading to improvements in rural employment. This industry offers viable employment options for the rural uneducated populace, thus serving as a crucial avenue for occupation. Recognizing its employment potential, the carpet industry deserves substantial support to maximize the benefits of an export-led growth strategy [6]

In Indian literary circles, there's a growing body of recent research delving into micro-level analysis using household or individual data, often employing statistical or econometric methods. These studies aim to unravel the rationale and processes behind participation in various industries. Surprisingly, there's been scant investigation into carpet weaving at the household level in West Bengal.

In 1851, handmade carpets gained widespread recognition in Indian history for their outstanding quality, intricate designs, skilled weaving, and vibrant color palettes during the renowned London exhibition. After the British colonial period, the carpet industry saw a revival across various parts of India, with notable differences in design, color, quality, weaving techniques, and materials. Over time, carpet weaving spread throughout the Indian subcontinent, with different regions cultivating their own distinctive styles and methods, enriching the legacy of Indian carpet craftsmanship [7].

Furthermore, there remains a significant gap in understanding how this type of employment interacts with and impacts rural poverty at the household level, as this connection has yet to be thoroughly explored and established.

3. Materials & Methods

The study's purpose is to provide an overview, significance and influences on the popularity of the Indian Carpet industry. This study is established based on data collected from secondary sources. A literature review was conducted to analyse consumer and manufacturing initiatives, as well as technological advancements over the past few decades, in order to understand the significance and evolution of carpets and rugs.

4. Results and Discussion

4.1 History of Carpets in India

Studies on Mughal carpets often begin by exploring the historical context in which these remarkable creations emerged. Researchers focus on the Mughal Empire's patronage of the arts, particularly carpet weaving, as a reflection of power, prestige, and cultural identity. They examine the influence of Persian, Central Asian, and Indian artistic traditions on Mughal carpet design and production, tracing the evolution of styles and motifs over time. Scholars also investigate the significance of royal workshops and the role of skilled artisans in crafting carpets for the Mughal court and elite patrons [8].

In 1851, Indian handmade carpets gained international recognition for their quality, design, weaving techniques, and color palette at the Great Exhibition in London. Following the British era, the Indian carpet industry experienced a revival, with regional variations in design, color, quality, weaving methods, and materials contributing to its renewed success.

Over time, carpet weaving spread across the Indian subcontinent, with various regions developing their own unique styles and techniques. The royal patronage, growing demand, and widespread admiration during this period transformed the carpet industry from a modest craft into a thriving small-scale industry, producing innovative designs and styles. One of the most notable examples is the depiction of natural-looking flowering plants arranged in outlines or rows against a bare backdrop. Evidence of carpet making from the 17th century onward suggests that royal patronage of weaving centers may have declined due to socio-political conflicts [9]. However, some royal workshops remained active, as seen when Mughal emperor Aurangzeb appointed an official to oversee carpet weaving for the royal family. During this period, Deccan, Bharatpur, Jaunpur, and Zafrabad emerged as major centers of carpet production, although the designs and patterns of the carpets remained unchanged.

Royal patronage and workshops continued under Akbar's successor, Jahangir, with Agra developing into a commercial center for carpets by the seventeenth century. Under Jahangir's investment, artisans like Akhund Rahmuna, who briefly served as the governor of Kashmir, traveled to Central Asia to learn carpet making in Andijan, Uzbekistan. They brought these skills back to Kashmiri weavers, transforming Kashmir into a hub of carpet production. Carpets from this period featured Central Asian influences, incorporating motifs such as trees, hills, lakes, fish, and wild animals [10].

Over the centuries, carpets have been used in numerous ways. Intricately decorated carpets were primarily used as ornamental floor coverings in imperial courts and religious buildings such as mosques and shrines, as well as seating for guests at community events. They also served as luxurious gift coverings in royal courts. Lower-quality floor coverings, known as dhurries, were used by the community at home or in public spaces [11].

India's extensive heritage of carpet design and production has resulted in a diverse array of carpet styles and practices, including kaleen, gabba, khabdan, and galeecha. Knotted carpets from Mirzapur, Bhadohi, Agra, Bomdila, Machilipatnam, Varanasi, and Warangal, as well as Tibetan carpets from Kullu, Ganjam, Darjeeling, and Dehradun, have all gained popularity.

4.2 Current State of the Indian Carpet Industry

Today, India is one of the world's second-largest makers of carpets and the biggest of handmade carpets. These are woven in many different styles and designs, and motifs vary from the traditional naturalistic to stylized and very modern and chic.Indian carpets are identified with their elaborate motifs and vibrant colors [12].

They are created using a variety of materials, often wool, silk, and cotton. These are generally hand-knotted and each knot in these carpets is tied by hand. The raw materials used for making carpets are typically wool, with the warp and weft made of cotton. In regions like Kashmir, silk carpets are also produced.. Indian carpets are primarily made using roller-beam looms. Using the two-knot or double-knot technique, the weaver forms a coarse substance called a selvage, onto which the carpet's end knots are reinforced.

Only Indian carpets use the asymmetrical Persian knot, which involves tying a yarn strand across two adjacent warp threads. The kind and quantity of knots in these rugs define its fineness. As they are knotted, handmade carpets are rolled back into the loom. Repeating designs such as florals, palmettes, geometric forms, the tree of life, and occasionally animals can be found on these carpets. Furthermore, landscapes are a common motif in Indian carpets [13].

Currently, Indian carpet industry is predominantly export-oriented, targeting selling in Europe, USA, Middle East , Australia, Turkey, Japan etc. Remarkable assortments that showcasing Indian carpets at the Victoria & Albert Museum, London; the Metropolitan Museum of Art, New York; Calico Museum of Textiles, Ahmedabad; Maharaja Sawai Ram Singh II Museum, Jaipur etc speak volumes of Indian Carpetry [14].

4.3 Reasons for the growing demand for Carpets

The Carpets considered to be outstanding preferences for augmenting aesthetics of domestic as well as industrial areas, especially in Europe and America. Seemingly, expanding demand for these home flooring merchandise can be ascribed to numerous key factors, which comprise the following:

a. Suburbanization: with the suburban area growing, the challenge for carpets experiences a noteworthy rise. These versatile carpets are benefited for their capability to alter staying and working spaces and make them comfortable

b. Expanding structures: The expansion of the carpet market is greatly aided by the construction sector. Carpets are thought to be crucial components for new urban constructions' interior design since they improve the atmosphere and comfort level overall.

c. People of the Middle Class: Due to promptly growing middle-class population, there is a mounting appeal for well-well-resourced households. Carpets are significant factors in establishing relaxing and fashionable residing spaces.

d. Furniture demand: The up surging need for furniture dwellings that propose complete answers for interior decoration is growing. Carpeting works as decisive add-ons to these arrangements, emphasizing the general charm of the furniture.

e. Lifestyle deviations: As people's tastes and lifestyles change, carpets are becoming more and more valued as necessary elements of interior design. In addition to providing comfort, carpets allow homeowners to express their individual tastes and styles.

f. Varied Design Selection: The wide variety of designs found in Indian carpets is a key factor in their worldwide appeal, providing a vast selection of patterns, styles, and motifs that cater to different tastes and preferences. This diversity not only showcases the abundant cultural legacy of India but also exemplifies the flexibility and creativity within the business. Indian carpets frequently showcase elaborate patterns influenced by Persian and Mughal artistic styles. The themes include intricate flower designs, vines, and medallions, which showcase the magnificence and luxury of past royal courts. India's indigenous and traditional customs play a significant role in the creation of a diverse range of distinctive carpet patterns. These patterns frequently incorporate geometric forms, animal depictions, and symbolic motifs that narrate tales and communicate cultural importance [15].

In modern and contemporary designs, the Indian carpet business has skillfully adjusted to current design trends, manufacturing carpets with abstract and minimalist designs. These designs frequently incorporate sleek lines, understated color schemes, and inventive materials, rendering them well-suited for contemporary interiors and attractive to a younger audience. Fusion designs combine old motifs with modern components, resulting in a distinctive look that connects the worlds of classic and trendy. The wide variety of designs found in Indian carpets is evidence of the industry's capacity to adjust and innovate. The Indian carpet business continues to capture a global audience by providing a diverse range of patterns that combine traditional craftsmanship with modern aesthetics [16]. The wide range of styles and patterns found in Indian carpets not only adds to their attractiveness but also assures their significance in a constantly changing market, establishing their position as a fundamental element in both traditional and modern interior design.

4.4 Global Admiration

Indian handmade Carpets and Carpet and rugs are extremely valued around the world for their unique aesthetic appeal and craftsmanship. This admiration is reflected in the extensive role that India plays in global exports of handmade Carpets and rugs. The distinctive patterns, vibrant colors, and meticulous techniques used in Indian carpets and rugs make them sought after in various international markets.

4.5 Export Reach

India exports handmade Carpets and Carpet and rugs to over 70 countries, demonstrating the global demand and reach of its Carpet and rug-making industry. The primary importers of our ethnic Woven Carpets consist of USA, Canada, Europe, Australia, South Africa, Brazil etc. These countries appreciate blend of tradition and quality that Indian Carpets and rugs represent, leading to a steady demand in these markets [17].

4.6 Impact of Globalization

The advent of globalization has substantially expanded prospects for the Indian carpet market. This global interconnectedness has facilitated:

1. Market Expansion: Indian Carpet and rug makers can now reach a broader audience, tapping into new markets and demographics.

2. Increased Trade: Trade agreements and international collaborations have made it easier for Indian carpets and rugs to be exported worldwide.

3. Innovation and Adaptation: Exposure to global trends has encouraged Indian Carpet and rug makers to innovate and adapt their designs to meet diverse consumer preferences.

4. Enhanced Quality and Standards: To compete globally, Indian Carpet and rug manufacturers have continually improved their quality standards and adopted sustainable practices.

4.7 Economic Significance

The export of handmade Carpets and Carpet and rugs is not only a source of cultural pride but also a significant contributor to India's economy. The industry supports millions of artisans and craftsmen across the country, providing employment and sustaining traditional skills.

4.8 Influence of carpet weaving on the daily lives of artisans and their communities

This exploration could shed light on the following aspects:

4.8.1 Economic Impact on Artisans

While the economic data typically focuses on income levels, sales, and market trends, understanding the day-to-day experiences of artisans can offer a richer narrative. The labor involved in weaving carpets is a primary means of livelihood, offering artisans a sense of economic independence and sustainability.

4.8.2 Cultural and Social Significance

Beyond the financial aspects, Indian carpet weaving often holds deep cultural significance for artisans. Many artisans belong to traditional weaving communities, and carpet weaving may be passed down through generations. This practice fosters strong family bonds and a sense of cultural pride. The artisans' emotional connection to the craft provides a more personal, emotional dimension to the craft and reveals their heritage and identity.

4.8.3 Skill Development and Empowerment

Carpet weaving is often a learned craft that takes years of practice. The process of mastering weaving techniques empowers artisans with valuable skills that can have wider implications, such as increased access to new opportunities, recognition in national and international markets, and the ability to train future generations. The Indian carpet making industry plays a crucial role in skill development and empowerment, particularly for artisans in rural and semi-urban areas. The traditional art of carpet weaving involves a combination of intricate techniques, creativity, and craftsmanship, passed down through generations.

4.8.4 Community and Economic Networks

Many carpet weaving communities are part of larger networks that include suppliers of raw materials, transporters, traders, and other stakeholders. These networks help to strengthen local economies, as artisans often rely on local resources for weaving. The Indian carpet making industry is not just a means of livelihood for individual artisans but also a significant driver of community and economic networks. These networks play a crucial role in the success and sustainability of the industry, as they connect various stakeholders, facilitate the flow of resources, and enable the growth of local economies.

4.8.5 Challenges and Struggles

He challenges faced by artisans in the Indian carpet-making industry—ranging from fair pay and health risks to fluctuating demand and inadequate infrastructure—highlight the need for systemic change and support. Addressing these issues requires a multi-faceted approach, including fair wages, improved working conditions, access to healthcare, better training opportunities, and greater market access. By supporting the well-being of artisans and addressing these challenges, the industry can continue to thrive while ensuring sustainable livelihoods for the artisans who preserve its rich cultural heritage.

4.8.6 Environmental and Social Responsibility

Many artisans use natural dyes and locally sourced materials, making their work inherently more sustainable than mass-produced goods. However, this can also come with environmental and social challenges, such as ensuring the sustainability of resources or addressing any negative impacts on the community from industrialization.

4.9 India's Leadership in Handmade Carpet and rugs

India stands at the forefront of the handmade Carpet and Carpet and rug industry, both in terms of its production capacity and value. This leadership position is a testament to India's rich heritage and skilled craftsmanship in Carpet and rug making. The country's handmade Carpets and rugs are renowned globally for their intricate designs, high quality, and cultural significance. It is very pertinent to mention that 90% of the carpets and rugs produced in India are exported. In the later part of 2019, India's trades of handcrafted Carpet the global carpet market is expected to expand at a compound annual growth rate (CAGR) of 4.6% from 2024 to 2029, from USD 67.73 billion in 2024 to USD 84.81 billion. It is anticipated that the rug market will grow to INR 64,407.19 crore .The global carpet market has experienced significant transformations in recent years, driven by various factors that have collectively enhanced its competitiveness and growth potential. Here is a more detailed exploration of these changes [18].

India's Leadership in Handmade Carpets and Rugs is due to the following factors:

4.9.1 Cost Efficiency: Advances in manufacturing technologies and supply chain optimization have led to reduced production costs, allowing companies to offer carpets at more competitive prices. Economies of scale, improved raw material sourcing, and automation have all contributed to this trend.

4.9.2 Rapid Delivery: There have been Enhancements in logistics and distribution networks that have enabled faster delivery times. Innovations in transportation and inventory management systems, along with the use of real-time tracking technologies, ensure that products reach customers more quickly and efficiently.

4.9.3 Quality Upgrades: Technological advancements have improved the quality of carpets, ensuring better durability, texture, and design precision. Techniques such as digital printing and enhanced fiber treatments have raised the standards of carpet manufacturing.

4.9.4 Sustainability: Increasing consumer awareness and demand for sustainable products have prompted the industry to adopt eco-friendly practices. The use of recycled materials, sustainable sourcing of raw materials, and energy-efficient manufacturing processes are becoming standard. Additionally, industry stakeholders are focusing on producing recyclable rugs, minimizing waste, and reducing the environmental impact [19].

4.9.5 Innovative Technologies: The adoption of new technologies has revolutionized various aspects of the carpet industry. These include:

4.9.5.1 Inventory Management: Advanced systems leverage data analytics and AI to optimize stock levels, minimizing overproduction and waste while ensuring product availability.

4.9.5.2 Real-Time Monitoring: IOT devices and smart sensors provide real-time data on manufacturing processes, allowing for immediate adjustments and improvements in efficiency.

4.9.5.3 Efficient Manufacturing Cycles: Automation and robotics streamline production processes, reducing human error, and increasing output rates. This results in higher productivity and lower operational costs.

4.9.5.4 Supply Chain Optimization: Technologies such as blockchain enhance transparency and traceability in the supply chain, improving reliability and trust between manufacturers, suppliers, and customers.

4.9.5.5 Antimicrobial and Antiallergic Carpets: Health-conscious consumers drive demand for carpets with antimicrobial and antiallergic properties. These carpets are treated with special chemicals or use materials that prevent the growth of bacteria, mold, and allergens, contributing to a healthier indoor environment.

4.9.5.6 LED Mats: The introduction of LED technology into carpets and mats represents a significant innovation. LED mats can be used for decorative purposes, interactive floor displays, or even safety features in public and private spaces. These high-tech carpets offer unique functionalities that cater to modern consumer needs and preferences.

5. Comparative analysis with other carpet-producing countries

Comparative analysis of India's carpet industry with other prominent carpet-producing countries highlighting the key aspects of carpet industries

Table 1 - Comparative analysis with other carpet-producing countries

S. N.	Aspect	India	Iran	Turkey	China
1	**Raw Material**	Wool, silk, cotton, recycled materials	High-quality wool and silk	Premium wool, synthetic fibers	Synthetic materials for mass production
2	**Production Methods**	Combination of traditional and modern (CAD integration)	Predominantly traditional handwoven methods	Semi-industrialized with mechanized production	Dominated by machine-made carpet manufacturing
3	**Market Orientation**	Export-driven; key markets in U.S., Europe, and Middle East	Luxury segment; limited access due to sanctions	Mid-range to premium; strong presence in Europe	Mass-market focus; affordability-driven
4	**Cost Competitiveness**	Cheap	Expensive	Very expensive	Very cheap
5	**Sustainability Focus**	Increasing focus on recycled materials and circular economy	Minimal focus; traditional methods dominate	Moderate eco-friendly practices	Limited sustainability practices; reliance on synthetic materials
6	**Challenges**	Fragmented industry, weak branding, and limited luxury penetration	Trade sanctions, competition from cheaper alternatives	Rising labor costs, competition in mid-range segments	Overdependence on synthetic, machine-made carpets

5.1 Detailed Technological Examples

Technology has profoundly transformed the carpet business, improving design accuracy, manufacturing efficiency, and sustainability. In Bhadohi, India, tools like CAD facilitate complex design workflows, while digital printing employed by firms like Milliken allows for customizable and environmentally sustainable carpets. Automation, shown as robotic tufting in Turkey, enhances production velocity and uniformity. Recycling efforts, such as Interface's Re Entry program, and the use of eco-friendly materials by Ege Carpets promote sustainability. Jaipur Rugs utilizes blockchain technology to guarantee transparency and equitable trading practices, while e-commerce platforms provide direct connections between artists and worldwide marketplaces. Shaw Industries employs AI to forecast market trends, therefore reducing waste and enhancing customer attractiveness. These developments integrate heritage with modernity, ensuring the industry's worldwide competitiveness.

5.2 Market Dynamics and Growth Opportunities

5.2.1 Competitive Landscape

The carpet market has become increasingly competitive, with companies striving to differentiate themselves through innovation, quality, and sustainability. Strategic alliances, mergers, and acquirements are prevalent as companies aim to expand their market presence and enhance their capabilities [20].

5.2.2 Consumer Trends

There is a growing preference for customized and personalized carpets. Advances in digital printing and design software enable manufacturers to offer bespoke products tailored to individual tastes and requirements.

5.2.3 Global Expansion

Emerging markets present significant growth opportunities for the carpet industry. Rising disposable incomes, urbanization, and evolving lifestyle preferences in regions like Asia-Pacific, Latin America, and the Middle East are driving demand for high-quality carpets [21].

5.3 Industry Commitment

5.3.1 Stakeholder Engagement

Industry stakeholders, including manufacturers, suppliers, and retailers, are committed to continuous improvement and innovation. Collaborative efforts focus on research and development, sustainability initiatives, and enhancing customer experiences.

5.3.2 Regulatory Compliance

Adherence to environmental regulations and standards is crucial. Companies are investing in green technologies and practices to comply with international and local regulations, further promoting sustainability.

6. Conclusion

In conclusion, the global carpet market is undergoing a dynamic evolution characterized by optimal pricing, enhanced delivery systems, superior quality, and a strong emphasis on sustainability. Technological innovations and new product developments are at the forefront of this transformation, driving growth and creating new opportunities in an increasingly competitive landscape.

7. Future Prospects

With globalization continuing to create new opportunities, the Indian Handmade Carpet and rug industry is poised for further growth. Embracing modern technology, enhancing design capabilities, and maintaining high-quality standards will be crucial for sustaining and expanding India's leadership in the global market for handmade Carpets and rugs. India's carpet business is a cottage industry reliant on labor in rural areas. Indian silk rugs and carpets are quite popular among consumers and weavers due to its uniqueness, vivid colors, excellent craftsmanship, detailed patterns, and longevity. However, because more synthetic materials are being used, it is anticipated that the market for tufted carpets and rugs will grow, which make them more affordable and less labor-intensive to produce. As consumer preferences evolve in the international market, there is a growing trend towards washable and cheaper carpets and rugs.

In recent years, there have been major changes to the worldwide carpet market. High quality, quick delivery, and competitive price have bolstered the worldwide market. In the fiercely competitive carpet business, technological innovations propelled by sustainability will be the principal development engine. Stakeholders in the industry are dedicated to creating recyclable, economical, and high-quality carpets and rugs. The implementation of cutting-edge technologies has enhanced supply chain optimization, efficient manufacturing cycles, real-time monitoring, and inventory management. In addition, the carpet industry now has more room to expand thanks to the advent of LED mats and antimicrobial and antiallergic technologies.

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APPAREL

Sustainable Apparel Purchase Intention: Influence of Branding on Indian Consumers

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Abstract:

Background: Sustainable apparel which combines ethical production with environmental responsibility, has become an integral part of the global fashion industry. This evolution reflects increasing consumer demand for products that reduce environmental harm while upholding social accountability. As the textile sector faces heightened scrutiny over its environmental footprint, sustainable apparel provides a pathway for aligning industry practices with global sustainability objectives. This study explores how branding influences consumer purchase intentions for sustainable apparel.

Method: An empirical study was conducted based on data gathered from 210 consumers in Delhi NCR who consistently buy sustainable apparel. SPSS 26 was used to do regression analysis.

Results: These results underscore the critical value of branding in shaping consumer choice and propelling eco-friendly purchasing behaviors. Focusing on branding, the article fills a gap in the current literature, where more research accounts for issues of cost and functionality vis-a-vis other concerns such as sustainability. The findings show that sustainable brands should invest in being perceived as authentic and trustworthy, to win loyalty. Effective communication and powerful sustainability stories are critical to align with changing consumer values.

Conclusion: This body of study offers new insights for businesses, marketers, and policymakers, underlining the integration of branding strategy with sustainability that targets responsible consumption and supports larger societal and environmental goals.

Keywords: *Branding, brand authenticity, brand reputation, purchase intention, sustainable apparel*

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1. Introduction

The apparel industry has greatly contributed to global environmental concerns and fast fashion has been the focus of all sustainability discussions. Consumers are becoming increasingly aware of their choices and their impact on the environment. Hence there is an influx of products that are sustainable and more environment-friendly. On the other hand, however, despite this growing awareness, traditional aspects like price, quality, style, and fit are still key influencers of most purchase decisions. It is a challenge for sustainable apparel brands to meet customer expectations on these conventional considerations [2, 11].

Branding has emerged as a key tool for influencing consumer behavior, particularly in sectors where differentiation is vital. A strong brand can foster trust, create emotional connections, and signal reliability and quality. This is especially important in the sustainable apparel market, where unfamiliarity with eco-friendly materials and processes can complicate purchasing decisions. Consumers often rely on brand cues, such as reputation and authenticity, to guide their choices, especially when a brand is perceived as a leader in sustainability. Despite the growing interest in eco-friendly fashion, the influence of branding on purchase intentions for sustainable apparel remains underexplored. The influence of branding attributes on the purchase intention of sustainable products is underexplored and a smaller number of studies examined the branding variables in the sustainable category [4, 7, 8, 9].

This paper investigates the influence of branding factors such as brand strength, reputation, and authenticity on consumers' purchase intentions of sustainable apparel. It assists in understanding the drivers of sustainable shopping behavior. Knowledge of the role of branding in consumer choice is thus pertinent to the business community, as well as policymakers who wish to encourage more sustainable consumption. This study fills an important gap in existing literature by highlighting how branding can be a strategic tool to encourage sustainable fashion choices. Therefore, the three objectives of this study are:

RO1: To examine the influence of brand strength on consumer purchase intention for sustainable apparel.

RO2: To examine the influence of brand reputation on consumers' purchase intention for sustainable apparel.

RO3: To examine the influence of brand authenticity on consumer purchase intention for sustainable apparel.

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2. Review of Literature and Hypothesis Development

The increased pressure on the apparel industry to reduce its negative environmental and social impact highlights the importance of research in sustainable apparel. Prior work has focussed on the role of factors like cultural influence, price sensitivity, environmental concern, and perceived value in consumer decision-making. However, the aspect of branding in the context of sustainable apparel consumption remains largely unexplored. This literature gap thus calls for further research into the sustainability factors that influence consumer choice in the sustainable apparel and textile industry [1, 3, 5 & 10].

2.1 Brand Strength

Brand strength encompasses brand recognition, loyalty, trust, and perceived quality, which are important consumer behavior aspects. In the sustainable apparel and textile sector, brand strength has attracted considerable attention as consumers increasingly search for brands that satisfy their demands and underpin their green and ethical values. For example, the sustainable apparel brand 'Patagonia', is having high consumer loyalty due to consistently demonstrating leadership in environmental activism, high-quality outdoor clothing, and transparent supply chain practices. Having a unique brand identity based on sustainability can build trust and loyalty. Hence, it is hypothesized that:

H1: Brand strength significantly and positively influences consumer purchase intention for sustainable apparel.

2.2 Brand Reputation

Brand reputation is the overall perception related to the reliability and quality of the brand as well as whether it stands behind its values, including sustainability. Research indicates that consumers buy from a brand they view positively in terms of ethics and sustainable practices, where trust is a critical success factor for the marketplace. . The brand openly shares details about its factories, production costs, and environmental impact. For example, the sustainable apparel brand 'Stella McCartney' is synonymous with high-end, sustainable fashion, earning a stellar reputation among both consumers and industry experts. The brand combines luxury with ethical practices, standing out in a market often criticized for unsustainable practices. The influence of brand reputation on sustainable apparel purchase intention underlines its relevance as a driving force of consumer behavior. Hence, it is hypothesized that:

H2: Brand reputation significantly and positively influences purchase intention for sustainable apparel.

2.3 Brand Authenticity

Brand authenticity is how authentic and transparent a brand is, about its values, more so in terms of sustainability. Authenticity can create trust and emotional engagement on the part of the consumer, especially when brands make some clear commitments toward sustainability. For example, the sustainable apparel brand 'Everlane' is celebrated for its transparency and commitment to ethical manufacturing, and 'Anokha Bandhan' is having the green certifications embodying brand authenticity and emphasis on modern essentials made with sustainable materials like organic cotton and recycled polyester. In the sustainable apparel industry, authenticity is a tool for brands to differentiate and convince the consumer that the brand is serious about both environmental and social responsibility. Hence, it is hypothesized that:

H3: Brand authenticity significantly and positively influences consumer purchase intention for sustainable apparel.

Together, these hypotheses explore the pivotal role of branding in shaping sustainable consumer behavior, emphasizing how strength, reputation, and authenticity can drive the adoption of eco-conscious apparel. The conceptual model for the study based on the above hypothesis can be seen in Figure 1. The conceptual model demonstrates how different factors that influence sustainable apparel PI are connected. The figure displays how brand strength directly influences consumer purchasing behavior. Additionally, it shows that brand reputation and authenticity also influence the decision to buy. The model displays how important strategic branding elements encourage consumers in the apparel business to practice sustainable consumption.

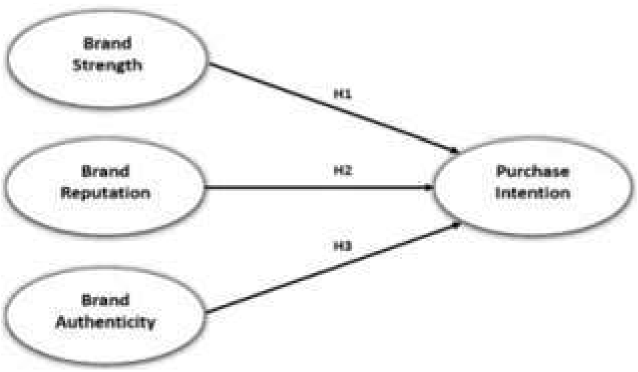

Figure 1 – Conceptual Model (Source; Author's own elaboration

3. Methodology

This study adopts a quantitative research design to investigate the influence of branding on consumers' purchase intentions toward sustainable apparel. A structured questionnaire was administered to gather data on key variables viz., brand strength, brand reputation, brand authenticity, and consumers' purchase intentions. The research approach enabled systematic exploration of the relationships between branding factors and sustainable apparel consumption, which are areas where literature is scarce.

3.1 Sample Profile

The proposed study targeted consumers in Delhi NCR who consistently buy sustainable apparel. Using convenient sampling procedure, 385 questionnaires were administered, and 264 responses were received. Amongst the received responses, 210 were found to be valid for analysis. The demographic profile of respondents includes the age (21 years or more) and a filtering question of "do you know about sustainable apparel" was applied.

3.2 Data Collection Procedure

An offline surveying method was adopted to retrieve the data from the actual consumers of sustainable apparel. The questionnaire in the format of closed-ended and Likert-type scales was used to gather in-depth information on brand strength, reputation, and authenticity aspects. Before the actual distribution of the questionnaires, pretesting was done amongst a few consumers to check on clarity and reliability. Informed consent and confidentiality assurances were maintained throughout the process.

3.3 Measurement and Instrumentation

A structured questionnaire was used to collect the data. Brand reputation was measured based on quality, reliability, and credibility dimensions. Brand authenticity was measured basis of integrity, credibility, symbolism, and continuity and purchase intentions were measured basis the willingness of the consumers to buy sustainable apparel and their willingness to pay a premium. A 7-point Likert scale was used to capture the ratings. [6, 9]

3.4 Data Analysis

The data was analysed using SPSS version 26 to compute descriptive statistics viz. mean and standard deviation. Regression analysis was conducted to test the relationships amongst brand strength, reputation, authenticity and purchase intentions. This enabled us to find out the association, in terms of the significance and strength, between branding and consumers' purchase behavior.

4. Results and Discussion

The regression analysis results reveal significant findings regarding the influence of brand strength, reputation, and authenticity on consumers' purchase intention for sustainable apparel. Each of the three hypotheses is tested with the following key results.

4.1 Brand Strength and Purchase Intention

The regression analysis revealed that brand strength significantly influences consumers' purchase intention for sustainable apparel, explaining 15.8% of the variance. With a moderate positive correlation (R = 0.397), brand strength is a significant predictor of purchase intention ($p < 0.05$). The unstandardized coefficient of 0.379 suggests that for each unit increase in brand strength, consumer purchase intention increases by 0.379 units. The model fit is confirmed with a statistically significant F-value of 38.922 ($p < 0.05$), supporting H1. The model summary, ANOVA, and coefficients can be seen in the following tables (Table 1, 2, and 3).

Table 1 – Model summary table for brand strength

Model	R Square	Adjusted R Square	R	Std. Error of the Estimate
	0.158	0.154	397^2	2.28976
Predictors: (Constant), Brand strength				

Table 2 - ANOVA table for brand strength

Model	Mean square	df	Sum of square	F	Sig.
Regression	204.068	1	204.068	38.922	$.000^b$
Residual	5.243	208	1090.547		
Total	1294.614	209	1294.614		
Dependent variable: Purchase intention for sustainable apparel					
Predictors: (constant), Brand strength					

Table 3 – Coefficients table for brand strength

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
(Constant)	B	Std. Error	Beta		
Brand Strength	6.109	0.681		8.969	0
	0.379	0.061	0.397	6.239	0
Dependent Variable: Purchase intention for sustainable apparel					

4.2 Brand Reputation and Purchase Intention

Brand reputation has a stronger influence, explaining 27.6% of the variance in purchase intention. The R-value of 0.526 indicates a stronger positive correlation than brand strength. The unstandardized coefficient for brand reputation is 0.429, meaning a unit increase in brand reputation results in a 0.429-unit increase in purchase intention. The model fit is also statistically significant with an F-value of 79.476 ($p < 0.05$), confirming the importance of brand reputation in shaping sustainable apparel consumption. Thus, H2 is supported. The model summary, ANOVA, and coefficients can be seen in the following tables (Table 4, 5, and 6)

Table 4 – Model summary table for brand reputation

Model	R Square	Adjusted R Square	R	Std. error of the estimate
	0.276	0.273	$.526^a$	2..6317
Predictors: (Constant), Brand reputation				

Table 5 – ANOVA table for brand reputation

Model	Mean Square	df	Sum of Squares	F	Sig.
Regression	338.304	1	338.304	79.476	$.000^b$
Residual	4.257	208	885.391		
Total		209	1223.695		
Dependent Variable: Consumers' purchase intention					
Predictors: (Constant), brand reputation					

Table 6 - Coefficient table for brand reputation

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.415	0.473		11.442	0
Brand reputation	0.429	0.048	0.526	8.915	
Dependent Variable: Consumers' purchase intention					

4.3 Brand Authenticity and Purchase Intention

Brand authenticity, while important, explains a smaller portion of the variance (7.9%) compared to brand strength and reputation. The R-value of 0.280 indicates a positive correlation. The unstandardized coefficient for brand authenticity is 0.272, suggesting a moderate influence on purchase intention. The F-value of 17.760 ($p < 0.05$) indicates a statistically significant contribution to purchase intention. Although the influence is smaller, H3 is supported, highlighting that brand authenticity remains a significant factor. The model summary, ANOVA, and coefficients can be seen in the following tables (Table 7, 8, and 9).

Table 7 – Model summary table for brand authenticity

Model	R Square	Adjusted R square	R	Std. Error of the Estimate
	0.079	0.074	.280[a]	2.44027
Predictors: (Constant), brand authenticity				

Table 8 – ANOVA table for brand authenticity

Model	Sum of squares	df	Mean square	F	Sig.
Regression	105.757	1	105.757	17.76	.000[b]
Residual	1238.624	208	5.955		
Total	1344.381	209			
Dependent Variable: Consumers' purchase intention					
Predictors: (Constant), brand authenticity					

Table 9 – Coefficient table for brand authenticity

Model	Unstandardized coefficient		Unstandardized coefficient	t	Sig.
	B	Std. Error	Beta		
(Constant)	8.138	0.656		12.409	0
Brand authenticity	0.272	0.065	0.28	4.214	0
Dependent Variable: Consumers' purchase intention					

This research sheds light on the significant role that branding plays in influencing consumer decisions regarding sustainable apparel. The study reveals that elements such as brand strength, reputation, and authenticity are pivotal factors in shaping purchase intentions within this sector. Brand strength, which refers to aspects like brand recognition, loyalty, and trust, is found to positively influence the purchase intention, though its influence is moderate. This supports prior studies suggesting that a strong brand identity fosters consumer trust and preference, particularly in sustainability-driven markets. Furthermore, the influence of brand reputation, which explained 27.6% of the variance in purchase intention, underscores the importance of consumer perceptions of a brand's reliability and ethical standing. Consumers gravitate toward brands with a strong reputation for ethical practices, enhancing the brand's ability to drive sustainable consumption. Brand authenticity is a strong dimension but is found to be slightly less influential compared to brand strength and reputation. This is consistent with studies that have established that authenticity influences consumer trust and emotional engagement, especially in cases where the brands are transparent about the green activities that they undertake. Consumers are attracted to brands that provide a personal type of value identification. It rings well with a person's sense of ethical alignment and social responsibility.

A key outcome of this study is that the importance of sustainability in branding should not be undermined. Sustainable apparel brands should work to establish stable, respectable, and legitimate brands to attract environmentally concerned consumers. Moreover, openness and communication regarding their efforts for sustainability are essential for building trust and promoting purchasing behavior in today's competitive fashion market. Further research can explore the association between branding and price or examine the influence of social media.

4.4 Implications

The results have key implications for business and policy. Sustainable apparel brands need to strengthen brand reputation and authenticity as they emerge as important purchase drivers by including authentic certifications (e.g., FSC, B Corp). Effective and transparent communication regarding their sustainability practices, ethical sourcing, and environmental responsibility will promote trust and loyalty amongst eco-conscious consumers. By focusing on building a strong brand that upholds values related to sustainability, sustainable apparel manufacturers can create long-term relationships with consumers. This implies that policymakers need to provide an environment that encourages sustainable apparel manufacturers so that it fosters more responsible consumer behaviour. Insights from this study can lead to the development of influential marketing strategies that address the growing environmental concerns amongst consumers.

4.5 Limitations and Future Research Directions

The study also has its limitations. Since the research sample is drawn from a single geographical region, based on convenience sampling, generalizations of findings to other markets may be limited. Moreover, further research should be conducted in different regions and represent a greater variety of demographic groups by taking a larger sample size. Future studies can also conduct a cross-cultural comparison and the role of social media to understand the influence of branding attributes. This will enable the capturing of more in-depth sustainable apparel consumption patterns. Further, gaining an understanding of how branding is related to other influencing factors such as social media and pricing will help learn more about consumer purchase intention. Longitudinal studies on the long-term influence of sustainable apparel branding can also be conducted as future research. This study provides rich insights into how brand strength, reputation, and authenticity influence sustainable apparel consumption. It also has future research and practical implications for the dynamic sustainable apparel industry.

5. Conclusion

This study provides insights into the process of how branding influences sustainable apparel purchase intention. Brands, by creating a trustworthy and positive brand image, would be able to foster consumer loyalty and ultimately enhance demand for sustainable apparel. Furthermore, the authenticity of a brand indicates that a brand effectively and openly communicates its sustainability practices to its consumers, to build consumer confidence. Useful insights have been garnered from this research, yet there is much room for further exploration. The purchase intention could be explored further based on attitude toward sustainability, product quality, and demographic differences. As sustainability becomes a growing concern for consumers, businesses need to change their branding practices so that they align with the emerging expectations of their target audience.

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Sustainable Solutions: Transforming Textile Waste from Design to Marketing

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Abstract:

Background: Every year, India generates more than 7,793 tonnes of textile waste, accounting for 8.5% of the global total. Due to issues with quality and visibility, only a small portion of this waste—59%—finds its way back into the worldwide supply chains for high-end goods in the textile sector. The "Waste to Wealth" report, which was released in July 2022, provides an outline of the potential and challenges India is facing regarding the flow of textile waste as well as the various subtitles of the country's developing circular economy.

Methods: This study describes several kinds of pre-consumer synthetic textile waste accessible in the textile industry for conversion into functional recycled value-added products. Synthetic textile waste is converted into fibers, which are then used to make product which promotes eco-cycle solutions. From starting from collecting synthetic textile waste from the textile industry to development of recycled outcomes.

Results: The findings revealed that fibre derived from synthetic textile waste is highly valued and accepted in terms of long-term growth in the textile industry.

Conclusion: This research represents a minor step towards the textile industry's sustainable growth. Furthermore, this type of venture will help to drive economic development. The goal is to recycle synthetic textile waste to the extent that it is non-biodegradable.

Keywords: *Fibers, Recycling, Sustainable, Synthetic, Textiles, Value-added product*

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1. Introduction

Recycling is essential, as we all know that the textile sector is the second most polluting industry. By collecting synthetic textile waste and processing various sorts of pre-consumer textile waste that would otherwise end up in landfills as garbage, the robust system will reprocess them into materials or goods for the development of value-added products. Recycling textile waste will benefit not just the environment, but also the textile industry's economic development. As it's rightly said, "Be part of the solution, not part of pollution". This technique aims to design and manufacture home furnishings using materials that have a lesser environmental impact than fashion products, with an emphasis on creating products that consumers like, feel connected to, and want to keep and use. The rapid evolution of fashion has led to an increase in both fabric manufacture and waste generation. The environmental impacts of textile production, use, and disposal are well-documented. The textile industry is shifting from the "take-make-waste" model to a circular economy. This effort aims to reintegrate textiles into the product lifecycle, reducing waste and creating a sustainable loop that saves resources and reduces environmental impact. As a result, the process of valorizing fabric company waste to salvage fibres and create high-value products has been increasingly popular. Textile waste is valorized through three phases: pretreatment, enzymatic hydrolysis, and fiber regeneration. After the fiber has been retrieved from synthetic textile trash, it can be used to make new value-added products. The apparel and textile industries' growth and rapid fashion demand have led to a significant increase in textile waste, with 75% landfilled and 25% recycled. Consumer awareness, closed-loop circular systems, and innovative textile recycling technologies are needed to promote sustainable consumption [1].

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2. Materials and Methods

Synthetic Textile Waste is used as a primary material for the fiber-to-fiber recycling and production of value-added products to market in the sustainable community market. Fibres in textile products are commonly made up of bi- or multi-component yarns with mixed components. Products are functionalised by combining the properties of fibre components with this material mixture. Fibre construction expands the range of product materials (clothing textiles), including haberdashery (zip, button, bias binding), multilayer constructions (membrane, lining, or wadding on jacket), functional coatings (water-repellent coating), dyes, prints, and practices. One prerequisite for sustainable recycling is to make the material flow as pure and suitable as possible. The mixing of components in this process can create barriers or make recycling uneconomical, non-natural, or technologically impractical [2]. A sustainable design strategy for producing a value-added product from synthetic textile waste composite material by mixing waste textiles and other components. Synthetic textile wastes are non-biodegradable, the extension of recycling the waste to reduce the waste material and produce economic development, providing a long-term, environmentally beneficial option for minimizing pollution and waste [3].

Synthetic fibre recycling can be carried out against textile wastes whose composition and internal structure are primarily made up of synthetic and/or artificial fibres. Nylon/polyamide, polyester, elastomer, or acrylic are materials used by textile and hosiery manufacturers and laboratories to make consumer items such as socks, knitwear, and garments.

2.1 Starting from collecting synthetic textile waste from the textile industry

There have been numerous suggestions for collecting the pile of old fabric people need to get rid of. There are different options available for the collection of synthetic textile waste.

The fashion industry faces significant structural challenges, requiring a paradigm shift. Agamben's concept of intempestivity aids in resilience, promoting innovation and sustainability. Case studies demonstrate successful changes through recycling, upcycling, material circularity, and textile waste valorisation. The study explores post-consumer waste dynamics and upcycling processes' effectiveness in sustainable transformation, aiming to shift the textile/clothing sector's paradigm between sustainable logic and recycling design. Fashion and Textile Design explores post-consumer waste dynamics, revealing upcycling processes' effectiveness in long-term transformation. This shift between sustainable logic and recycling design perspectives is reflected in the textile/clothing sector [4].

Textile waste is segregated according to fabric type, quality, and applicability. Sorting textile waste is crucial for successful textile recycling since it determines the quality and quantity of recycled fibres and products. It is problematic since the textile waste streams contain a variety of fabrics, colours, patterns, and contaminants. Technologies have been developed to help separate textile waste. One of the technologies incorporates hyperspectral imaging and artificial intelligence. It employs a camera that can photograph textile waste in a variety of wavelengths and lighting conditions. The images are then fed into an algorithm, which examines and classifies the fabric based on fibre content and contaminants. This approach allows for high precision and speed for sorting textile waste [5]. Emerging technology solutions, such as re-polymerization, can enhance textile recycling efficiency by reducing PET to its molecular level, subsequently polymerizing it to create new fibers.

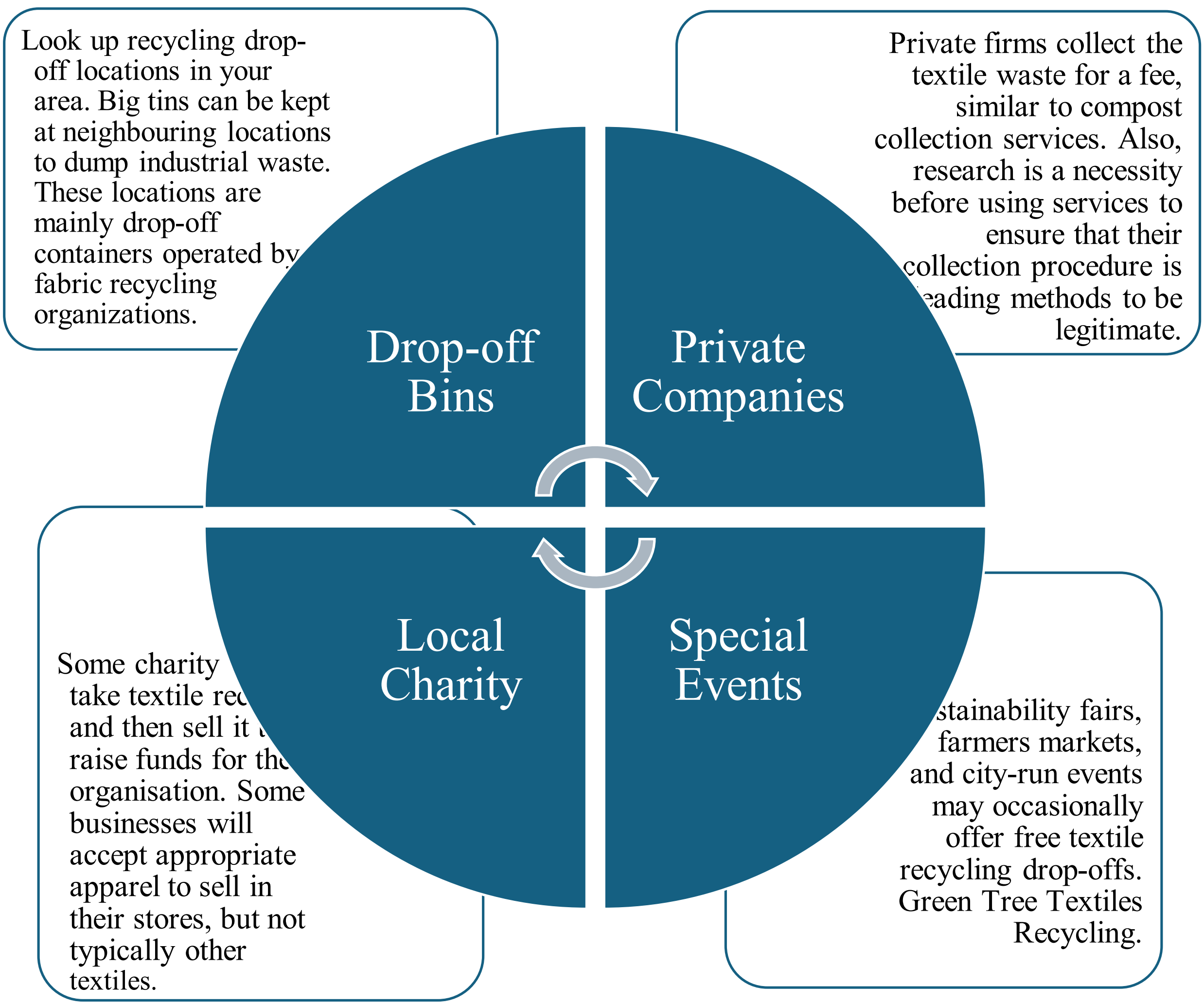


Table 1 - Options for collection of Synthetic Textile Waste

2.2 Determining end use of textile waste in community.

Table 2 - End-use of textile waste split by waste streams

End Use	Pre- Consumer (of 3265 ktons)	Domestic post-consumer (of 3944 ktons)	Imported (of 584 ktons)
Reuse	**16%** is being used, the current production process primarily consists of surplus fabrics and garments from overproduction (66%), with a small amount coming from cutting and mill waste.	**51%** clothing is being repurposed, sorted, and sold at secondhand markets.	**16%** is being re-exported to other countries as secondhand apparel. These re-exports primarily consist of clean, trendy, lightweight apparel that is in high demand in tropical African and Asian countries.
Recycle	**46%** is being recycled. The recycling of waste primarily consists of fibre waste (86%), cutting waste (10%), and mill waste (4%), indicating that a significant portion of this waste is utilized in various applications.	**4%** is getting recycled. India's recycling of non-wearables is limited to pre-consumer and imported garbage, as non-wearables are highly contaminated in this waste stream.	**47 %** is recycled and accounts for a significant amount of woollen and acrylic waste, as these materials are not in high demand in nations that accept secondhand apparel. It also comprises polluted and mangled cotton-rich materials that cannot be worn.
Downcycle	**37%** is being downcycled, this primarily includes cutting waste, mill waste, and fiber waste.	**2%** of material is being utilized for the production of wipes and as filling for bedding and quilts.	**36%** waste is being downcycled into non-textile sectors, including wipes and bedding fillers, which are used domestically and exported for international manufacturing.
Incineration/ Disposal	**1%** is being burned or landfilled.	**43%** Does not make its way back into the textile business, with a large portion being burnt and landfilled.	**1%** is known to be burnt for energy, significantly going to landfills, possibly due to high import costs and stakeholder desire for maximum value.

Table Source [6]

Textile recycling can help reduce waste by extending product life and designing materials for circularity. Our goal is to create a sustainable and comprehensive textile waste management system that enables efficient collection, recovery, reuse, and recycling of textile materials. Textile waste management requires collaboration among producers, recycling centres, brands, consumers, and public agencies. Implementing innovative technologies and efficient and sustainable collection and sorting systems is a vital step towards accomplishing these objectives and promoting the highest level of sustainability. The projects aim to convert textile waste into raw materials, use more mechanically recycled fibres, overcome technical problems in thermo-mechanical recycling, and create capsule collections with post-consumer recycled items. Recover™, a mechanical recycling leader, is devoted to developing systems, standards, and physical tests to close the textile loop in Europe. Currently, it mostly uses post-industrial textiles as raw materials. Mechanically recycled fibres, including Recover™ RColorBlend, are a sustainable alternative to virgin fibres that minimise CO_2 emissions without post-production treatments.

A product's ability to be recyclable is determined by its material, separation methods, and recycling stages. Using integrated methodologies and tools to build sustainable clothing systems leads to innovative and sustainable solutions.

2.3 Retrieving fibre from the textile waste

Textiles that are disposed of in landfills represent lost value and remain there since landfills are meant to hold rather than decompose. Organic matter degrades in landfills by anaerobic decomposition, which is mediated by microbes and produces methane and carbon dioxide. The extent to which a material, such as glucose, degrades is determined by the microbial population present at the landfill site [8]. When the necessary facilities are available, some textiles are burned to generate electricity. Waste textiles discarded in the environment through incorrect disposal or partial disintegration may accumulate or decompose, depending on the circumstances. To redirect solid food and paper waste from traditional landfills to alternative biological waste treatment options, the European Commission landfill Directive defined "biodegradable waste" as "any waste that is food and green waste, as well as paper and paperboard, can decompose either anaerobically or aerobically." Melt reprocessing, chemical/enzymatic conversion, and biological conversion are all examples of industrial processing techniques. Circular processes recover useful components from waste while reducing waste material loss to the environment.

Fibre can be retrieved using the amber cycling approach. Amber cycling uses a biological recycling to regenerate materials from post-consumer trash. The process involves regenerating polyester into yarn, transforming T-shirts into new fibers, reducing landfill waste, and reducing the need for fresh materials [7].

A textile engineer from RWTH Aachen University in Germany, products created with man-made fibres or synthetic blends can be recycled using one of four methods:

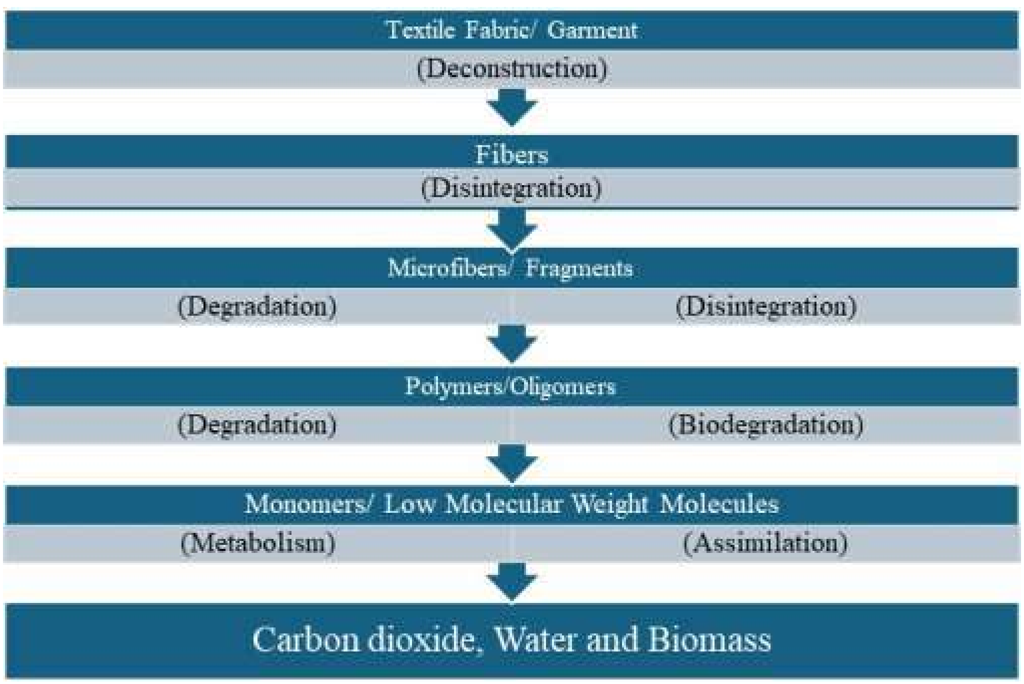
i) Mechanical recycling (tear)
Mechanical textile recycling is the process of shredding textile fabric and recycling it into fibres without the use of chemicals. The carding process produces yarn for knitted or woven materials. Textiles with mechanical damage are cut into smaller pieces and fed into a garnett machine for carding. The collected fibres are blended with virgin fibres at varying rates, resulting in a finer yarn. Recycled yarn is 15-18% cheaper than virgin fiber, impacting fabric prices.

ii) Thermal-mechanical recycling (regranulation)
Thermo-mechanical recycling (regranulation) is a method that involves melting, filtering, and extruding synthetic fibres or textiles as input material. Thermo-mechanical recycling is a method for reusing post-industrial wastes by melting plastic with built-in heating elements and frictional heat, removing volatile substances, and subsequently cooled before being chopped into short strands, potentially reducing resource costs and trash disposal.

iii) Physicochemical recycling (solvent-based separation)
Physicochemical recycling uses solvent-based separation to separate synthetic/natural fibers, convert them into RePAN pellets, and spin until primary fiber is obtained, reclaiming polymer waste streams, producing virgin plastic quality, and achieving high-grade polymer characteristics.

iv) Chemical recycling (returning to Oligomer / monomer)
Chemical recycling converts polymers into oligomers or monomers, producing virgin quality products with no physical loss. Procedures for PET textiles include hydrolysis, alcoholysis, and aminolysis, making it superior to mechanical recycling in technology. Filtration/separation purifies oligomers or monomers, converting them into polymers or chemicals. This yields high-quality secondary raw materials for spinning and textile fibre production.

Table 3 - Schematic path of deconstruction, disintegration, and degradation results



Microbial composting totally degrades natural fibres, while some plastics have been developed to do the same. However, process pollutants in bioplastics can cause ecotoxicity. Anaerobic digestion (AD) is a waste-to-energy process that generates biogas (methane) by digesting organic wastes such manure, municipal wastewater, agricultural residues, and food waste. AD procedures typically require liquid slurries (< 20% solids) as feedstocks, which is uncommon for waste textiles. Proposed processes for converting textile waste and evaluating the digestibility of plastic waste in AD and landfill conditions have been reviewed. Natural and manufactured textile fibres are semi-crystalline, containing both amorphous and crystalline areas. This crucial feature gives textile fibres a combination of toughness and strength [9]. The initial disintegration and degradation of fibres occurs in amorphous regions, which are more accessible to water and other chemicals due to their increased free volume, causing fibres to break apart into minute pieces and microfibers. When materials biodegrade in the environment, minute fragments depolymerise into low molecular weight molecules that microorganisms consume for energy and convert to carbon dioxide and water. Some molecules are turned into biomass, which forms the cells. Fibers and plastic materials can resist degradation, disrupting the full degradation pathway and causing environmental accumulation.

2.4 Development of recycled outcomes

a. Shoes made by Kwabena Obiri Yeboah KoliKoWear, Ghana. They have collected over 2000kg of textile waste and produced over 5000 pairs of shoes since its inception. The first aim was to help with unemployment in their city by creating something with the cheap resources available locally. A businessman and a friend who works as a shoemaker began developing this venture. They search for the cheapest material which is discarded textile waste and transform it into something valuable with awareness of sustainability and the need to reduce waste's negative environmental impact [10]. They travel to the secondhand market to collect and sometimes buy discarded textiles, which they then bring into the factory. Jeans are repurposed into shoes. Soles are made using car tyres and conveyor belts.

b. Children's toys. Rosario Hevia Ecocitex, Chile said after having her second kid, she realised that much children's clothing goes to garbage. She devised a mechanism in which people could buy, exchange, or donate unwanted children's garments. After researching the environmental situation, she began seeking for remedies. After much experimentation, they upcycled the worn-out clothing into products such as children's toys and pencil cases, as well as yarns [10]. A staff of incarcerated women cuts and separates the clothes by colour. They sell yarn and have a product line that includes mats, blankets, cushions and headgear. The residual debris is utilised to stuff pillows or boxing punchbags.

c. Rugs. Ume Kulsum Hussain founder of East Rugs, Pakistan, turned the window upside down. She once visited her father's textile mill and saw thousands of tonnes of garbage produced. She began to visualise the garbage produced by hundreds of factories. After graduating in textile design, she came up with the idea of manufacturing carpets out of garbage. She collects waste from manufacturers and employs a crew of five women to sort it, chop it up, and turn it into yarn. Then they began weaving rugs on handlooms. Her objective was successful, and people became aware that the amount of textile waste is an issue [10].

d. Bricks: Clarisse Merlet, the founder of FabBRICK, uses bricks to produce furniture or partition walls. These bricks are not ordinary bricks, but recycled abandoned textiles transformed into an insulating, structural and aesthetically pleasing building material. While studying, Clarisse Merlet became concerned about pollution in the building business. She began constructing bricks out of mostly textiles, plastic bottles, and cardboard. To achieve a satisfactory result, the textile is squeezed in a mould and then crushed into fibres and little pieces of cloth.

3 Result and Discussion

Fast fashion trends in the textile industry have led to increased fibre consumption and waste generation, demanding research into sustainable recycling technologies. Most systems evaluate post-industrial textile waste and suggest chemical and biological recycling alternatives [11]. The global population growth, improved living circumstances, and shorter product life cycles have all contributed to an increasing textile waste problem. Issues include huge corporations, garbage collection challenges, and pollutants. Increased customer awareness is required for fiber-to-fiber recycling [12].

The textile sector emits the most pollutants in the world. Textile recycling is becoming seen as an important way to minimise pollution and greenhouse gas emissions. The textile business uses a lot of water, energy, and chemicals, which have a big influence on the environment. Cotton and polyester are the two most widely used fibres in the textile industry, accounting for more than 85% of global fibre output. Natural fibres can emit methane and CO_2 into the atmosphere and take weeks to years to disintegrate [13]. Synthetic textiles, on the other hand, are difficult to breakdown and can leach harmful compounds into groundwater and adjacent soil.

Textile production and consumption must be improved in order to implement fiber-to-fiber recycling.Currently, fabrics are not designed for recycling. Producers must prioritise 'design for recycling' textile materials.Increased monofilaments could boost recycling, while blended textiles are a major concern due to declining recycling rates. Less complex blending is feasible for textile fibers. Composting, biogas production, and reprocessing in industrial reactors are examples of alternative waste management solutions [14].

The sustainability component leads to a high acceptability of home furnishings created from textile waste because the sustainable market is growing by the day, and the demand for unique value-added product is gaining traction in the trend market. The fashion industry is undergoing a shift towards sustainable fashion, aiming to reduce its environmental and social impact by utilizing eco-friendly and socially responsible textiles. Biodegradable synthetic fibres, made from natural resources like corn or potato starch, are being developed to reduce environmental impact while maintaining durability and performance. The use of biodegradable synthetic fibres can reduce environmental impact while maintaining durability and performance. The textile sector's influence on the environment and workers can be enhanced by sustainable practices, with consumers driving change [15]. Fast fashion has increased textile product discarded, prompting the development of recycling systems to convert waste into raw materials for value-added products, aiming to reduce environmental impact.

By implementing a sustainable marketing plan, you can strike a delicate balance between promoting products or services and ostensibly minimising harmful short and long-term effects on the environment, society, and economy.Several advantages of sustainable marketing include improved brand reputation, consumer loyalty, shared employee beliefs, and the exploration of new areas for ongoing innovation.

4. Conclusion

The problem of textile waste in India requires a complex solution. India's textile sector can become a global leader in social and environmental responsibility by embracing circularity, promoting sustainable production, educating consumers, developing infrastructure, and supporting innovation. In addition to protecting the environment, this change will strengthen communities, provide new business opportunities, minimise textile industry waste, and ensure a more sustainable future for both the sector and the country as a whole. Reusing pre-consumer textile waste is essential nowadays. This research study represents a minor step towards the community's long-term growth. Pre-consumer textile waste can come from the garment and upholstery sectors. Designs were developed and assessed. The creation was carried out based on the evaluation. Marketers praised the idea of recycling textile waste to repurpose fibre and create home goods. Recycling and sustainable development were also promoted. The only answers to textile industrial waste are reuse, recycling, and reduction, and we must treat it as vital as any other industrial activity in the textile industry. Waste recycling systems are examined from an economic standpoint, and they can be processed at several levels. The technological modalities for processing fibrous waste, which rely on mechanical, physical, and chemical means of influencing the material, are briefly outlined. Based on the findings, it was determined that recycling can be utilised to successfully and economically reuse not only industrial waste but also other fibrous materials and products that have become obsolete in industry.

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Sustainable Fashion Consumer Behaviour – A Comprehensive Literature Review and Future Research Agenda

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Abstract:

There have been numerous academic discussions about the importance of apparel that is ethically and sustainably produced due to the growing awareness of environmental concerns among consumers. The aim of this study is to present a review of literature on consumer behaviour in the context sustainable fashion apparel by conducting a systematic evaluation and critical assessment of the studies on sustainable consumer behaviour. A final sample of 68 articles was synthesized to conduct a descriptive analysis of the research methodologies, research trends, and theoretical foundations. Additionally, a synthetic analysis was conducted using the Stimulus-Organism-Response (S-O-R) framework. According to the findings, there are noticeably less qualitative, experimental, cross-cultural, and longitudinal studies in the literature, suggesting a need for more study.

Keywords: *Consumer conduct, Comprehensive literature review, deliberate fashion, Eco-friendly fashion, Quick fashion, Stimulus-organism-response model*

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1. Introduction

A sustainable strategy requires a collaborative approach and a thorough overhaul of the business model by all stakeholders. However, some of the important findings suggest that the link between consumer intention and actual purchase is weak [1]. Despite the attitude-behaviour gap and the inconsistency in between consumers' attitudes and actual buying behaviour, many studies have identified that sustainable attributes are becoming increasingly important in a brand valuation. [2]. While the body of empirical research analysing consumer attitudes and behaviour in relation to sustainable fashion has grown [3], the research is dispersed and shows few signs of definitive conclusions or implications. Additionally, most existing reviews of the literature on sustainable fashion do not approach the topic from the perspective of consumer behaviour [4]. Our research aims to address the questions:

a) What techniques and approaches are employed in consumer behaviour studies on sustainable fashion?

b) What variables was the investigation looking into to comprehend the behaviour of customers?

c) How has research on sustainable fashion and consumer behaviour changed over time?

Technology has transformed the apparel business [5]attempting to adapt to shifting consumer demands and fashion trends more quickly[6,7]. The issue of greenwashing also poses a significant challenge. However, regulations such as the EU's proposed Eco-design for Sustainable Products Regulation [8] and New York's Fashion Sustainability and Social Accountability Act [9], will hold companies accountable and expose those who engage in greenwashing. The vast array of definitions and words used in the literature (see Table 1) reflects the broad view of what sustainable fashion encompasses [10].

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2. Materials and Methods

A systematic review provides knowledge on research issues [17]. One can carry out systematic reviews in multiple ways, including: structured reviews [18-21] framework-based reviews [18, 22 & 23], hybrid-narrative reviews with a framework for a future research agenda [17], bibliometric review [24], meta-analysis reviews [25], and theory development reviews [17]. In this analysis, we used a framework-based review process, S-O-R Framework to classify consumer behaviour's causes and effects in an environmentally friendly way. The stimulus-response (SOR) hypothesis [26] was expanded upon by [27] to create the S-O-R Framework. According to [28], the S-O-R Framework serves as a versatile lens through which to view consumer behaviour.

The S-O-R Framework is composed of three main components: (i) Stimulus, which is defined as an external factor that affects an individual's internal condition and piques their interest; (ii) The term "Organism" refers to the evaluation made by the customer; The organism, which may be a particular form of emotive or cognitive state or activity, serves as the intermediary between inputs and consumer reactions. (iii) Response is the result of the customer's response. In order to make sure that the studies chosen were relevant to our review we established the inclusion and exclusion criteria (see Table 2).

Table 1: Definitions of terminology related to sustainable fashion

Category	Reference	Category	Definition
Environmental	Reimers et al., 2016[11]	Ethical apparel	Apparel that uses methods such as slow fashion, among others, to reduce the harm it causes to the environment, its workers, and animals.
Social and environmental	Sung & Woo, 2019[12]	Slow fashion	Clothing produced using methods that are ethical, socially, and environmentally responsible.
Social and environmental	Niinimäki, 2010[13]	Eco-fashion	Durable apparel with little to no environmental impact that is produced ethically, potentially even locally, using recycled or eco-labelled materials.
Social and environmental	Goworek et al., 2012[14]	Sustainable clothing	Apparel that combines elements of environmental and social sustainability, such as Fair-Trade production or cloth made from raw materials cultivated organically.
Environmental	Shin & Kang, 2021[15]	Environmentally sustainable apparel	Clothing that includes organic fabric, eco-friendly apparel, recycling, and second-hand clothing.
Environmental	Kang et al., 2013[16]	Environmentally sustainable textiles and apparel	Clothing made and used using methods that prevent resource depletion or irreversible damage.

Table 2: Inclusion and Exclusion Criteria

Criteria for Inclusion	Criteria for exclusion
Journal articles	White papers, conceptual, books and book chapters, conference paper
Examines the behaviour of consumers in the context of sustainable fashion	Studies in the fashion industry that examine a firm or organization behaviour
Published between 1 January 2014 and 1 July 2024	Papers that were published outside the included period of time
Indexed in Scopus	Journal articles published outside the selected database
Journal articles in the Subject Areas of Business, Management and Accounting, Social Sciences, Environment Science and Material Science	Journal articles outside the selected Subject Areas
Written in English language	Non-English language journal articles

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [29] to effectively perform the search. The PRISMA protocol involves four phases: identification, screening, eligibility, and inclusion (See Figure 1).

In the identification process, we looked through the Scopus online database. Using particular keywords and string searches - Sustainable fashion, Consumer behaviour, Fashion sustainability, Consumer purchasing behaviour, Eco fashion, Organic fashion, the online database was searched. We conducted a backward search [30]; [31] [32] to make sure that the final sample contained all pertinent studies connected to this review. After going through this procedure, a final sample of 68 journal articles formed the dataset for evaluation.

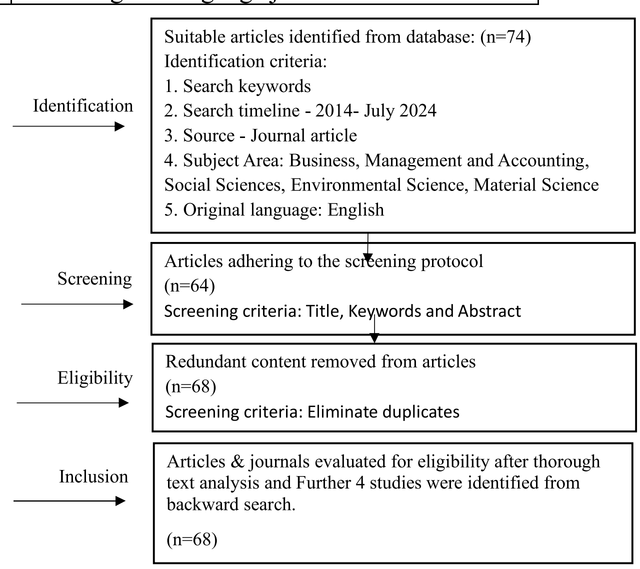


Figure 1: PRISMA Protocol

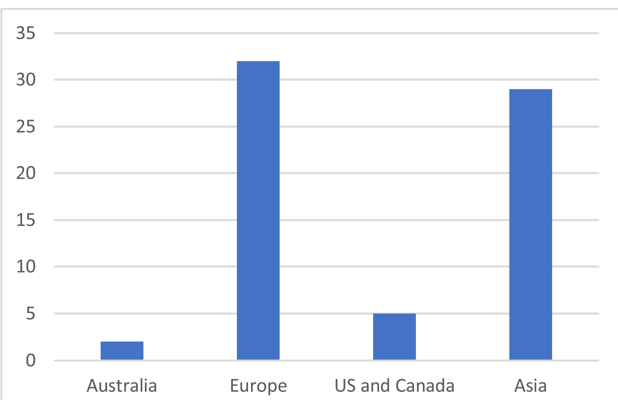
3. Results

We offer two sets of analyses: one that is synthetic and uses the S-O-R Framework, and the other is descriptive that are complementary to one another and offer insight into the future direction of the field of study, trends as well as possible topics that need more research.

a. Descriptive Analysis - publication channels, geographical area, research methodologies and outcomes

We present a descriptive survey of the literature from 2014 to July 2024 on sustainable fashion consumer behaviour from four perspectives: publication channels, geographical area, research methodologies and outcomes. From 2014 to 2018, the number of studies looking at consumer behaviour in the context of sustainable fashion increased annually. Publications decreased in 2019 following a period of modest but consistent increase, before progressively rising and reaching a high in 2023. This implies that in the upcoming years, additional studies will probably be published. According to Figure 2, the majority of the research was carried out in Europe (47%), Asia (43%), and North America (7%). The majority of Asian studies concentrated on Indonesia (n=2), South Korea (n=8), and India (n=1). The findings indicate that only 47 of the published research (n = 21) were carried out across many nations, with the majority (n = 21) focusing on three countries: South Korea (n = 8), India (n = 7), and Italy (n = 6).

Figure 2: No. of publications as per region



This suggests that there is a significant research gap in the study of cross-cultural influences. Cultural differences among nations can have an impact on consumers' worries about the environment [33]. The majority of the studies in the review used one of the three broad research methodologies: quantitative research (71%) [34], followed by qualitative (19%) [35] [36]and a minor number of mixed-method studies (10%) [37]. Of the studies that used research methods, more than 75% used a survey method. A number of research used qualitative techniques, including focus groups (n = 8) or interviews (n = 9), to comprehend how consumers are responding to the sustainable fashion phenomena. Furthermore, regarding the study sample, over half of the studies (n = 65) expressly mentioned that the consumer sample was employed regardless of the gender of participants. The most widely used theory (n=27) is the Theory of Planned Behaviour (TPB)[38]. The research also makes use of other theories, including the Theory of Reasoned Action (TRA)[39], Behavioural Reasoning Theory[40], and Fashion Adoption Theory[41] (see Table 3).

Table 3: Most utilized theories in the dataset

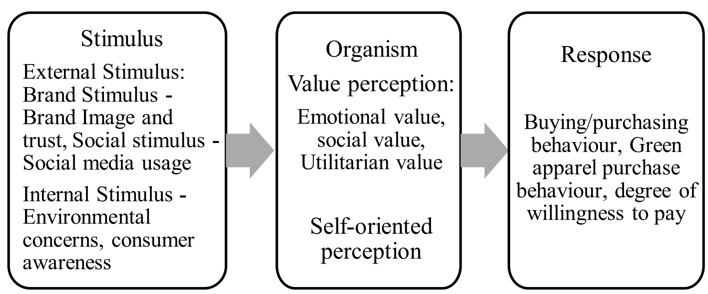
Behavioural and Attitude Theories	No. of studies
Theory of Planned Behaviour	27
Theory of Reasoned Action	15
Fashion Adoption theory	7

There were just three studies (n = 3) [42]. That examined how social media affects customer behaviour and attitudes. Few were based on environmental, social, and governance (ESG) factors [43].

b. Synthetic Analysis Using the S-O-R Framework

The term "stimulus" in the S-O-R Framework describes the motivators or inducers for customers. Consumer perceptions of sustainable fashion, as per the dataset, are likely to be influenced by utilitarian, emotional, and social values [45] (Figure 3). According to Parasuraman, A., Zeithaml, V.A., Berry, L.L.: Servqual [46], perceived value is the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given. Perceived value was highlighted in the view of the growing impact of social media on individual knowledge, attitudes, and behaviours, particularly social media's role in promoting sustainable fashion values and encouraging appropriate consumer behaviour [47] [44]. Consumer attitudes towards second-hand and rental clothing were also examined by a few studies [42] [48] [45]. The dataset's most researched response was the consumer's intention to purchase (n=53).

Figure 3: S-O-R framework in context of the dataset



Other studies looked at customers' willingness to spend more for sustainable fashion items based on their attitudes, knowledge, and views about the environment.[49]. In addition, studies have also examined other consumer responses such as brand and responsible consumer behaviour [50].

4. Conclusion

Several significant research gaps are highlighted by the analysis of the examined studies. Our analysis revealed that none of the examined studies made use of social theories other than TPB, TRA and Fashion Adoption Theory, such as social support theory, social influence theory, or social capital theory. The findings demonstrated that there is a dearth of diversity in research methodologies, including data science, mixed-methods, and qualitative methodologies. Qualitative techniques like focus groups and interviews might be helpful in gaining a deeper knowledge of the reasons behind the actions of consumers. We suggest that future research should take into account the valuable topic of examining how social media use and consumer attitudes towards second-hand and rental clothing may help close the attitude-behaviour gap.

5. Limitations

The research only included papers written in English. The implication of our research is limited by the number of studies (journal articles) that satisfy the inclusion criteria.The S-O-R framework has limitations. For synthetic analysis, other frameworks like ADO and TCCM may be used.

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7. Declaration of Interest

During the preparation of this work the author used Generative artificial intelligence (AI) and AI-assisted technology, QuillBot for language and readability. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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Influence of Lycra Content on Core Spun Yarn Properties on Apparel Buying

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Abstract:

Lycra core spun yarn is a type of innovative yarn designed to combine the superior stretch and recovery property of spandex with the comfort and aesthetic quality of natural or synthetic fibres. In this research the effect of spandex denier from 40, 70, 105 & 140 D is seen on core spun yarn properties. With increase in Lycra denier significant effect is seen in physical properties of core spun yarn such as RKM, Breaking force, elongation %, Dynamic elastic recovery % and stretch %. Non-significant effect is observed for Unevenness%, Hairiness Index and Twist per inch. This hybrid yarn finds extensive use in apparel, particularly in activewear, denim, and intimate apparel, where comfort, fit, and flexibility is paramount.

Keywords: *Dynamic elastic recovery%, influence, Lycra %, Stretch%, Unevenness %*

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1. Introduction

Lycra core spun yarns have emerged as a groundbreaking development in textile manufacturing, offering enhanced elasticity, strength, and comfort. These yarns integrate a Lycra (spandex) filament as the core, which is enveloped by a sheath of natural or synthetic fibers. This structure makes them ideal for applications requiring stretch and recovery, such as sportswear, denim, and intimate apparel [1, 2 & 3].

The mechanical properties of Lycra core spun yarns, including breaking force, elongation, stretch percentage, and recovery, are significantly influenced by factors such as the denier of the Lycra core, spinning methods, and the outer fiber composition [4, 5 & 6]. An increase in Lycra denier typically enhances elasticity, though it may negatively affect tensile strength and dynamic recovery due to the increased proportion of Lycra in the yarn [5, 6]. Conversely, properties such as unevenness (U %) and hairiness remain relatively unaffected by changes in Lycra denier, indicating the robustness of modern spinning technologies [7, 8 & 13].

Technological advancements in core spinning have enabled the production of high-performance Lycra core spun yarns with consistent quality. These innovations allow for customization of yarn characteristics to suit specific applications [9, 10]. Additionally, recent studies have focused on sustainable practices in Lycra yarn production, addressing environmental concerns associated with synthetic fibers [11, 12 & 13].

The apparel fabric must possess a comfortable fit to the body in steady state and elasticity during body movement. This performance can be efficiently achieved by a fabric that has two special properties along with other required mechanical properties. Firstly, stretch properties to handle formability and body fitting and secondly, the recovery properties that deals with regaining body shape by the fabric after stretching.

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2. Material and Methods

2.1 Material

A Lycra core spun yarn with resultant count 10s Ne is manufactured with Lycra deniers 40, 70, 105 & 140 D in the core.

Fibre properties of yarn produced in spinning are as follows

- Length: 29 mm
- Strength: 29 g/Tex
- Uniformity: 82 %
- Mic: 3.6 µg/inch
- SFI: 8%
- Rd: 69.3
- +b: 9.6
- SCI: 131
- Trash: 3.5%

2.2 Methodology

A 10s Ne Lycra core-spun yarn is manufactured using the following machines in sequence:

- Blendomat Trützschler
- TC5 Carding
- SB-D22 Rieter Draw frame
- FL681 Speed frame
- Zinser 351 Ring frame
- Schlafhorst Autoconer

Specifications of the Zinser 351 Ring frame:

- Lycra Draft: 3.5
- Lycra Percentage: 3% to 8%
- Lycra Speed: 17.50 m/min
- Twist Per Inch (TPI): 15.2
- Twist Multiplier (TM): 4.8
- Spindle Speed: 10,500 rpm

2.3 Testing

Testing of core-spun yarn was carried out using the following standards:

- Count: ASTM D1907
- Tensile Strength & Elongation: ASTM D2256
- Lycra %: Weight method
- Hairiness Index: ASTM D5647
- Unevenness %: ASTM D1425
- Twist per Inch TPI: ASTM D1422
- Dynamic Elastic Recovery & Stretch (Hysteresis Method): ASTM D2594-99A

A one-way ANOVA was applied to the results to observe the effect of Lycra on the spun yarn properties.

3. Result & Discussion

10s Ne core-spun yarn is manufactured using Lycra deniers of 40, 70, 105, and 140D. The table below provides the test results obtained.

Table 1 - Physical Properties of Core Spun Yarn

Lycra Denier D	RKM cN/tex	Breaking Force g/den	Elongation %	Core Spun Ne	TPI	Lycra %
40	18.79	1.11	7.77	9.901	14.25	2.17
70	18.90	1.12	8.26	9.811	13.21	3.84
105	18.31	1.08	8.92	9.487	14.21	5.20
140	17.51	1.01	9.29	9.251	14.21	7.28

Table 2 - Evenness & Elastic Properties of Core Spun Yarn

Lycra Denier D	U%	Hairiness Index	Dynamic Elastic Recovery%	Stretch %
40	7.34	8.69	27.75	72.25
70	7.43	8.86	25.46	74.54
105	7.65	8.72	20.95	79.05
140	7.78	8.85	19.78	80.22

3.1 Effect on RKM, Breaking Force of Core spun yarn

Figure 1 - Effect on RKM of Core spun yarn

Figure shows statistically the above properties have effect on core spun yarn with change in Lycra denier. Breaking force and RKM reduces with change in Lycra denier from 40, 70, 105 & 140 D. This phenomenon can be attributed to the reduced proportion of the outer covering fibers, which are primarily responsible for the yarn's tensile strength, as the Lycra content increases. Through a series of tensile tests and mechanical analyses, the research highlights that while higher denier Lycra enhances elasticity, it simultaneously compromises the overall tensile strength and RKM of the yarn.

3.2 Effect on Elongation% of Core spun yarn

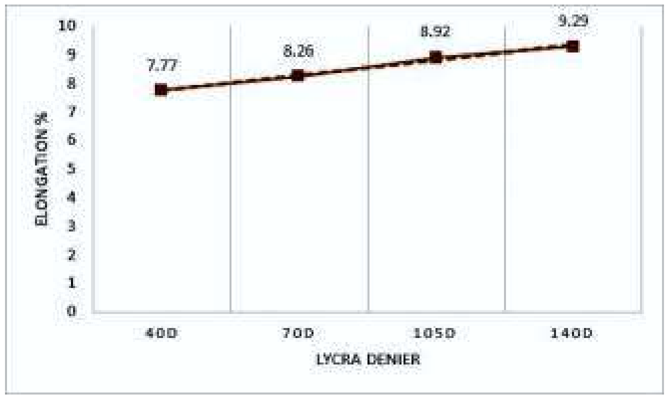

Figure 2 - Effect on Elongation% of Core spun yarn

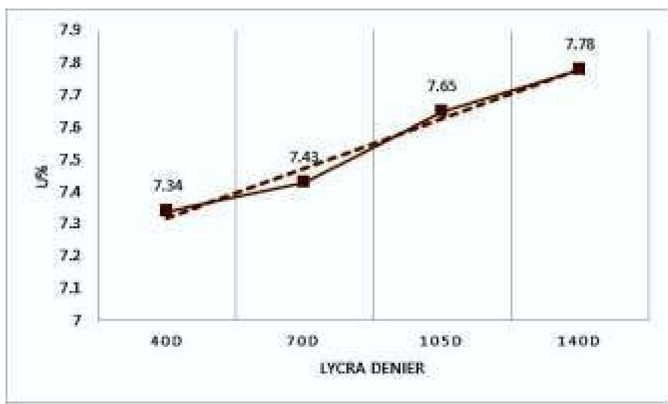

Figure 3 - Effect on Unevenness% of Core spun yarn

Statistically Elongation % shows significant effect with change in Lycra denier. It increases with change in Lycra denier from 40, 70, 105 & 140 D. Elongation % measures the yarn's ability to stretch before breaking, was evaluated across yarns with varying Lycra deniers. The results indicate that as the Lycra denier increases, the elongation percentage of the core spun yarns also increases. This trend is due to the higher Lycra content %, which enhances the yarn's stretchability and flexibility. Through detailed experimental analysis and mechanical testing, the research shows that thicker Lycra filaments provide greater extensibility, making the yarn more suitable for applications requiring high levels of elongation. These findings are crucial for textile manufacturers and engineers, suggesting that optimizing Lycra denier can effectively improve the elongation properties of the yarn, ensuring better performance in products such as activewear, stretch denim, and other high-elasticity textiles.

3.3 Effect on Unevenness % of Core spun yarn

Unevenness (U %), a critical parameter influencing the quality and appearance of yarn, was analyzed across different Lycra deniers. The findings reveal that changes in Lycra denier do not significantly impact the U% of the core spun yarns. This non-significant effect suggests that the spinning process effectively maintains yarn uniformity regardless of the Lycra filament's denier. Through comprehensive testing and statistical analysis, the research demonstrates that other factors, such as spinning conditions and the type of outer covering fibers, play a more pivotal role in determining yarn evenness.

3.4 Effect on Hairiness Index of Core spun yarn

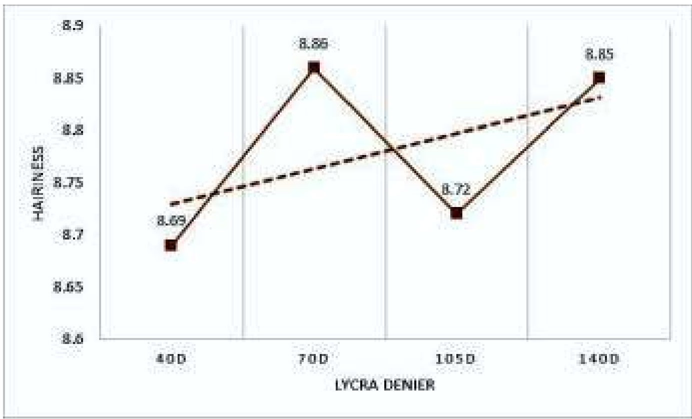

Figure 4 - Effect on Hairiness Index of Core spun yarn

Hairiness, which affects the yarn's texture, appearance, and performance, was measured across yarns with varying Lycra deniers. The results indicate that changes in Lycra denier have a non-significant effect on the hairiness of the core spun yarns. This finding suggests that the increase in Lycra content does not adversely influence the protrusion of fibers from the yarn surface. Through detailed experimental analysis and measurement, it was observed that factors such as spinning technique, fiber blend, and outer fiber type play more crucial roles in determining yarn hairiness.

3.5 Effect on Twist per Inch (TPI) of Core spun yarn

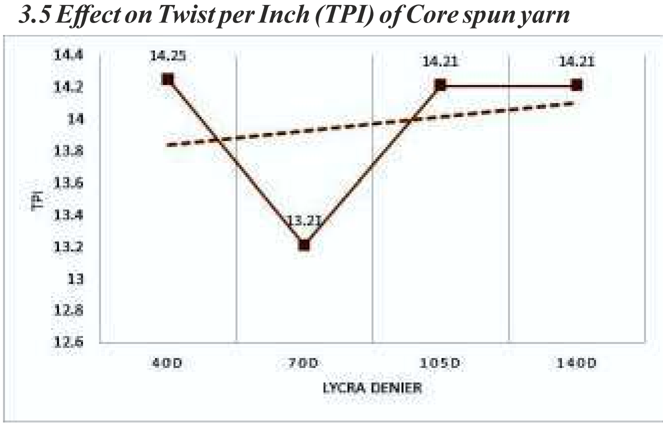

Figure 5 - Effect on Twist per Inch (TPI) of Core spun yarn

TPI, a crucial factor in determining the yarn's strength, elasticity, and overall performance, was analyzed across yarns with different Lycra deniers. The findings reveal that changes in Lycra denier do not have a significant impact on the TPI of the core spun yarns. This non-significant effect suggests that the incorporation of Lycra, regardless of its denier, does not alter the twisting process or the resultant twist level of the yarn. Through comprehensive testing and statistical analysis, the research highlights those other factors, such as spinning parameters and the properties of the outer covering fibers, are more influential in determining the TPI.

3.6 Effect on Dynamic Elastic Recovery % of Core spun yarn

Figure 6 - Effect on Dynamic Elastic Recovery %of Core spun yarn

There is significant effect on DER of core spun yarn with Lycra denier. As denier increases in core spun yarn DER% reduces, but reverse trend is seen in Stretch %, it increases with change in Lycra Denier. The DER helps to evaluate the garment response to body movement.

Dynamic elastic recovery, a critical property for applications requiring high elasticity and shape retention, was analyzed across yarns with different Lycra deniers. The results demonstrate that an increase in Lycra denier leads to a decrease in the dynamic elastic recovery of the core spun yarns. This decrease can be attributed to the higher Lycra content, which, while enhancing initial elasticity, may lead to reduced recovery efficiency due to the increased resistance and lower recoil strength of thicker filaments. Through extensive testing and analysis, the research underscores the importance of optimizing Lycra denier to balance elasticity with effective recovery properties.

3.7 Effect on Stretch% of Core spun yarn

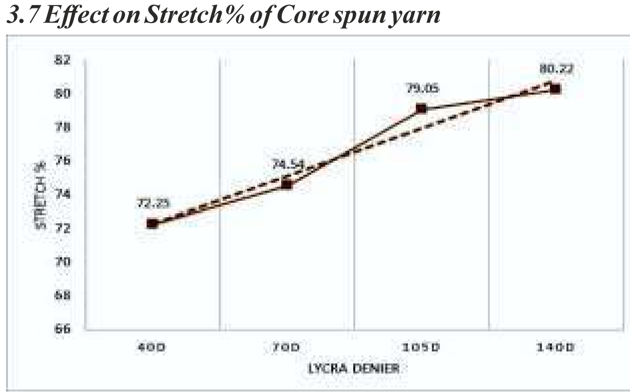

Figure 7 - Effect on Stretch% of Core spun yarn

Stretch percentage, a critical property for assessing the yarn's ability to elongate under tension, was measured across yarns with different Lycra deniers. The findings reveal that as the Lycra denier increases, the stretch percentage of the core spun yarns also increases. This increase in stretch percentage is attributed to the higher Lycra content, which enhances the yarn's elasticity and ability to elongate. Through comprehensive testing and analysis, the research demonstrates that higher denier Lycra filaments contribute to greater extensibility, making the yarn more suitable for applications requiring significant elasticity.

4. Conclusion

An increase in lycra denier from 40, 70, 105 & 140 D in 10s Ne core spun yarn resulted decreasing trend in breaking force, relative breaking force (RKM) and dynamic elastic recovery. Non-significant effect is observed for Unevenness %, hairiness and TPI. Stretch % and elongation % shows increasing trend with varying Lycra denier. Overall, the study highlights the complex interplay between Lycra denier and the mechanical properties of Lycra core spun yarns. While higher deniers improve stretch and elongation properties, they may compromise tensile strength and dynamic elastic recovery. These insights are critical for textile manufacturers aiming to optimize yarn properties for specific applications, balancing elasticity, strength, and recovery to meet the demands of modern performance textiles.

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PROCESSING

Exploring the Synthesis Processes of Graphene Oxide and Silicon Dioxide Nanospheres: A Comprehensive Study

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Abstract:

This work presents the synthesis and characterization of graphene oxide (GO), SiO_2 nanospheres, and SiO_2-graphene oxide (SiO_2-GO) hybrid materials. GO was synthesized through a modified Hummers' method involving the oxidation and exfoliation of graphite in a strong acidic medium, followed by sonication, centrifugation, and vacuum drying. SiO_2 nanospheres were produced using the Stober method, which involves the controlled hydrolysis and condensation of tetraethyl orthosilicate (TEOS) in the presence of ethanol, water, and ammonium hydroxide. The resulting SiO_2 nanospheres were purified by centrifugation and washing. Finally, SiO_2-GO hybrids were synthesized by dispersing GO in tetrahydrofuran (THF) and performing in situ hydrolysis of TEOS, leading to the deposition of SiO_2 nanoparticles onto the GO sheets. The hybrid material was isolated, washed, and dried for further characterization. This study demonstrates the successful fabrication of these nanomaterials, which hold significant potential for applications in lithium ion battery.

The practical benefits of GO, SiO_2 nanospheres, and SiO_2-GO hybrids in lithium-ion batteries include enhanced energy density, improved cycle stability, and reduced electrode degradation. GO offers high conductivity and flexibility, SiO_2 nanospheres contribute structural stability, and the SiO_2-GO hybrid combines these advantages, effectively mitigating silicon expansion and enhancing overall battery performance.

Keywords: *Graphene Oxide, SiO_2 Nanospheres, Stober Method, Modified Hummers Method, "Nanocomposites and Lithium-ion Batteries*

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1. Introduction

Nanomaterials are materials characterized by structural features at the nanoscale, typically ranging from 1 to 100 nanometers [1]. Their unique properties, which differ significantly from those of bulk materials, have made them highly valuable across various fields such as electronics, energy storage, catalysis, and biomedicine [2]. The nanoscale size of these materials results in a higher surface area-to-volume ratio, quantum effects, and enhanced reactivity, enabling novel applications in areas like drug delivery, advanced composites, and environmental remediation [3]. Among the diverse array of nanomaterials, graphene oxide (GO), silicon dioxide (SiO_2) nanospheres, and hybrid materials such as SiO_2-GO have garnered considerable attention due to their multifunctional properties and potential in cutting-edge technologies. Graphene oxide is a promising nanomaterial derived from the oxidation of graphene, resulting in the introduction of oxygen-containing functional groups [4].

Graphene oxide is a derivative of graphene, possessing functional groups that enhance its solubility and reactivity, making it suitable for various applications, including energy storage devices, sensors, and biomedical applications [5]. Its exceptional mechanical strength, thermal stability, and electronic properties have prompted extensive research into its synthesis and functionalization, allowing for the development of innovative materials and devices. The oxidation of graphite, the precursor for GO, leads to the introduction of oxygen-containing functional groups, which play a crucial role in the material's chemical behavior and compatibility with other substances Silicon dioxide nanospheres, on the other hand, are an important class of ceramic nanomaterials that have gained significant attention due to their unique optical, electronic, and biocompatible properties [6].

Silicon dioxide (SiO_2) nanospheres are another category of nanomaterials that exhibit unique properties, such as biocompatibility, chemical stability, and ease of functionalization. These properties render SiO_2 nanospheres particularly useful in drug delivery systems, optical applications, and as fillers in composites [7]. The Stober method, widely recognized for producing uniform SiO_2 nanospheres, involves the controlled hydrolysis of tetraethyl orthosilicate (TEOS) in the presence of a base, enabling precise control over the size and morphology of the nanoparticles. This method has become a standard procedure in nanomaterial synthesis due to its simplicity and the high quality of the products obtained [8].

The integration of GO and SiO_2 into hybrid materials such as SiO_2-GO represents an exciting frontier in nanomaterial research. The synergistic effects arising from the combination of GO's electrical conductivity and SiO_2's mechanical stability can lead to materials with enhanced properties, making them suitable for applications in energy

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storage, environmental remediation, and composite materials [9]. The ability to tailor the properties of these hybrids opens up new avenues for innovation in various technological fields. For instance, the SiO_2-GO hybrids can be used in creating advanced membranes for filtration processes or as catalysts in chemical reactions, exploiting the unique properties of both components [10].

The synthesis process is pivotal in determining the properties, structure, and functionality of nanomaterials. Precise control over synthesis conditions such as temperature, concentration, reaction time, and method—can lead to tailored material properties suitable for specific applications. The ability to consistently and reproducibly synthesize nanomaterials with desired characteristics is essential for both fundamental research and technological applications [11]. In particular, the synthesis of GO, SiO_2 nanospheres, and SiO_2-GO hybrids requires careful optimization to ensure high-quality materials with controlled morphology, size, and chemical composition. Proper synthesis is the foundation for studying the performance of nanomaterials in various domains, including electronics, sensors, and catalysis [12].

This paper focuses exclusively on the synthesis processes of graphene oxide (GO), SiO_2 nanospheres, and SiO_2-GO hybrids, providing detailed step-by-step procedures and methodologies involved. The goal is to present a comprehensive guide on synthesizing these nanomaterials, from the preparation of starting materials to final product isolation [13]. By concentrating on the synthesis processes, this paper aims to serve as a valuable reference for researchers and students interested in fabricating these nanomaterials for future experiments and applications. The detailed protocols for each synthesis technique emphasize reproducibility and scalability, ensuring that these methodologies can be effectively implemented in various laboratory settings [14].

Moreover, understanding the nuances of these synthesis techniques not only aids in developing specific nanomaterials but also enhances the potential for discovering novel applications in emerging fields. For example, advances in nanotechnology could lead to breakthroughs in targeted drug delivery systems, improving patient outcomes in medicine. Similarly, the development of highly efficient nanomaterials could revolutionize energy storage technologies, contributing to a more sustainable future [15].

While this paper prioritizes the experimental synthesis methods, future studies may expand upon the characterization and application aspects, furthering the understanding and utility of these versatile nanomaterials in modern science and technology. By laying a solid foundation in the synthesis of GO, SiO_2 nanospheres, and SiO_2-GO hybrids, this research can catalyze further innovations and exploration in the vast landscape of nanomaterials [16].

In addition to the modified Hummers' and Stober methods, the sol-gel method is a valuable alternative for synthesizing silicon-based nanomaterials like SiO_2. This method enables precise control over particle size, shape, and surface characteristics, which is beneficial for achieving uniform nanospheres. The sol-gel process is cost-effective and scalable, making it suitable for industrial applications. Discussing the sol-gel method alongside the chosen approaches would highlight various synthesis pathways, each with specific advantages in tailoring material properties for optimized lithium-ion battery performance.

Beyond lithium-ion batteries, the synthesized materials—GO, SiO_2 nanospheres, and SiO_2-GO hybrids—demonstrate significant versatility across various fields. In energy storage, they are ideal for supercapacitors due to their high surface area and conductivity, which enhance charge storage and discharge rates. In catalysis, the stability and surface properties of GO and SiO_2 make them effective as catalysts and catalyst supports, beneficial for fuel cells and chemical reactors. Additionally, these materials show promise in sensor applications, where their high sensitivity allows for precise detection in environmental and biochemical monitoring. Their biocompatibility also opens pathways in biomedical fields, such as drug delivery systems, tissue engineering, and medical imaging, where controlled release and targeting are essential. These diverse applications highlight the broad potential of GO and SiO_2-GO hybrids across various industries, extending their impact well beyond energy storage.

2. Methods and Method

2.1 Chemicals and Reagents

The synthesis of graphene oxide (GO), SiO_2 nanospheres, and SiO_2-GO hybrids requires high-purity chemicals and reagents to ensure the accuracy and quality of the resulting nanomaterials. The key chemicals used in these processes include graphite powder (1 g), which serves as the starting material for GO synthesis, and concentrated nitric acid (HNO_3, 45 mL) and sulfuric acid (H_2SO_4, 90 mL), which act as oxidizing agents during the GO preparation. Tetraethyl orthosilicate (TEOS, 6.2 mL for SiO_2 and 0.5 mL for SiO_2-GO hybrids) is the precursor for the formation of silicon dioxide nanospheres and their hybrid structures with GO. Additionally, ammonium hydroxide (NH_4OH, 6.5 mL) catalyzes the hydrolysis of TEOS in the Stober method for SiO_2 synthesis. Ethanol (100 mL) and deionized water (7 mL) are used as solvents in the SiO_2 nanosphere synthesis, while anhydrous tetrahydrofuran (THF, 120 mL) serves as a solvent for the exfoliation of graphene oxide and the in situ deposition of SiO_2 on GO sheets. Finally, 1 M hydrochloric acid (HCl) is used to wash GO during its purification. All chemicals were of analytical grade and sourced from reliable suppliers to ensure consistent results throughout the synthesis processes [17].

2.2 Equipment and Instrumentation

The equipment necessary for these synthesis methods includes round-bottom flasks of various sizes for mixing and reacting the chemicals, and an ice bath to maintain low temperatures during the GO synthesis. An ultrasonicator is used to exfoliate graphite oxide into GO sheets and to disperse GO in THF during the preparation of hybrid materials. A reflux apparatus facilitates the prolonged heating required to drive the oxidation of graphite in the GO synthesis, while a centrifuge is employed for separating solid materials from their suspensions in both GO and SiO_2 synthesis processes. A vacuum drying system is used to dry the synthesized GO and SiO_2 nanospheres under controlled conditions, and a pH meter monitors the pH of the filtrates during washing to ensure neutralization. Magnetic stirrers continuously stir the reaction mixtures, and filter paper with a vacuum filtration setup is used to collect the solid materials after washing [18].

2.3 General Precautions and Laboratory Setup

The synthesis of nanomaterials involves the handling of reactive chemicals, necessitating strict safety precautions to protect the researchers and maintain the integrity of the materials. Personal protective equipment (PPE) including laboratory coats, gloves, and safety goggles was worn at all times to safeguard against chemical exposure. All reactions involving concentrated acids, particularly the mixing of nitric and sulfuric acids, were conducted inside a fume hood to prevent exposure to harmful fumes. Temperature control was critical during the exothermic reactions, especially in the GO synthesis, and ice baths were employed to maintain low temperatures. Proper waste disposal procedures were followed for acid residues and solvents, in accordance with chemical waste protocols. The laboratory was well-ventilated, and exhaust systems ensured the proper handling of volatile organic compounds (VOCs), especially from THF and ethanol. Care was taken to balance the centrifuge tubes to avoid damage to the equipment and ensure effective separation of the materials. Emergency equipment such as eyewash stations, spill kits, and fire extinguishers were readily available in the laboratory to address any accidental spills or hazardous reactions. These precautions and setup details provided the foundation for safe, reproducible, and accurate experimental work throughout the synthesis processes [19].

3. Synthesis of Graphene Oxide (GO)

The synthesis of graphene oxide (GO) begins with the preparation of an acidic solution by mixing concentrated nitric acid and sulfuric acid in a round-bottom flask, with the mixture being stirred in an ice bath to maintain low temperatures. Graphite powder is then added to this acidic solution, and the mixture is stirred for 30 minutes, followed by a two-hour sonication at room temperature to initiate exfoliation. The dispersion undergoes a 24-hour reflux, resulting in a brown-grey paste. This paste is then separated via centrifugation, and the solid material is re-dispersed in deionized water and purified through sonication. After filtration and washing with HCl and DI water, the black powdered graphite oxide is dispersed in anhydrous tetrahydrofuran (THF) and sonicated to exfoliate it into graphene oxide (GO) sheets. The GO is separated by centrifugation and dried under a vacuum at 40°C, yielding graphene oxide powder. This powder can then be dispersed in water to form a stable suspension [20].

4. Synthesis of silicon Dioxide (SiO_2) nanospheres

The synthesis of SiO_2 nanospheres is carried out using the Stober method, which involves the controlled hydrolysis of tetraethyl orthosilicate (TEOS) in the presence of a catalyst. The materials required for this process include TEOS (6.2 mL), ammonium hydroxide (NH_4OH, 6.5 mL), ethanol (100 mL), and water (7 mL).

The process begins by preparing the reaction medium. In a clean container, 7 mL of water is mixed with 100 mL of ethanol. To this mixture, 6.5 mL of ammonium hydroxide is added as a catalyst to promote the hydrolysis reaction. The mixture is stirred thoroughly at room temperature to ensure proper mixing [21].

Once the reaction medium is prepared, the hydrolysis of TEOS is initiated. TEOS (6.2 mL) is slowly added dropwise to the reaction mixture while continuously stirring. The stirring is maintained for 3 hours at room temperature to allow the complete formation of SiO_2 nanospheres. During this time, a white turbid suspension forms, indicating the successful formation of SiO_2 nanospheres.

After the reaction, the mixture undergoes centrifugation to separate the solid SiO_2 nanospheres from the suspension. The mixture is centrifuged for 20 minutes, resulting in the precipitation of white SiO_2 nanospheres. The precipitate is then washed several times with ethanol to remove any unreacted materials and impurities, ensuring a clean product [22].

Finally, the washed SiO_2 nanospheres are collected and dried, making them ready for further characterization and possible functionalization. This step completes the synthesis of SiO_2 nanospheres, which can then be used for various applications in material science.

Figure 1 - Chemicals and Reagents for the Synthesis of Graphene Oxide (GO)

Figure 2 - Chemicals and Reagents for the Synthesis of Silicon Dioxide (SiO2)

Figure 3 -Chemicals and Reagents for the Hybrid Synthesis

5. Synthesis of SiO_2-GO Hybrids

The synthesis of SiO_2-GO hybrids involves the in situ deposition of SiO_2 nanoparticles onto graphene oxide (GO) sheets. The process begins by dispersing 50 mg of GO in 120 mL of tetrahydrofuran (THF). This dispersion is achieved through sonication for 1 hour, ensuring a uniform suspension of GO in the solvent. After obtaining a homogeneous GO suspension, 0.5 mL of tetraethyl orthosilicate (TEOS) is slowly added to the mixture, followed by an additional hour of sonication to enhance the interaction between the GO sheets and the TEOS [23].

Once the TEOS is fully incorporated, the mixture is stirred at room temperature for 20 hours. During this period, the hydrolysis of TEOS occurs in situ, resulting in the gradual formation of SiO_2 nanoparticles, which are deposited onto the surface of the GO sheets, creating a hybrid material. After the reaction is complete, the SiO_2-GO hybrid is separated from the suspension by centrifugation.

The collected SiO_2-GO hybrids are then washed multiple times with alcohol to remove any unreacted TEOS or impurities, ensuring the purity of the hybrid material. Finally, the hybrids are dried under controlled conditions, making them ready for characterization. Microscopic and spectroscopic analyses are performed to confirm the successful synthesis of the SiO_2-GO hybrids, verifying the attachment of SiO_2 nanoparticles onto the GO sheets [24].

6. Conclusion

6.1 Summary of Synthesis Techniques

In this paper, three key synthesis methods were explored: the synthesis of graphene oxide (GO), SiO_2 nanospheres using the Stober method, and the formation of SiO_2-GO hybrids. The GO synthesis involved the oxidation of graphite using concentrated acids, followed by sonication and exfoliation to produce graphene oxide sheets. The Stober method facilitated the controlled hydrolysis of tetraethyl orthosilicate (TEOS) in the presence of ammonium hydroxide to create uniform SiO_2 nanospheres. Lastly, the in situ deposition of SiO_2 nanoparticles onto graphene oxide sheets was achieved through the hydrolysis of TEOS in a GO suspension, resulting in the formation of SiO_2-GO hybrids. Each synthesis method was carefully optimized to yield high-quality nanomaterials with specific structural and functional properties.

6.2 Importance of the Synthesized Nanomaterials

The synthesized nanomaterials hold significant importance across a wide range of applications. Graphene oxide (GO) is known for its exceptional mechanical strength, electrical conductivity, and large surface area, making it a promising material for use in energy storage, sensors, and catalysis. SiO_2 nanospheres, with their uniform size and surface chemistry, are widely applied in fields such as drug delivery, optics, and coatings. The SiO_2-GO hybrids offer a unique combination of the properties of both materials, potentially improving thermal stability, electrical properties, and mechanical strength in composite materials. These hybrid nanomaterials have potential uses in environmental remediation, energy storage systems, and nanocomposite materials, where the synergy between SiO_2 and GO can be harnessed for improved performance.

6.3 Future Perspectives

The development and application of nanomaterials are evolving rapidly, and the synthesis techniques presented in this study provide a foundation for future research. There are numerous opportunities for improving the functionalization and scalability of these materials. Future research could focus on enhancing the efficiency of the synthesis process, reducing environmental impact by exploring greener synthesis routes, and investigating the potential of these nanomaterials in emerging fields such as nanomedicine, flexible electronics, and energy harvesting. Additionally, exploring the hybridization of GO with other metal or metal oxide nanoparticles may open up new avenues for multifunctional materials with enhanced properties. The synthesized nanomaterials hold promise for advancing both fundamental research and industrial applications, making them a vital area of ongoing scientific inquiry.

Characterization Techniques: For future work, it is essential to outline the specific characterization techniques and testing methods that will be employed. Clearly specifying techniques such as FE-SEM, XRD, Raman spectroscopy, and electrochemical testing methods will provide readers with a comprehensive understanding of the methodology. This information will enable replication of results and better interpretation of the material's performance in lithium-ion batteries.

7. Authors' Contribution

Pawan D. Somavanshi has designed the experiments, performed the synthesis of nanomaterials, and wrote the manuscript.and Dr. Yogesh U. Sathe has supervised reviewed and finally approved the manuscript.

8. Conflicts of Interest

The authors declare no conflicts of interest about the publication of this research paper.

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Reducing Defects through Process Optimization Using Six Sigma

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Abstract:

Machining defects for the valves used in engines have also recorded high rejection level in Dent & Damages and Stem Roughness hence the quality of valves produced is compromised and the cost of producing them highly charged. These questions form the focal research concerns of this work; which utilize the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) rigorous frameworks. For Dent & Damages, the possible cause was found to be the metal to metal contact when unloading, which has therefore been resolved by placing polypropylene (PP) layer onto the output chute. In the case of Stem Roughness, the frequencies of replacing the grinding dresser were too spaced out, a situation that stemmed from the lack of an efficient method of tracking the dresser's state and expiry time. A solution was developed where changing of the dresser was synchronized with an automatic alarm, such that the machine was switched off after an expiry of the set limit of dresser usage. These interventions helped to reduce the defects significantly and proved that using DMAIC methodology in industry can help to enhance both the product quality and the production processes.

Defects in engine valve manufacturing were reduced significantly by addressing root causes: metal-to-metal contact was mitigated using a polypropylene (PP) layer, and irregular grinding dresser changes were resolved with automated alerts. Rejection rates decreased from 2.86% (Sigma Level 3.5) to 0.27% (Sigma Level 4.3), improving quality and operational efficiency. The Six Sigma DMAIC methodology proved broadly applicable for process optimization in manufacturing.

Keywords: *Defect Reduction, DMAIC Methodology, Manufacturing Defects, Manufacturing Efficiency, Process Improvement, Six Sigma*

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1. Introduction

The manufacturing industry of the world is always on the process of development to manage to fulfill the requirements of the market. In automotive industries, manufacturing of engine valves is very crucial in the overall performance of internal combustion engines [1]. The engine valves play an important role in the proper functioning of the engine, and defects in these components can be a foundation for numerous trouble, higher emissions, and, at worst, recall campaigns. As a result, it is crucial to have an enormous effort in the practice of quality assurance in the production process [2].

Consequently, defects like the "Dent & Damages" and "Stem Roughness" are still relevant in the production process, thus high rejection rate of products and high cost of production [3]. These defects do not only enhance the mechanical soundness and operation of the valves but also hit the customer confidence and the brand recognition. Hence, it is critical for organisations to have beneficial and efficient quality enhancement processes that can systematically reduce such flaws efficiently [4].

Six Sigma is defined as methodical, fact-based approach that targets at the elimination of inconsistency and the improvement of organizational products' quality. In Six Sigma, the Define, Measure, Analyze, Improve, and Control (DMAIC) approach subsets the manufacturing problems and offers advanced solutions [5]. Thus, DMAIC directs attention at the critical areas in which change is likely to have maximal impacts for manufacturers in terms of enhancing the quality of processes, eliminating waste and generating higher levels of performance [6].

In this research paper the Six Sigma DMAIC methodology is implemented on the context of the engine valve manufacturing process specifically with respect to the reduction of "Dent & Damages" and "Stem Roughness" This work is intended to prove the effectiveness of the proposed DMAIC model in improvement of product quality and rejection ratios. Therefore, it endeavors to add to knowledge concerning the application of Six Sigma in manufacturing by establishing the causes of these defects, as well as finding workable ways in addressing them [7].

To address these challenges, manufacturers need efficient and structured approaches to enhance quality and reduce waste. Six Sigma, a proven methodology in manufacturing industries, offers a systematic and data-driven solution. The DMAIC framework (Define, Measure, Analyze, Improve, and Control) is particularly well-suited for addressing specific defects in textile production by identifying root causes, optimizing processes, and implementing long-lasting improvements [8].

The findings of this study demonstrate the potential for applying Six Sigma and the DMAIC methodology to other

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manufacturing contexts, such as the textile industry. In textiles, these methodologies can address quality issues like fabric defects, uneven dyeing, and stitching inconsistencies by systematically identifying root causes—such as machine inefficiencies, operator errors, or material inconsistencies—and implementing targeted improvements. For example, fabric defects can be reduced by optimizing machine settings and introducing real-time monitoring systems, while uniformity in dyeing processes can be enhanced through precise chemical application and temperature control. These approaches not only improve product quality but also minimize waste, enhance customer satisfaction, and reduce costs, showcasing the versatility and effectiveness of Six Sigma in diverse manufacturing environments [9].

The primary objectives are to identify and address the root causes of critical defects, namely "Dent & Damages" and "Stem Roughness," in engine valve manufacturing, and to demonstrate the effectiveness of the Six Sigma DMAIC methodology in reducing these defects. Additionally, the study aims to improve process quality and operational efficiency through targeted interventions, including the use of a polypropylene (PP) layer and automated dresser change alerts. Lastly, the research highlights the sustainability of these improvements and discusses the broader applicability of the DMAIC approach for addressing similar challenges in other manufacturing contexts. These objectives are consistently aligned with the conclusions drawn, emphasizing the practical and adaptable nature of the proposed solutions.

2. Methodology

This research adopts the Six Sigma DMAIC (Define, Measure, Analyze, Improve and Control) approach to analyses' defects in the engine valve production line systematically. The DMAIC process is a systematic approach that helps manufacturers improve their production processes to deliver high-quality products [10].

2.1 Six Sigma and DMAIC

Six Sigma is an analytical methodology for reducing defects and controlling process variation that is, identifying six standard deviations away from the mean. Six Sigma is a methodology which was developed in the 1980s by Motorola Company and is used in the contemporary world in different sectors as a way of enhancing customer satisfaction through process improvement. The DMAIC process, a core component of Six Sigma, involves five key phases: The DMAIC process, a core component of Six Sigma, involves five key phases [11].

Define: Outline the general objectives, overall aim and intended area or scope of improvement projects.

Measure: Identify and document the data that are necessary in order to have a starting point of measuring the current performance of the processes.

Analyse: Useful for understanding the causes of defects and as a basis for recommendations for improvement.

Improve: Design strategic and tactical actions for avoiding or involving and eradicating defects in products and services.
Control: After any improvements have been made controls should be put in place to keep the improvements going and maintain high standards.

2.2 Define Phase

In the Define phase, the emphasis is made to determine the type of defects that occurred in the engine valves, and the baseline of the project is created. The main defects defined in this study were "Dent & Damages" and "Stem Roughness," which contributed to high rejection rates and increased production costs. This study was conducted at Durovalves India Pvt. Ltd., MIDC, Waluj, and Aurangabad. To address these issues, a project charter was prepared, outlining the project's scope, deliverables, required resources, start and end dates, and the projected outcomes. The objective of this research was to reduce the rejection rates associated with these defects, thereby achieving a better-quality product.

2.3 Measure Phase

In the Measure phase, matters of fact were developed for the purpose of testing the degrees of the flaws that were identified above and the current state of the manufacturing activity. The following steps were taken: The following steps were taken:

Data Collection: The statistical information concerning the defects, the manufacture procedure, and costs of the relevant produced items were collected in a six-month period. This was on quality inspections, production, and defects records among them being quality inspections, production logs and effects reports.

Process Mapping: The use of a process map was helpful and a process map for the manufacturing of engine valves was developed in order to understand the different points where defects may occur. It was useful in focusing on the areas of interest more immensely.

Baseline Metrics: Defect rates were also set as baseline, with the following: Dent & Damage, Stem Roughness. These acted as benchmark in assessing outcomes of the improvement intervention [12].

Table 1 - Major Contributing Defect

Defect	Quantity	Percentage	% Contribution
Dent & Damages	3827	31.26%	66.58%
Stem Roughness not ok	1820	14.87%	81.45%

3. Analysis

The Analysis phase targets to explain the causes of the defects that have been defined or measured in the first two phases, using analysis tools.

This section covers the identification of the root causes of defects from the data another in the Measure phase [13].

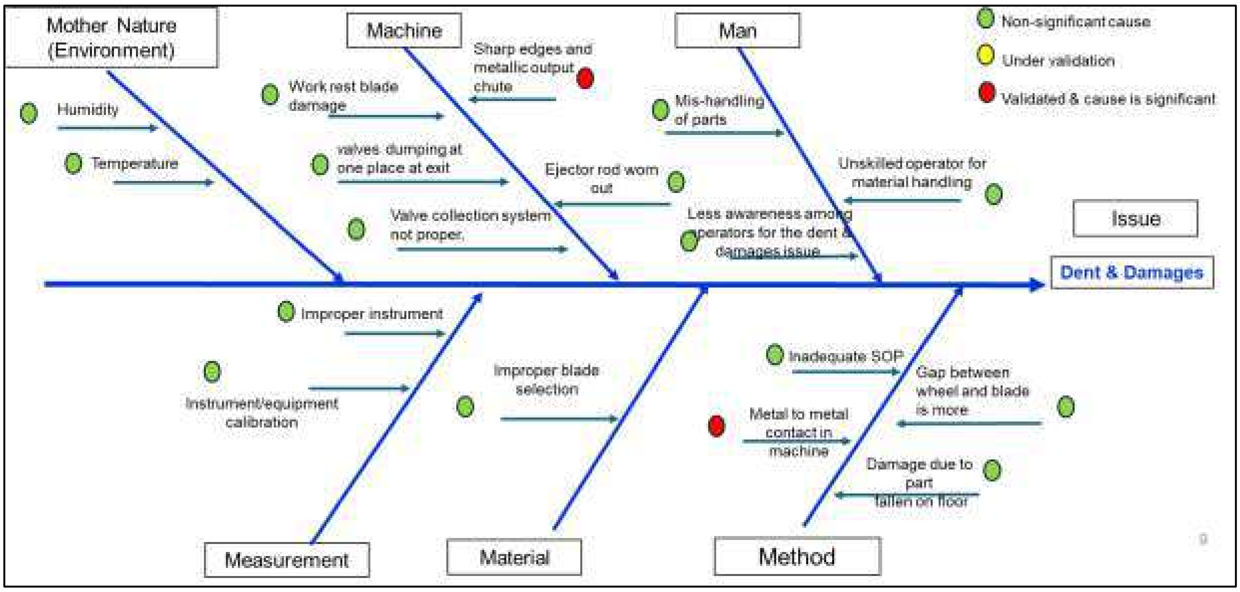

Figure 1 - 6M Analysis (Ishikawa/Fishbone Diagram)

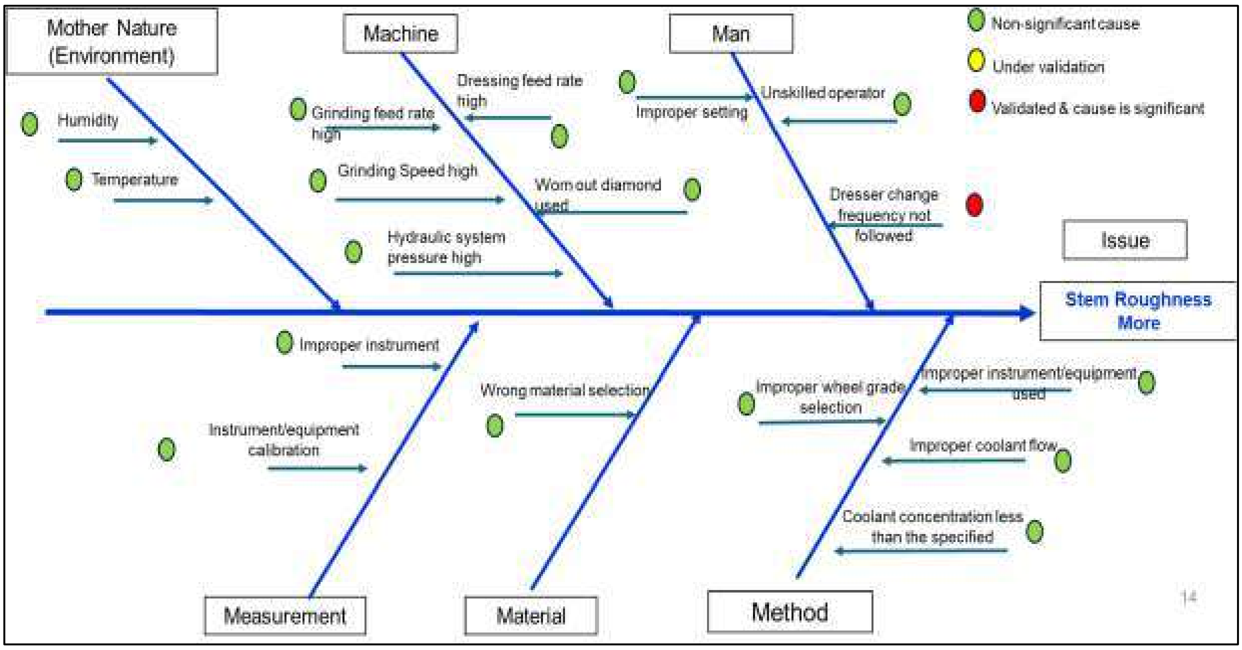

Figure 2 - 6M Analysis (Ishi-Kawa/Fishbone diagram for Dent & Damages)

An Ishikawa/Fishbone diagram was used to visually represent potential causes of "Dent & Damages" and "Stem Roughness." The diagram categorizes potential causes under the 6Ms: Man, Machine, Material, Method, Measurement and Environment [14].

3.1 Possible Causes Validation

In the attempt to prove the feasible causes of defects in the engine valve manufacturing process, two of the categories; Dent & Damages and Stem Roughness, were also taken through a close analysis. In the validation process, an evaluation of the contribution of every potential cause reported in the 6M Analysis and the rationale based on empirical findings, consultation with experts and data analysis was done [15].

3.2 Significant Causes

Sharp Edges and Metallic Output Chute (Dent & Damages): To this the metal output chutes were found to be sharp and were contributing largely to indentations and damages to engine valves. This was done through physical inspection and from the opinion of experts in the field.

Metal to Metal Contact in Machine (Dent & Damages): The fact that the finish-end grinding incorporated a metallic stopper meant metal on to metal contact was a major player in dents and damages.

Wheel Dresser Change Frequency Not Followed (Stem Roughness): Applying interviews to the operators and study of the collected data, it was found that the dresser change frequency was not constant that caused the stem roughness to rise. This was described as a serious concern that required some of the most focused efforts and interventions [16].

3.3 Non-Significant Causes

Some other possible sources like environmental factors, type of materials and equipment's used, calibration of machines, and trainability or experience of the operators were also considered and these were found to have negligible or no effects on the formation of defects. The implementation of proper training, development of standard operating procedures as well as habitually maintaining the equipment made these factors not to impact greatly in the "Dent & Damages" or "Stem Roughness".

The main causes were outlined and were followed by formulation of relevant solutions to these causes as a way of enhancing the quality of the end product and the reduction in the rates of defects in the manufacturing process [17].

3.4 Root Cause Analysis

This root cause analysis uses the "5 Whys" technique to identify and address the underlying causes of two critical defects in the engine valve manufacturing process: Some of the notable areas are "Dent & Damages" and "Stem Roughness". Through the analysis of these areas, the subsequent part shall seek to find the cause of the problem and subsequently an action plan [18].

- **Dent and damages 5 whys in root cause analysis.**

Why 1: Dent & Damages Observed: For final inspection minor dents and damages were observed on the engine valves making it to affect the quality of the product and the rate of rejection.

Why 2: Metal-to-Metal Contact: These defects originated from the metal-to-metal contact especially during unloading of the machine.

Why 3: The Chute is Metallic with Sharp Edges: The metallic output chute also had sharp edges problem by making it easier for a part to be damaged.

Why 4: During Unloading, Parts Hit the Metal Chute and Get Damaged: The parts would rub against the sharp edges of the chute during the unloading process leading to develops of dents and damages.

Why 5: Lack of Cushioning on the Chute: There was no material in the chute that would help in dampening impacts which created metal on metal contact [19].

- **Stem Roughness 5 whys in root cause analysis.**

Why 1: Stem Roughness Observed More: These stems focused some roughness on the product and thus caused high rejection rates of the products that were manufactured.

Why 2: Dressing Was Not Smooth: The cause of rough surface finish was poor dressing of the grinding wheel.

Why 3: Diamond Dresser Worn Out: This led to a situation where the diamond dresser is worn out leading to poor dressing of the diamonds.

Why 4: Dresser Not Changed at Defined Frequency: Sometimes, the dresser was not replaced in the recommended durations thus it affected dressing efficiency.

Why 5: Dresser Change Frequency Manually Controlled: The change frequency was also manually dependent where it would be quite irregular or even sometimes changes would be overlooked [20].

4. Improvement

This section describes the actions taken to address the root causes and improve the manufacturing process.

a. Action Plan for Dent & Damages

PP layer provided on output chute to prevent the metal-to-metal contact

Figure 3-Comparison of Metallic Output Chute and PP Layer Modification

b. Action Plan for Stem Roughness

Dresser change frequency interlocked in the program, after that the counter reached alarm generates and machine stops for dresser change.

Training provided to operators for newly added controls.

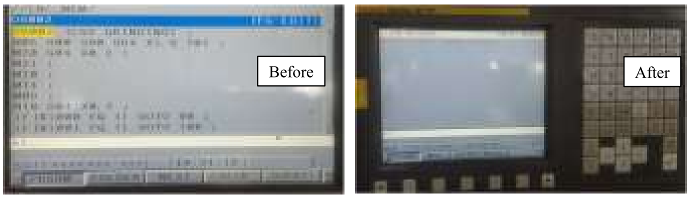

Figure 3- Impact of Interlocking Dresser Change Frequency in the Program

5. Results

5.1 Effectiveness of Actions

Following the implementation of the corrective actions, the rejection rates for the major contributing defects decreased over the monitored period. Specifically, for "Dent &

Damages," the rejection rate gradually declined, showing a clear decreasing trend. This reduction demonstrates that the addition of a polypropylene (PP) layer at the output chute effectively prevented metal-to-metal contact, thereby reducing the formation of dents and damages.

In the same way, the rejection quantity for Stem Roughness significantly reduced, due to an effective relationship between the dresser change frequency and an automated alarm system. This system encouraged timely replacement of the grinding dresser, and this improved the surface finish of the stems enormously. The reduction of the period taken to an average of three months to achieve decreased figures of defects gives endorsement to what was done in a bid to remove the sources of the defects to confirm the quality of the products.

5.2 Sigma levels before & after actions implementation

This upward trend in the Sigma Level from 3. 5 to 4. 3 signifies a significant improvement in the process efficiency hence the suitability of interventions in minimizing the defect rates.

Table 2 - Sigma levels before & after actions implementation

Before			After		
Rejection	**PPM**	**Sigma Level**	**Rejection**	**PPM**	**Sigma Level**
2.86%	28600	3.5	0.27%	2710	4.3

6. Conclusions

1) Reduction in Defects: DMAIC best approach of Six Sigma revived the incidence of “Dent & Damages” and “Stem Roughness” in the manufacturing of the engine valve. The addition of a polypropylene (PP) layer at the output chute and the synchronization of the dresser change frequency with the automated alarm system were found practical for eliminating the causative factors of these defects.

2) Improvement in Process Quality: The rejection rate decreased from 2.86% to 0.27%, improving the Sigma level from 3.5 to 4.3. That way there is evidence of the corrective action applied and improvements in process quality and wastes reduction are realized.Sustainability of Improvements: Some of the controls which have been put in place have been more of the nature of automation and training of the operators to detect and correct any quality deviations which has made these improvements sustainable hence improving product quality and hence operational efficiency in the manufacturing process.

3) Broader Applicability: The implications of this research also extend to the usefulness of the Six Sigma DMAIC in tackling comparable issues in manufacturing in other organizations and industries, providing a framework for decision-making to improve processes and quality.

7. Authors' Contribution

Ravindra L. Karwande planned, conducted the experiments, analyzed the data, conceptualization, methodology, investigation, and writing the original draft and Dr. Ashok J. Keche, was involved in the review and editing of the manuscript and Dr. Santosh P. Bhosle supervised reviewed and finally approved the manuscript.

8. Conflicts of Interest

The authors declare no conflicts of interest about the publication of this research paper.

9. Acknowledgments

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Exploring Vetiver Grass as Sustainable Fiber for Textile Industry

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Abstract:

Purpose: *This study aims to explore the potential of Vetiver, a native grass, as a sustainable fiber for the textile industry in India, considering the growing environmental concerns and the need for sustainable practices within the sector.*

Design/Methodology/Approach: *A comprehensive analysis was conducted integrating Field Emission Scanning Electron Microscopy (FESEM), X-ray Diffraction (XRD), and chemical composition testing to investigate the structural, crystalline, and compositional characteristics of Vetiver fiber. FESEM imaging was employed to examine the fibrous arrangement and cellulose bundles, while XRD analysis identified crystalline phases within the fiber. Chemical composition testing provided quantitative data on cellulose, lignin, wax, and other constituents, offering insights into Vetiver grass fiber's suitability for textile applications.*

Findings: *FESEM imaging revealed a fibrous arrangement with well-defined cellulose bundles, indicating the potential of Vetiver grass fiber for textile applications. XRD analysis identified distinct crystalline phases within the fiber, further supporting its suitability for use in textiles. Chemical composition testing highlighted the high cellulose content and moderate lignin content of Vetiver grass fiber, positioning it as a promising and sustainable option for various textile applications.*

Originality/Value: *This study contributes to the understanding of Vetiver grass fiber as a sustainable material for the textile industry in India. By providing insights into its structural, crystalline, and compositional characteristics, this research underscores the potential of Vetiver fiber to drive innovation and sustainability in the textile sector. Collaboration between academia, industry, and government agencies is emphasized as essential to harnessing the full potential of Vetiver fiber and fostering a more environmentally friendly and economically prosperous textile industry in India.*

Keywords: *Chrysopogon Zizanioides, Khas, Khuskhus, Sustainable Fiber, Vetiver Fiber, Vetiveria Zizanioides*

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1. Introduction

The textile industry in India holds a pivotal position in the nation's economy, serving as one of the largest contributors to industrial output, employment generation, and export earnings. With its rich heritage and diverse array of textiles, India has long been renowned as a global hub for textile production and trade [1, 2]. The industry encompasses a wide spectrum of activities ranging from spinning, weaving, and dyeing to garment manufacturing, thus providing livelihoods to millions of people across the country. In addition to its economic significance, the textile sector plays a crucial role in preserving and promoting India's cultural heritage, as many traditional crafts and techniques are still practiced and revered within the industry [3]. Moreover, the sector's dynamism and adaptability have enabled it to embrace modern technologies and international collaborations, ensuring its continued growth and relevance in the global marketplace [4].

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The textile industry in India not only contributes significantly to the nation's GDP but also plays a crucial role in its overall socio-economic development. As one of the largest employers in both rural and urban areas, the industry fosters inclusive growth by providing livelihood opportunities to a diverse workforce, including skilled artisans and laborers from marginalized communities [5, 6]. Furthermore, the sector's backward and forward linkages with agriculture, manufacturing, and retail sectors contribute to overall industrial growth and economic diversification. Moreover, the textile industry serves as a catalyst for rural development by promoting decentralized production centers and fostering entrepreneurship at the grassroots level. Additionally, the industry's global competitiveness and export orientation have positioned India as a key player in the international market, thereby enhancing its trade relations and foreign exchange reserves [7]. Thus, the textile industry not only drives economic growth but also fosters social development, making it a cornerstone of India's progress and prosperity.

In response to growing environmental concerns, there has been an increasing emphasis on the adoption of sustainable practices within the textile industry. This includes the use of eco-friendly and renewable materials, such as sustainable fibers, to mitigate the environmental impact of textile production processes. Sustainable fibers are characterized by their lower carbon footprint, reduced water and energy consumption, and biodegradability, making them an attractive alternative to conventional materials [8, 9]. The incorporation of sustainable fibers not only addresses environmental challenges but also aligns with consumer preferences for ethically sourced and environmentally friendly products. As such, the integration of sustainable fibers in the textile industry represents a significant step towards achieving sustainability goals while maintaining economic viability [10]. Moreover, the adoption of sustainable practices can enhance the industry's competitiveness in the global market by catering to the growing demand for sustainable and ethical products [11]. Thus, the integration of sustainable fibers in the textile industry is essential for promoting environmental stewardship and ensuring long-term sustainability in the sector.

The textile industry in India stands as a cornerstone of economic growth and social development, contributing significantly to the nation's GDP and providing employment to millions. Amidst growing concerns about environmental sustainability, there is a pressing need to explore alternative materials that can reduce the industry's ecological footprint while maintaining economic viability. In this context, Vetiver (Vetiveriazizanioides), a perennial grass native to India, emerges as a promising candidate for sustainable fiber production [12]. Vetiver possesses unique characteristics such as high tensile strength, durability, and resistance to pests and diseases [13]. Additionally, Vetiver cultivation requires minimal water and agrochemical inputs, making it a highly sustainable option for fiber production [14].

The utilization of Vetiver as a sustainable fiber aligns with India's rich agricultural heritage and offers a potential solution to the environmental challenges faced by the textile industry [15]. By promoting Vetiver cultivation and incorporating its fibers into textile production processes, the industry can reduce its reliance on resource-intensive materials and contribute to environmental conservation efforts [16]. Furthermore, Vetiver cultivation has the potential to generate additional income for farmers, particularly in regions prone to water scarcity and soil erosion [17]. Thus, the integration of Vetiver as a sustainable fiber in the Indian textile industry not only enhances environmental sustainability but also fosters socio-economic development at the grassroots level.

Vetiver, also called as Khas-Khas, Khas, or Khus grass, belongs to the Poaceae family and is closely related to corn, sorghum, sugar cane, and lemon grass. Vetiver, scientifically known as ChrysopogonZizanioides (formerly VetiveriaZizanioides), is a perennial grass that is indigenous to India. Vetiveriazizanioides, often known as Valo in Gujarati, Vava in Marathi, Vettiver in Tamil and English, Ramaccham or Vettiveru in Malayalam, Vattiveeru or Laamancha or Kaddu or KaridappasajjeHullu in Kannad, Kuruveeru or Vettiveellu or Vettiveerum in Telugu, and Ushira in Ayurvedic.

2. Review of Literature

A study on "Vetiver Grass Fiber Reinforced Polymer Composites: A Review on Preparation, Properties, Applications and Challenges". This study provided a comprehensive overview of Vetiver grass fibers as a potential reinforcement in polymer composites. It delves into the preparation methods of these composites, highlighting techniques such as fiber extraction, surface treatment, and composite fabrication. The review emphasizes the mechanical properties of Vetiver grass fiber composites, including their tensile strength, modulus, and impact resistance. Furthermore, it explores the wide range of applications for these composites across industries, such as automotive, construction, and aerospace. Challenges associated with the use of Vetiver grass fibers in polymer composites, including processing difficulties and compatibility issues with matrices, are also discussed [18].

A studied on "A Review on Natural Fiber Reinforced Polymer Composite and Its Applications" where the study offered a comprehensive examination of natural fibers, with a specific focus on their incorporation as reinforcements in polymer composites. It discusses the properties and characteristics of Vetiver grass fibers, including their tensile strength, modulus, and thermal stability. The review also explored various processing techniques employed to prepare Vetiver grass fiber-reinforced composites, such as compression molding and injection molding. Additionally, it highlights the diverse applications of these composites in industries ranging from automotive to construction and packaging, citing their potential to replace traditional materials and contribute to sustainability efforts [19].

The study on "Natural Fiber Reinforced Polymer Composite: An Overview" review provided a broad overview of natural fibers as reinforcements in polymer composites, with a specific focus on Vetiver grass fibers. It discusses the advantages of using natural fibers, including their renewability, biodegradability, and low cost. The review explored various processing techniques for Vetiver grass fibers, such as retting and decortication, and highlights their potential applications in sectors such as automotive components, building materials, and consumer goods. Furthermore, it addresses the environmental benefits of utilizing natural fibers in composites and emphasizes the need for further research to optimize processing methods and enhance composite performance [20].

"Natural Fiber Reinforced Polymer Composites: A Review on Fiber, Manufacturing and Properties" review offered a comprehensive examination of natural fibers as reinforcements in polymer composites, including Vetiver grass fibers. It discusses the manufacturing processes involved in preparing these composites, such as extrusion, compression molding, and injection molding. The review explores the mechanical properties of Vetiver grass fiber-reinforced composites, highlighting their tensile strength, modulus, and impact resistance. Additionally, it examines the potential applications of these composites across various industries, such as automotive, construction, and packaging. Finally, the review addresses challenges associated with the use of natural fibers in composites, such as fiber-matrix compatibility and processing difficulties, and suggests avenues for future research to overcome these challenges [21].

2.1 Research Gap

One potential research gap in the exploration of Vetiver grass as a sustainable fiber for the textile industry could be the lack of comprehensive studies focusing on the scalability and economic viability of large-scale production and commercialization. While numerous studies have investigated the technical feasibility and performance of Vetiver grass fiber in textile applications, there may be limited research addressing the challenges associated with scaling up production to meet industrial demands while maintaining cost-effectiveness and environmental sustainability. Exploring the optimization of cultivation techniques, fiber extraction processes, and manufacturing methods on a larger scale could be an area where further research is needed. Additionally, assessing the life cycle environmental impacts and conducting techno-economic analyses to evaluate the competitiveness of Vetiver grass fiber compared to conventional textile fibers would be valuable contributions to the literature. Addressing this research gap could provide valuable insights into the practical challenges and opportunities for integrating Vetiver grass fiber into mainstream textile production, thereby facilitating the transition towards a more sustainable and environment friendly textile industry.

3. Methodology

3.1 Fiber extraction from vetiver grass

Vetiver plants are commonly harvested when they reach the age of 12 months. Vetiver plants are commercially cultivated for its roots, which is used in Perfumery and cosmetics industry. Vetiver grasses are left over as agricultural waste. These Vetiver grasses are obtained from the region of Coimbatore. Cleansing the stems meticulously in tank water to eliminate any traces of sand and grime. Afterwards, the fibers are exposed to sunshine to ensure thorough drying, and then they are sorted. The sorted fibers undergo pressurized steaming in an autoclave for 1-2 hours at a temperature of 1100 degrees Celsius specifically for vetiver grass. Following this procedure, the material is permitted to cool within the autoclave for a designated period, after which the fibers are extracted. These fibers are opened in an opener to separate the fibers. Vetiver-extracted fibers can be used for sustainable textile production, including eco-friendly fabrics for clothing, bags, and mats. They are also suitable for geotextiles in erosion control and soil stabilization. Additionally, Vetiver fibers can be utilized in handicrafts and as reinforcement in composite materials for construction or packaging.

3.2 FESEM Analysis

For Field Emission Scanning Electron Microscopy (FESEM) analysis, cross-sectional and longitudinal images of Vetiver fibers are obtained. Sample preparation involves coating the fibers with a conductive layer to enhance imaging quality. FESEM imaging is conducted to visualize the surface morphology and microstructure of Vetiver fibers at high magnifications.

3.3 XRD Analysis

X-ray Diffraction (XRD) analysis is performed to determine the crystalline structure of Vetiver fibers. Sample preparation involves grinding the fibers into a fine powder and mounting them on a sample holder. XRD patterns are obtained to analyze the crystalline phases present in the fibers and assess their crystallinity index.

3.4 Chemical Composition Analysis

The chemical composition of Vetiver fibers is determined to assess their suitability for textile applications. Cellulose content, lignin content, wax content, ash content, moisture content, pectin content, and hemicellulose content are quantified using standardized methods. Spectrophotometric techniques and gravimetric methods are employed for accurate measurement of chemical constituents.

3.5 Density Measurement

Density of Vetiver fibers is measured to understand their physical properties. Sample preparation involves measuring the mass and volume of Vetiver fibers using a precision balance and a graduated cylinder, respectively. Density is calculated using the formula: Density = Mass / Volume.
Adopting the above-mentioned methodology, the current study was attempted and the results are being discussed as follows.

4. Result and Discussion

The following sections bring out the findings and discussion of the Vetiver fiber and its test towards textile industry implication.

4.1 Cross-sectional Images

The cross-sectional images obtained through Field Emission Scanning Electron Microscopy (FESEM) reveal valuable insights into the internal structure of Vetiver fibers. These images showcase the fibrous arrangement and morphology of the fibers, indicating a dense and uniform composition. The presence of distinct cellulose bundles within the fibers suggests a well-defined structural organization, which is crucial for their mechanical strength and durability. The observed compactness and uniformity of the fibers highlight their potential suitability for textile applications, where such characteristics are desirable for ensuring fabric integrity and performance. Additionally, the FESEM images provide a visual representation of the inherent qualities of Vetiver fibers, supporting their viability as a sustainable alternative in the textile industry. Cross-sectional Images are shown in the Figure 1.

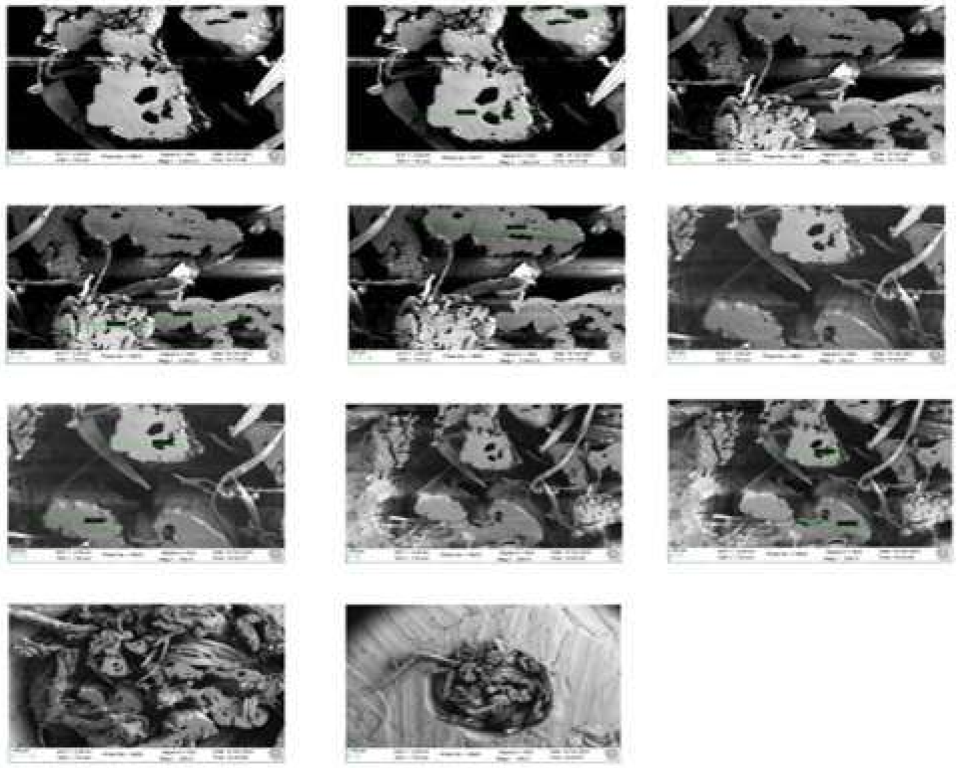

Figure 1: Cross-sectional Images

4.2 Longitudinal Images

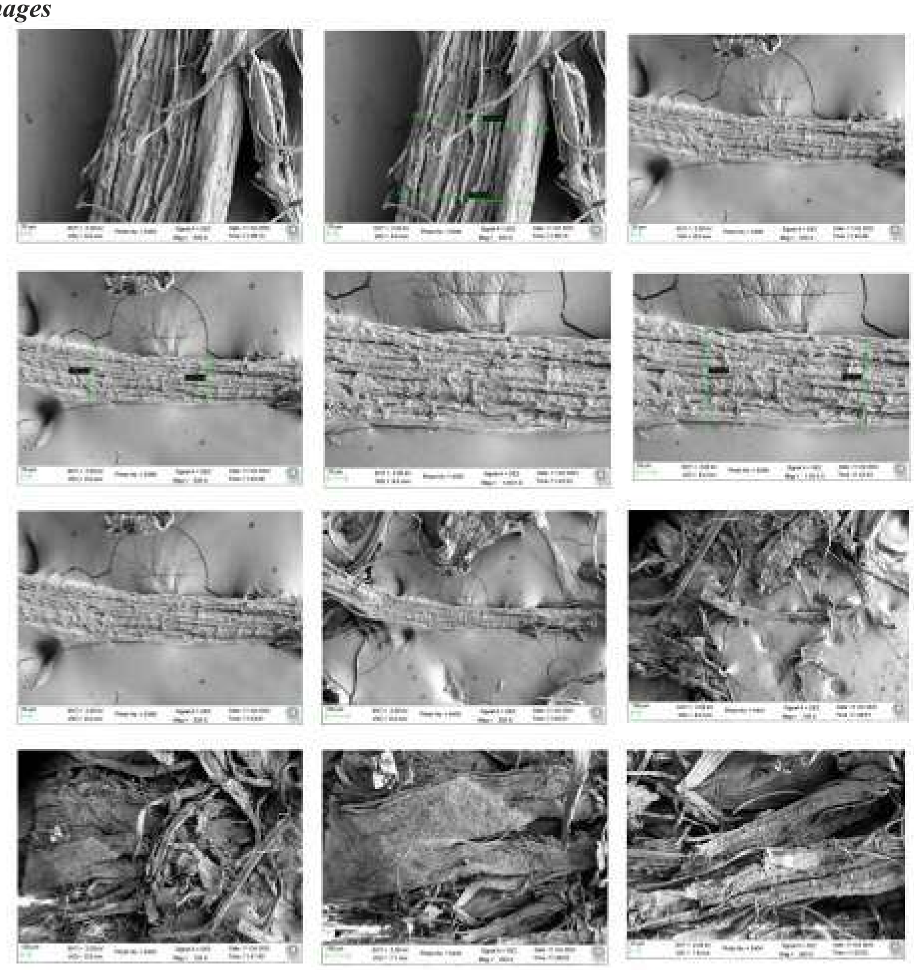

Figure 2: Longitudinal Images

Longitudinal images obtained through Field Emission Scanning Electron Microscopy (FESEM) provide a detailed examination of the morphology and structure of Vetiver fibers along their length. These images offer insights into the surface features, such as texture, roughness, and surface treatments, present along the entire span of the fibers. By observing the longitudinal profile, it becomes possible to assess the uniformity and consistency of the fibers, as well as any variations or irregularities that may be present. The longitudinal view allows for the detection of striations, twists, or other morphological features that could impact the fiber's mechanical properties and performance in textile applications. Longitudinal Images are shown in the Figure 2.

Furthermore, longitudinal images facilitate the identification of any potential defects or abnormalities within the fibers, including cracks, breaks, or impurities. The presence of such defects can have significant implications for the quality and usability of the fibers in textile production processes. Therefore, thorough examination of longitudinal images is essential for ensuring the integrity and reliability of Vetiver fibers as a sustainable textile material.

In addition to assessing structural characteristics, longitudinal images provide valuable information regarding fiber orientation and alignment. The alignment of fibers plays a crucial role in determining the overall strength, flexibility, and dimensional stability of textile materials. By analyzing the longitudinal images, it is possible to evaluate the degree of fiber alignment and assess its impact on the mechanical properties of Vetiver-based textiles. Overall, the detailed examination of longitudinal images acquired through FESEM enables a comprehensive understanding of the physical properties and structural attributes of Vetiver fibers.

4.3 XRD

The following figure provides the XRD for vetiver fiber.

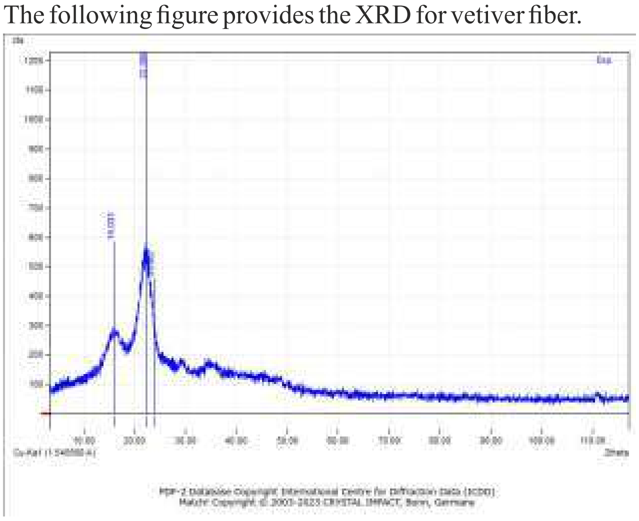

Figure 3: XRD for vetiver fiber

The X-ray Diffraction (XRD) analysis of Vetiver fiber provides valuable insights into its crystalline structure and composition. The XRD pattern reveals characteristic diffraction peaks corresponding to the crystallographic planes of the fiber's molecular arrangement. These diffraction peaks indicate the presence of crystalline phases within the fiber, which can be further analyzed to determine the degree of crystallinity and identify specific crystalline structures. The XRD pattern typically exhibits distinct peaks at specific angles (2θ), which correspond to the spacing between atomic planes in the crystal lattice. By analyzing the position, intensity, and width of these peaks, it is possible to assess the crystalline nature of the fiber and quantify its crystallinity index. Additionally, the XRD results can provide information about the crystallographic orientation, preferred crystal planes, and overall structural integrity of the fiber. XRD for vetiver fiber are shown in the Figure 3.

Interpreting the XRD pattern allows researchers to understand the molecular arrangement and packing of constituent molecules within the Vetiver fiber. This information is essential for elucidating the fiber's mechanical properties, thermal stability, and chemical reactivity, which are crucial factors influencing its performance in textile applications. Overall, the XRD analysis offers valuable insights into the structural characteristics and crystalline properties of Vetiver fiber, contributing to a comprehensive understanding of its potential as a sustainable textile material.

4.4 Chemical Composition Testing

The following Table 1 brings out the chemical composition testing of the vettiver fiber.

Table 1: Chemical composition testing of the vettiver fiber

Fibre Chemical Composition Testing	Natural Fibre
Cellulose Content, %	63.70
Lignin Content, %	16.08
Wax Content, %	0.91
Ash Content (on dry basis), %	4.13
Moisture Content, %	8.79
Pectin, %	6.34
Hemi Cellulose, %	30.95
Density, g/cc	1.18

The chemical composition testing results for Vetiver fiber reveal valuable insights into its composition and characteristics, which are crucial for understanding its suitability for textile applications. Vetiver fiber exhibits a cellulose content of 63.70%, indicating that it is predominantly composed of cellulose, which is known for providing strength and durability to natural fibers. This high cellulose content suggests that Vetiver fiber possesses desirable mechanical properties, making it a promising candidate for textile manufacturing. The lignin content of 16.08% contributes to the rigidity and structural integrity of Vetiver fiber. Lignin serves as a binding material in plant fibers, enhancing their resistance to environmental factors and mechanical stress. The relatively moderate lignin content in Vetiver fiber suggests a balance between flexibility and rigidity, making it suitable for a wide range of textile applications. The low wax content of 0.91% indicates minimal presence of waxy substances on the surface of Vetiver fiber. This suggests that the fiber may exhibit good moisture management properties, allowing for efficient moisture absorption and release during textile processing and use. The ash content, measured at 4.13% on a dry basis, represents the inorganic residue left after combustion of Vetiver fiber. While ash content is typically low in natural fibers, its presence may influence the fiber's thermal properties and combustion behavior, which are important considerations in textile processing and end-use applications. Moisture content, measured at 8.79%, is an important parameter affecting the handling and processing of Vetiver fiber. Proper moisture management is essential to prevent fiber degradation and ensure consistency in textile production processes. The presence of pectin (6.34%) and hemicellulose (30.95%) contributes to the overall composition and structure of Vetiver fiber. Pectin acts as a binding agent in plant cell walls, while hemicellulose provides additional strength and cohesion to the fiber structure.

Finally, the density of Vetiver fiber is measured at 1.18 g/cc, indicating its mass per unit volume. This density value provides insights into the compactness and structural density of the fiber, which are important considerations in textile processing and fabric performance. Overall, the chemical composition testing results highlight the favorable characteristics of Vetiver fiber, including its high cellulose content, moderate lignin content, low wax content, and balanced moisture management properties. These attributes make Vetiver fiber a promising and sustainable option for various textile applications, ranging from apparel and home textiles to technical textiles and composites.

5. Discussion

Vetiver holds significant importance in the textile industry for several key reasons. Firstly, its sustainability makes it an attractive option for environmentally conscious textile production. Vetiver cultivation requires minimal water and pesticides, making it a renewable and eco-friendly resource compared to conventional crops. Additionally, Vetiver's biodegradability ensures that textiles made from this fiber naturally decompose at the end of their lifecycle, reducing environmental pollution and waste accumulation.

Furthermore, Vetiver fibers possess desirable mechanical properties, including strength, durability, and moisture management. Fabrics made from Vetiver fibers are known for their robustness, resilience, and comfort, appealing to both consumers and manufacturers. This versatility allows Vetiver to be utilized in various textile applications, from apparel and home textiles to upholstery and technical textiles. Moreover, Vetiver has cultural significance in many regions where it is native, adding a unique cultural element to textiles and promoting traditional craftsmanship and heritage preservation. In response to increasing consumer demand for sustainable products, there is a growing market for textiles made from natural and eco-friendly fibers like Vetiver.

Research and innovation in Vetiver-based textiles offer opportunities for product differentiation and market competitiveness. Advancements in processing technologies, product development, and value-added applications can further enhance the appeal and commercial viability of Vetiver fibers in the textile industry. Vetiver represents a valuable and versatile resource for the textile industry, offering sustainable solutions that align with evolving consumer preferences and environmental concerns. Its importance lies not only in its practical utility but also in its contribution to a more sustainable and socially responsible textile ecosystem.

The pursuit of sustainability within the textile industry has catalyzed a growing interest in alternative materials that offer eco-friendly solutions without compromising on performance. Among these alternatives, Vetiver grass has emerged as a promising candidate due to its renewable nature, biodegradability, and inherent mechanical properties. To comprehensively evaluate Vetiver fiber's potential for textile applications, researchers have employed a multifaceted approach integrating advanced analytical techniques such as Field Emission Scanning Electron Microscopy (FESEM), X-ray Diffraction (XRD), and chemical composition testing.

FESEM imaging serves as a powerful tool for unveiling the intricate surface morphology and microstructure of Vetiver fiber. The images captured through FESEM reveal a fibrous arrangement characterized by a compact and uniform morphology, suggesting well-defined cellulose bundles intricately woven within the fiber matrix. This fibrous structure not only underscores the natural strength and resilience of Vetiver fiber but also hints at its potential for enhanced mechanical properties, making it well-suited for textile manufacturing applications.

Complementing FESEM analysis, XRD examination offers insights into the crystalline structure and orientation of Vetiver fiber at the molecular level. Through XRD, researchers can identify distinct diffraction peaks corresponding to the crystallographic planes of the fiber's molecular arrangement. These peaks signify a well-organized molecular packing and orientation within the fiber matrix, indicative of its inherent strength and stability. Moreover, the analysis of XRD data enables the determination of the fiber's crystallinity index and the identification of specific crystallographic structures, further enriching our understanding of Vetiver fiber's structural properties and its potential for textile applications.

Chemical composition testing provides quantitative data on the constituents of Vetiver fiber, offering valuable insights into its molecular makeup. The results of chemical composition analysis reveal that Vetiver fiber predominantly comprises cellulose, the primary structural component responsible for its strength and durability. Additionally, moderate levels of lignin, wax, and other constituents are detected, contributing to the fiber's rigidity, resilience, and resistance to degradation. The low wax content observed in chemical composition testing further suggests that Vetiver fiber possesses excellent moisture management properties, enhancing its suitability for textile applications where breathability and comfort are essential.

By integrating the results obtained from FESEM, XRD, and chemical composition testing, researchers gain a comprehensive understanding of Vetiver fiber's structural, crystalline, and compositional properties. The fibrous morphology observed in FESEM images aligns with the presence of cellulose bundles and crystalline structures identified through XRD analysis. Furthermore, the chemical composition data corroborate the structural and mechanical attributes observed in FESEM images and XRD patterns, collectively confirming the favorable characteristics of Vetiver fiber for textile applications.

Looking ahead, future research endeavors in this area may focus on further elucidating Vetiver fiber's mechanical properties under varying processing conditions, exploring its compatibility with textile dyes and finishes, and conducting life cycle assessments to evaluate its environmental impact. Collaboration among academia, industry stakeholders, and policymakers will be paramount in driving innovation and realizing the full potential of Vetiver as a sustainable fiber for the textile industry.

5.1 Limitation of the study

- The study's reliance on laboratory-scale or small-scale experiments might restrict the extent to which its findings accurately reflect the complexities and challenges inherent in large-scale industrial production processes commonly encountered in the textile industry.

- There may be limitations regarding the applicability of the study's findings across diverse geographical regions and varying climatic conditions. Factors such as soil type, temperature, and precipitation can significantly influence the growth and properties of Vetiver grass, potentially affecting its suitability for textile applications in different regions.

- While the study may have extensively analyzed certain aspects of Vetiver grass fiber, such as its structural, crystalline, and compositional characteristics, there could be a lack of exploration into other important properties. For instance, mechanical properties (such as tensile strength and elasticity) and durability considerations (such as resistance to abrasion and degradation) are crucial factors that determine the fiber's performance in practical textile applications.

- Depending on the study's methodology, there might be limitations related to the utilization of a single analytical technique or approach for assessing Vetiver grass fiber properties. Integrating multiple methodologies, such as spectroscopy, microscopy, and mechanical testing, could offer a more comprehensive understanding of the fiber's properties and behavior under different conditions.

- The study's depth and breadth may be constrained by the availability of data and resources. Conducting thorough and exhaustive research on Vetiver grass fiber, including field trials, long-term monitoring, and life cycle assessments, requires substantial investment in terms of time, funding, and collaborative efforts across multidisciplinary teams. However, resource constraints may limit the study's ability to achieve a comprehensive evaluation of Vetiver grass as a sustainable fiber for the textile industry.

5.2 Relevance of the study

- Academia: The study contributes to the academic community by expanding the knowledge base on sustainable fiber materials for the textile industry. It provides valuable insights into the structural, crystalline, and compositional characteristics of Vetiver grass fiber, adding to the scientific understanding of this alternative material. Moreover, the study can serve as a foundation for further research, encouraging academic institutions to explore interdisciplinary approaches and collaborate on advancing sustainable solutions for the textile sector.

- Researchers: For researchers, the study offers opportunities to delve deeper into specific aspects of Vetiver grass fiber, such as its mechanical properties, processing techniques, and environmental impacts. It provides a starting point for conducting more specialized investigations, fostering innovation and discovery in the field of sustainable materials. By building upon the findings of this study, researchers can contribute to the development of novel applications, processes, and technologies that enhance the viability and adoption of Vetiver grass fiber in textile production.

- Industry: The study holds significant relevance for the textile industry by presenting Vetiver grass fiber as a potential sustainable alternative to conventional textile fibers. Manufacturers and stakeholders in the industry can benefit from the insights provided regarding the fiber's properties, processing methods, and potential applications. By embracing Vetiver grass fiber, textile companies can diversify their material sourcing strategies, reduce their environmental footprint, and meet the growing demand for eco-friendly products among consumers. Additionally, the study may inspire industry collaborations with academic institutions and research organizations to further explore and commercialize Vetiver-based textiles.

- · Society: From a societal perspective, the study addresses pressing environmental concerns associated with the textile industry, such as resource depletion, pollution, and waste generation. By promoting the adoption of Vetiver grass fiber, the study contributes to sustainable development goals by supporting practices that conserve natural resources, mitigate climate change, and promote social equity. Furthermore, the widespread adoption of sustainable materials like Vetiver grass can lead to positive societal impacts, including job creation in rural areas, improved livelihoods for farmers, and enhanced consumer awareness and engagement with environmentally friendly products. Overall, the study underscores the importance of collective action from academia, industry, and society in fostering a more sustainable and resilient textile sector.

5.3 Future area of the study

- Scale-Up and Industrial Implementation: Investigate methods for scaling up Vetiver grass cultivation, fiber extraction, and textile manufacturing processes to meet industrial production demands. This includes optimizing agricultural practices, developing efficient extraction techniques, and implementing large-scale processing technologies.

- Mechanical and Performance Properties: Conduct comprehensive studies on the mechanical properties and performance characteristics of Vetiver grass fibers and their composites. Explore factors such as fiber orientation, matrix compatibility, and processing conditions to enhance the strength, durability, and functionality of Vetiver-based textiles.

- Life Cycle Assessment (LCA): Perform life cycle assessments to evaluate the environmental impact of Vetiver grass fiber production and its comparison with conventional textile fibers. Assess key environmental indicators such as energy consumption, water usage, greenhouse gas emissions, and waste generation to provide insights into the sustainability benefits of Vetiver-based textiles.

- Market Acceptance and Consumer Perception: Investigate consumer preferences, perceptions, and acceptance of Vetiver-based textiles through market research and consumer surveys. Explore factors influencing purchasing decisions, such as price, quality, performance, and eco-labeling, to understand market demand and opportunities for commercialization.

- Value-Added Products and Applications: Explore innovative applications and value-added products derived from Vetiver grass fiber. This may include functional textiles, composite materials, nonwoven products, and biodegradable packaging, among others. Investigate emerging technologies, such as additive manufacturing and smart textiles, to expand the range of Vetiver-based products.

- Supply Chain and Social Impact: Examine the entire supply chain of Vetiver grass fiber production, from cultivation to end product, to identify opportunities for improving efficiency, sustainability, and social responsibility. Assess the socioeconomic impact of Vetiver cultivation on local communities, including income generation, job creation, and rural development.

- Policy and Regulatory Frameworks: Analyze policy interventions and regulatory frameworks that support the adoption of sustainable fibers like Vetiver grass in the textile industry. Advocate for government incentives, certification programs, and standards that promote sustainable sourcing, production, and consumption practices.

- Interdisciplinary Collaboration: Foster interdisciplinary collaboration among researchers, industry stakeholders, policymakers, and community organizations to address complex challenges and leverage diverse expertise in advancing the sustainable use of Vetiver grass fiber. This may involve partnerships between academia, government agencies, non-profit organizations, and private sector entities.

6. Conclusion

The textile industry in India is a major pillar of economic growth and social development, contributing significantly to the aggregate gross domestic product (GDP) of the nation as well as the generation of employment opportunities. The adoption of environmentally responsible business practices is becoming increasingly important in the business sector as a response to the growing environmental concerns. This involves the investigation of alternative materials such as vetiver, which is a natural herb that has the potential to be made into a sustainable fibre for use in the creation of textiles. An exhaustive investigation that included the use of X-ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FESEM), and chemical composition testing has resulted in the acquisition of significant knowledge regarding the structural, crystalline, and compositional features of vetiver fibre. Imaging using a FESEM revealed a fibrous arrangement that had a compact and homogeneous shape. This was indicative of well-defined cellulose bundles inside the fibre matrix. X-ray diffraction (XRD) research revealed the presence of various crystalline phases within the fibre, which contributed to a deeper comprehension of the molecular packing and orientation of the fibre. Quantitative information on cellulose, lignin, wax, and other elements was obtained through chemical composition testing, which highlighted the feasibility of vetiver fibre for use in textile applications.

The combination of these findings provides further evidence that vetiver fibre possesses favourable qualities, which positions it as a potentially useful and environmentally friendly option for a variety of textile applications. Because of its high cellulose concentration, moderate lignin level, and low wax content, it possesses qualities that contribute to its strength, durability, and capacity to manage moisture. The structural integrity of vetiver fibre, in conjunction with its environmental sustainability, offers it as a valuable resource for the textile industry. This is in line with the industry's goals of promoting environmentally responsible methods and lessening the impact that it has on the environment. Moving forward, it is necessary to conduct additional research and development activities in order to maximise the efficiency of the processing and utilisation of vetiver fibre in the creation of textiles. In order to fully exploit the potential of vetiver fibre and propel innovation in the textile industry, it is vital for academic institutions, private companies, and government agencies to work together through collaboration. Continuing to prosper while also making a contribution to the preservation of the environment and the advancement of socioeconomic conditions is possible for the textile sector in India if it adopts environmentally friendly materials such as vetiver.

In the textile sector, vetiver fibre is a viable answer for achieving sustainability. It embodies the values of innovation, environmental stewardship, and economic prosperity, making it an ideal candidate for environmental sustainability. Vetiver fibre has the potential to revolutionise the textile landscape, opening the way for a more sustainable and resilient future. This potential may be realised with ongoing investment and support.

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Life Cycle Assessment on Denim: Focus on the Indian Consumer's Phase

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Abstract:
Denim has established itself as a prominent presence in the fashion industry, serving as an essential component in various clothing styles, ranging from formal attire to casual wear. India's domestic denim industry is experiencing significant growth, leading to intense competition in the international denim market. This study primarily investigates the life cycle assessment of denim garments, with a specific focus on energy and water consumption during the consumer phase. The analysis encompasses three distinct demographics in India: urban, semi-urban, and rural areas. This study investigated the consumer phase hotspots of denim garments among different demographic groups. This study finds that the consumer phase of the life cycle has the greatest climate change impact, primarily due to the consumption of non-renewable resources. Specifically, urban consumers in India are found to contribute more significantly to climate change through practices such as drying and ironing, while rural consumers tend to use fewer non-renewable energy sources for these activities. Hence, this study enables the identification of potential changes in the Indian denim consumer phase. Urban consumers tend to consume a greater amount of water and energy compared to other demographic groups when washing and drying their denim garments. Compared to other nations, a significant proportion of Indian consumers prefer cold-cold washing methods. This study helps identify hotspots, enabling actions to reduce environmental impacts in denim production's consumer phase by minimizing energy and water consumption. It also contributes to the attainment of the United Nations sustainability goals (SDGs).

Keywords: *denim consumers, domestic laundering, drying, India, LCA, microplastics*

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1. Introduction

Over the past two decades, the fashion garment sector has seen profound changes including mass manufacturing, growth in the number of fashion seasons, affordable and fast fashion, rising consumer spending, and other related factors. The Indian retail and fashion industry have seen significant expansion over the past two decades, particularly in the areas of western and casual clothing. Among these, denim is one of the fastest growing in the domestic market with a compound annual growth rate (CAGR) of 14.8% between 2021 and 2027, the Indian fashion industry is expected to rise from its 2021 value of $151.2 B to $344.1 B [1]. Worldwide one of the leading segments in apparel fashion is the denim wear segment. For the past decades, one of the most ubiquitous wardrobe essentials is blue denim. Compared to developed countries per capita jeans consumption in India is much lower which indicates a clear scope for growth in the domestic market [2, 3]. The young demographic (15-29) accounts for 26% of the country's consumer base and is the primary growth driver of denim wear [4].

The denim market in India is predicted to grow at a CAGR of 8 to 9% through 2028, reaching Rs. 91,894 crores (~ $12.27 billion) [5]. Denim is more than simply casual wear for most young Indians [6]. Whereas in India until recently, denim was only widely worn in metropolitan and semi-urban centers. Increases in education and access to information via the Internet have led to its rapid development into hitherto untapped rural sectors [6]. On one side, with very huge market potentials and gaining high profit and income, in a populated country like India, environmental impacts are a very series issue.

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It is crucial to address the mitigation of environmental issues arising from consumer products. Textiles and garments, specifically, make a substantial contribution to the generation of solid and liquid waste [7–10]. Additionally, there is growing concern regarding the emission of microplastics during the consumer phase, primarily resulting from domestic washing and subsequent related processes [11,12]. The utilization of Life Cycle Assessment (LCA) has been extensively employed in the evaluation of the environmental impacts associated with the textile industry and various clothing items. Accordingly, it is essential to perform the LCA on the denim to know the true environmental effect, which is guaranteed to raise consumer awareness and ultimately lead to fewer environmental hazards [13–15]. This research has ushered in a new era in our understanding of the environmental impacts of a single pair of jeans among Indian consumers across different demographics, including those in urban, semi-urban, and rural areas.

The most comprehensive approach to assessing the environmental impacts of denim is LCA which is graded by the ISO 14040-14043 industry standard [16–19]. This evaluation was conducted after defining its goal, scope, inventory analysis, conducting an impact assessment, and interpreting the results [20–22]. In the Indian consumer phase, this work provides a conceptual and analytical framework for the LCA of denim. This study was conducted in India concerning demographics including 7 urban, 7 semi-urban, and 7 rural. The average values used to analyze their life cycle assessment, including the global warming potential which is CO2 equivalents (CO2-e), water consumption, and energy consumption are described during the consumer use of one pair of jeans. A more systematic and holistic approach to developing strategies to respond to the environmental aspects of sustainable development in the denim industry concerning the consumer phase has been attempted to integrate it. This study mainly focuses on energy and water consumption, specifically the energy and water utilized in the washing, drying processes and ironing process of denim products in their consumer phase with the help of statistical tools. Despite the environmental implications that are involved with the consumer phase of denim goods, there is still a paucity of analysis about the amount of energy and water that is consumed during that phase. It is necessary to develop a system for locating the hotspots and factors that influence the amount of energy and water that is consumed during the consumer phase of denim garments.

2. Materials and Methods

The goal and scope phase establishes the functional unit of analysis, which includes both women's and men's denim (i.e., weighing approximately 350± 50 g), as well as the specific life cycle stages of interest. The study observed a use phase spanning a duration of 6 months. In this assessment, data regarding consumer use behavior was collected from various demographic groups in India through the administration of surveys. The responses from people living in urban and semi-urban areas were collected using a methodology that focused only on the internet, but in rural areas, face-to-face interviews and a system based on paper were used. The questionnaires (supplement) administered were standardized across all three demographic groups, with a sample size of over 500 participants at each location. The survey required respondents to be at least 15+ years old, residing in specific locations, owning at least one pair of denim with respective weights, and have knowledge of both machine and hand washing methods for denim. The present study seeks to offer consumers an initial understanding of the potential environmental effects of denim by examining various impact categories. The following metrics will be discussed: the global warming potential, referred to as carbon footprint, measured in kilograms of CO2-equivalents (CO2-eq); the non-renewable energy demand; and the water depletion, measured in water-equivalents (water-eq).

2.1. System Boundaries

The system boundaries of the current study are depicted in Figure 1, specifically referring to the consumer phase. Therefore, the system boundaries exclusively encompass the activities related to home laundering, including washing, drying, and pressing.

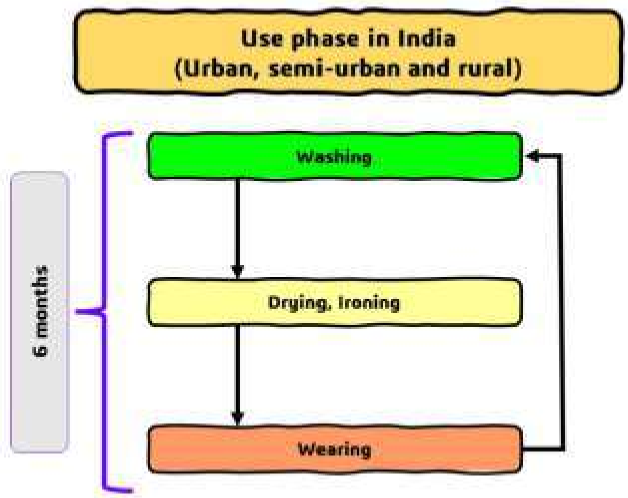

Figure 1: System boundary for the current study

2.2 Environmental Impact Categories

The environmental impact potential is expressed at a midpoint and endpoint level. The description of environmental impact categories is shown in Table 1.

Table. 1 Impact categories and descriptions

Category	Description	Units
Climate change	Global warming potential (GWP) of greenhouse gasses released into the environment.	e-CO_2 emission in kilograms
Water Consumption	Net freshwater taken from the environment minus water returned to the same watershed at the same quality or better.	Liters
Eutrophication	There is no major influence on the consumer phase of the lifecycle of the eutrophication process, but it has a considerable impact on the production phase (i.e., the fiber cultivation stage).	
Land occupation:	The cultivation of fiber is the most intensive use of land in the production of denim.	
Abiotic depletion:	There is no significant impact on the consumer phase of the lifecycle for abiotic depletion.	

3. Results and Discussion

The demographic characteristics of the respondents in each location are representative of the population depicted in Figure 2. In general, female respondents exhibit a 3-7% lower response rate compared to the average response rate of all respondents.

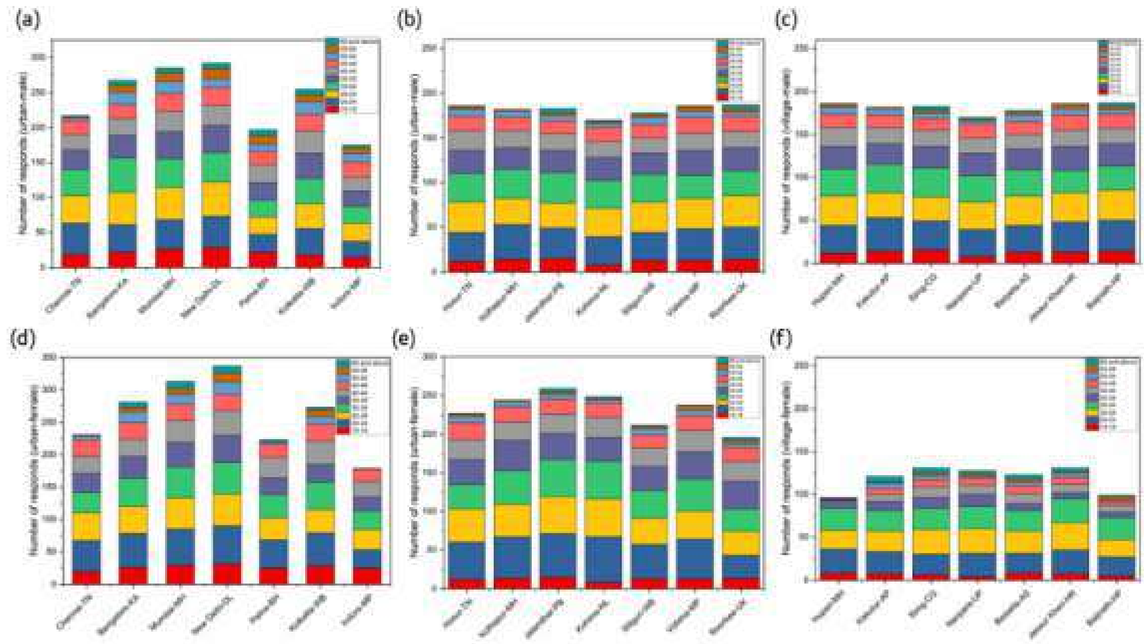

Figure 2 : Male (a,b,c) and female (d,e,f) respondent demographics in India by urban (a&d), semi-urban (b&e), and rural (c&f).

3.1 Washing and wearing frequencies

When conducting a consumer phase LCA for denim, it is crucial to account for the frequency of washes and the overall lifespan of denim garments. The frequency of laundering denim depends on factors such as the number of days it is worn before washing, the duration of use, and the frequency of wearing the garment. This survey specifically inquired about the frequency of laundering a single garment between its usage and overall lifespan. The average number of launderings performed by users from urban, semi-urban, and rural demographics was calculated using the responses for each choice. Rural residents have the lowest frequency of washing their clothing between wearing cycles, with an average of 6.4 washes per cycle (Figure 3a). In addition, rural residents demonstrated a higher lifetime usage rate compared to urban customers, with approximately double the usage (Figure 3b). The economic status of rural, metropolitan, and semi-urban customers varies due to differences in their purchasing habits and requirements. Wearing clothes for longer periods of time is a recommended practice in water conservation. This practice reduces water consumption during the consumer phase of the product lifecycle and minimizes the overall environmental impact. There is a need for increased frequency of washing in urban areas.

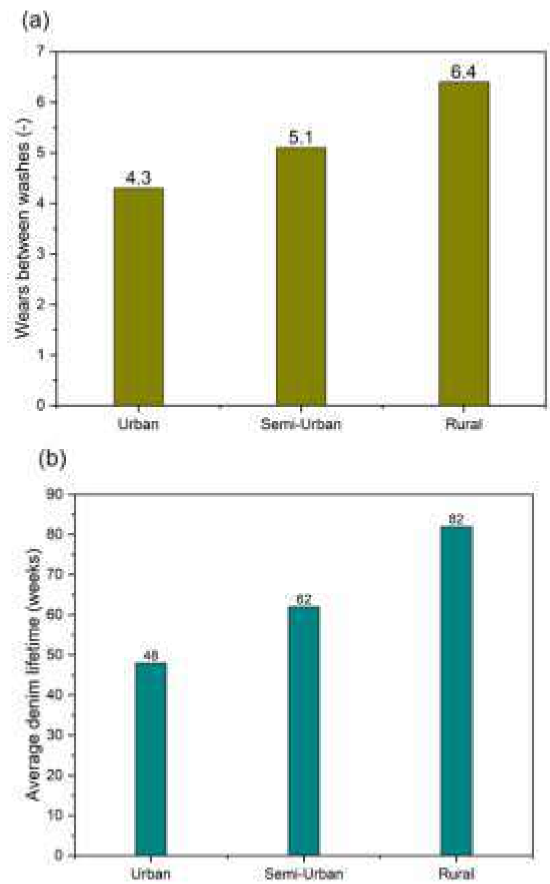

Figure 3 : Number of washings between wearing frequencies (a) and the denim lifetime (b).

3.2 Washing machine and washing type

It has been established that the activity of domestic washing is a substantial global warming potential (GWP) contribution to their life cycle [23]. According to the findings of the survey, most denim consumers who live in metropolitan areas do their laundry at home using a washing machine. The rate of people washing their hands at home in rural was found to be higher, at 69%. It's possible that the lower rates of machine washing in rural areas are due to long-standing cultural activities, lower levels of discretionary spending, or a smaller quantity of available space in homes for washing machines. However, in recent times the rate of machine washing may rise in the future as Indian rural continue to expand and their lifestyles improve. To get a more in-depth understanding of the washing machine technology that was reported, a study was carried out to determine the type of washing machines that are utilized in the various regions of India. In India, the cost of electricity varies by province and can be averaged. The cost of energy on average in India's cities, towns, and rural in 2022. Customers may be more likely to transition from low-efficiency to high-efficiency washing machines due to increased electricity costs in India and the marketing of Energy Star products, lessening the total environmental impact of the garment washing process.

Figure 5 shows the lifetime water intake for one pair of denim concerning different washing frequencies. In fact, the water intake for washing every time you wear is higher than other frequencies, in this case, urban and semi-urban consumers were consuming more quantity of water (1150 and 980 liters) than rural consumers, whereas they consume 815 liters of water with constant washing and wearing cycle (Figure 5a). Among these, rural consumers have good practices by reducing their water intake as compared to urban and semi-urban consumers.

The temperatures of the water also play an essential role in the laundry process since higher water temperatures need more energy and are considered to have a greater ability to mitigate the effects of climate change. During the survey, each participant was given information regarding two different washing temperatures: one for the washing process, and another for the rinsing process. The survey was constructed with three different washing practice options, including cold-cold washing, warm-cold washing, and warm-warm washing. It was reported by the average values of the Indian consumer phase that 99.9% of rural consumers in India use the cold-cold washing procedure. This is because of the traditional way of washing practices and living styles and the most important thing is that they do not prefer to use washing machines. In the meanwhile, 81% of consumers who live in metropolitan areas employ the warm-warm washing process (Figure 5b). Overall, customers residing in rural lowered the amount of energy required for washing denim. The reason for this is that they use of less washing machines and water that is colder; therefore, this has a substantial impact on reducing the amount of energy consumed.

In general, the lowest number of washing frequencies required higher non-renewable energy, the results proven with numerical values. On average, urban consumers use more energy to wash their denim than others, moreover rural

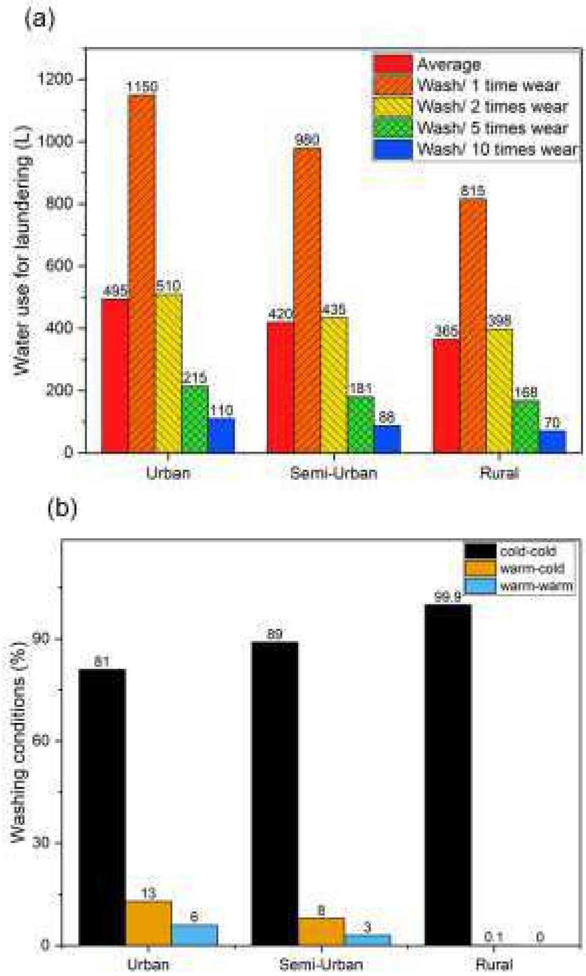

Figure 4 : Lifetime water consumption for different frequencies of washing between wears (a), washing habits (b).

consume less energy as well their washing frequency is less which resulting the lowest amount of energy utilization in the consumer phase of the life cycle. On average, the energy required for 1x washing frequency, urban consumers use 23.1 kWh, semi-urban use 15.4 kWh, and rural consumers 8kWh, which is shown in Figure 5b. On average, the energy required for 1x washing frequency always shows a higher impact on the CO2 emission, particularly with urban consumers showing the highest CO2 emission (11.3 kg e-CO2), it is due to the higher utilization of washing machines as well as the use of warm-cold (i.e., 13% responses) washing procedures. Generally, the climate change impact always depends on the amount of non-renewable energy usage, in this occasion, urban consumers play a vital role in climate change. In all washing frequencies, rural people show fewer carbon emissions (3.2 kg.e-CO2) than urban and semi-urban consumers due to less utilization of washing machines and their living style directly involved in reducing energy consumption (Figure 5b).

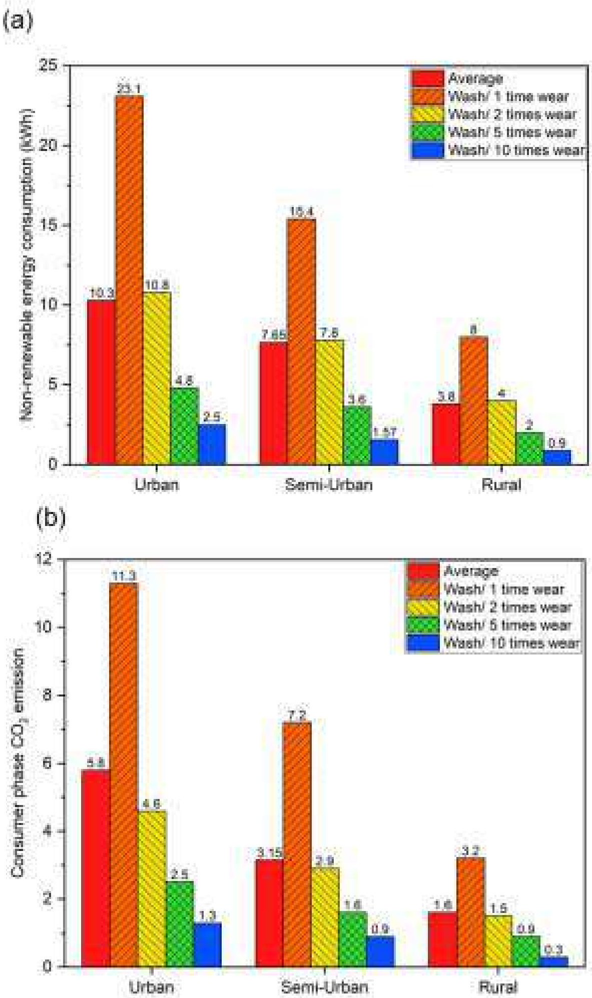

Figure 5 : Lifetime non-renewable energy consumption (a), and emission of CO2 during the consumer phase (b).

3.3 Effect of drying techniques

Drying is an important process which usually carried out after the laundering process, generally, there are two methods of drying, which are line drying (i.e., air drying) and using the machine to dry their denim. However, denim is made through cellulosic fibers (i.e., cotton and lyocell) and it is hygroscopic [24,25], also it is made through coarse counts which results in heavy fabric and absorbs more quantity of water, as a result, denim required more time for the drying process. Normally, the line drying process has many advantages no energy is required, it generally leaves your clothes fresh, mostly it does not require the ironing process and the most important point is environmentally friendly [26]. The only disadvantages of this process are it takes more time to dry the jeans (which may be a few hours to a day or sometimes more particularly in winter). Drying jeans in the line dry is the kind of practice rural people are doing regularly; On average, among this study's data, 88%, 67%, and 54% of the respondents from rural, semi-urban, and urban did not use a machine to dry their denim respectively (Figure 6-a). Like machine drying, the ironing process also impacts the GWP, as it consumes large energy. 12%, 24%, and 31% of the respondents from rural, semi-urban, and urban use ironing after line drying. Overall, rural consumers do not use the machine to dry and as well as ironing, which reduces their electricity consumption.

Urban consumers use ironing, and machine drying for their denim shows huge carbon emissions (Figure 6b), in this occasion, rural has the very least emission of CO2 during after washing process. Therefore, the utilization of line drying can reduce the utilization of non-renewable energy also, it reduces the climate impact. So, no doubt that line drying alone can save the environment as compared to other processes, in this point, the fashion brand should provide this information on their garments, and help to create awareness among their consumers. On average, the consumption of non-renewable energy for drying followed by ironing is the highest and always shows higher carbon emissions than other methods.

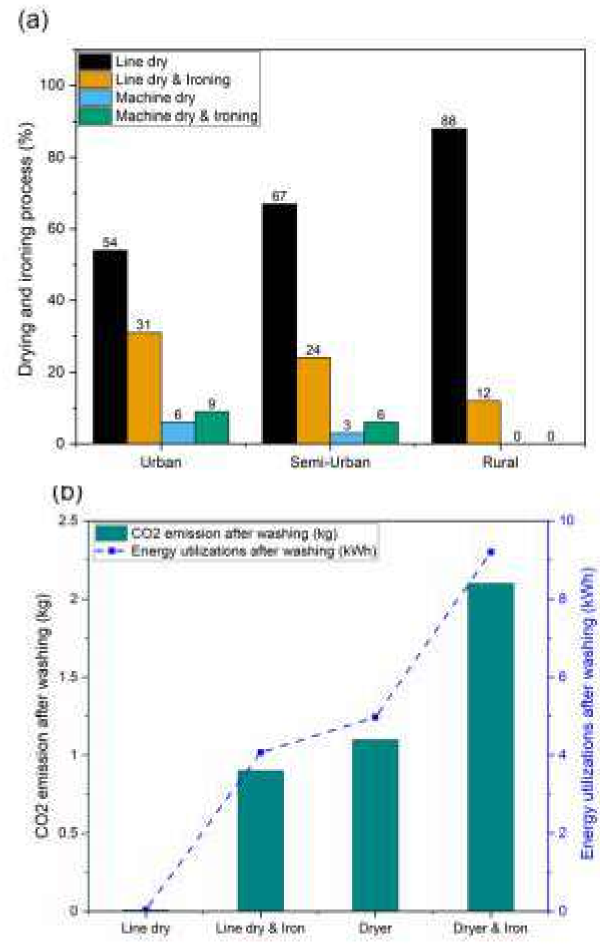

Figure 6 : Responses of drying and ironing process (a), their equivalent CO2 emission and energy consumption.

3.4. End of life of denim

More than one million metric tons of textiles are discarded every year in India, with most of this waste coming from household environments [27]. Nevertheless, even the highest-quality denim has a finite lifespan and will need to be replaced at some point. To gain a better understanding of their consumer use behavior and the end state of denim, a survey was carried out. This was done for two reasons: first, the effects of denim's end of life on waste, and second, the possibility of extending denim's lifespan. According to the findings of the survey, the end of life for denim varies by demographic. In response to the survey question, an average of 40.2% of urban residents said that they throw away their denim once it has reached the end of its life. In addition, 22% of urban residents said that they retain denim in their wardrobe (Figure 6). It is interesting to learn that consumers in rural areas reuse their denim in a variety of ways, such as a pillow cover, as stuffing materials for their mattress, as curtains, as cleaning cloth, and as a raw material for making threads to use in some domestic applications. However, consumers of all three demographic groups keep their old denim in their wardrobes, and because almost the same percentage of respondents from each group was collected, this research will focus on helping those demographic groups comprehend the significance of engaging in environmentally responsible shopping practices.

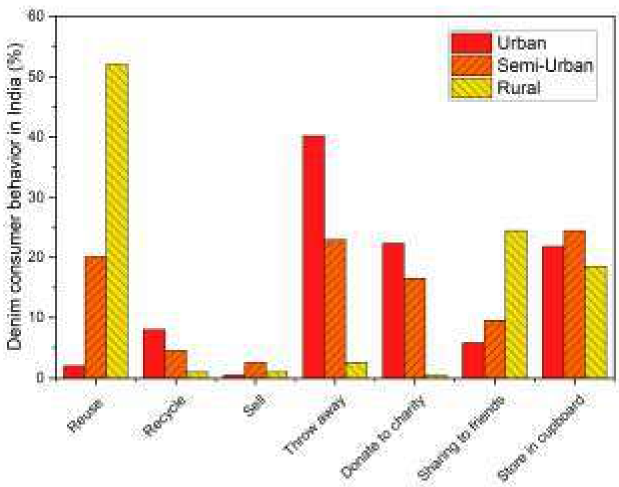

Figure 7 : Responses of end of life of denim consumer's behavior in India.

Recycling denim is the only method to boost their circular economy, and several denim brands are inventing creative techniques for recycling old denim into new denim clothes. These brands include captions such as “we want your jeans back” to encourage consumers to return their jeans, also they provide discounts that the customers can use to buy new garments. The concept of second-hand clothing stores is not very well known in India; however, this is expected to change in the coming years. In these stores, denim can be given additional lives, which not only helps cut down on the overall waste that is associated with clothing but also helps cut down on the impacts that garment production has over the journey of a product's lifetime. Overall, recycling, provides important environmental benefits, like it

- Reduces the need for landfill.
- Reduces pressure on virgin resources (i.e., cotton cultivation, etc.).
- Results in less pollution load, and energy savings.

Moreover, the consumer phase of any garments was responsible for another global threat known as microplastics (i.e., garments made from synthetic fibers) and microfibers (i.e., a garment made from natural fibers). It was determined that one of the key sources of microplastic contamination is created in the washing of textiles and garments. It is anticipated that the presence of microplastic pollution will increase to a greater extent as the human population will continue to grow and as people will continue to wash their garments more frequently [28–32]. Regrettably, denim is also one of the most significant contributors to microplastic emissions, according to the findings of the most current research, the denim fabric that was produced with 97% PET and 3% Lycra was discovered to contain an average of 2300000-4900000 microfibers per 1-kilogram wash load [23]. It confirms that each washing is the most responsible for the release of microplastics, the best way to reduce the microplastic releases could be to decrease the washing frequency, and however, there is no evidence for this statement [33-34].

4. Conclusion

The average washing, pressing, and drying frequencies concerning different demographics. Overall, urban consumers use more water and energy to wash and dry their denim than consumers in the other demography. One interesting finding is that most Indian consumers use cold-cold washing procedures as compared to other nations [3]. From this study, the consumer phase of the life cycle shows the highest impact of climate change due to the number of processes that consumes non-renewable resources, on average urban consumers from India are more responsible for climate change due to the drying, ironing habits, and other related practices, whereas, rural consumers use very less non-renewable energy (warm water, drying, ironing), therefore it reduces the carbon footprint. On the other hand, the urban consumers utilized the highest water consumption (i.e., 1150 liters for their entire lifetime), which is very high as compared to the rural consumers (i.e., 815 liters). Wearing jeans 10 times before washing has a significant influence on water consumption, as a result, denim users are recommended to use this strategy, which will have a significant global climate effect. There is no major influence on the consumer phase of the lifecycle of eutrophication, abiotic process, and land consumption.

i. Data availability

All data generated during this study are available to the corresponding author upon the request.

ii. Conflict of interest

No funding was received to assist with the preparation of this manuscript. The authors have no relevant financial or non-financial interests to disclose.

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Development of Functional Clothing for Sensory Sensitivities of Children with Autism Spectrum Disorder

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Abstract:

Clothing is especially significant to children with Autism Spectrum Disorder (ASD) because it not only helps them to feel independent, secure, and comfortable but also decreases the difficulty of using components of dressing, like buttons, zippers, etc. Due to the delay in developing motor abilities, caregivers of autistic children must aid their children in dressing. Most children with ASD have sensory difficulties, and some clothing attributes like texture, seams, and tags can heighten their sensitivities. The study aimed to design functional clothing for children with ASD tailored to their specific needs of reducing sensory sensitivities and stimming behavior. The objective was also to identify and incorporate clothing components that affect motor limitations, psychological concerns, and social demands. The current study involved children from two special schools for ASD. The methodology used a descriptive and exploratory research approach to gather information on clothing requirements, color and texture preferences, and factors that influence sensory sensitivities and stimming behavior in children with ASD. Data was collected through in-depth semi-structured and structured interviews with caregivers, occupational, and speech therapists, respectively; informal interviews with children with ASD substantiated by detailed observation of their individual and group behavior. After content analysis, a selection of tops and bottoms was constructed for pilot testing on individuals to assess the wearability, utility, and aesthetics of the clothes. Based on the test results, the final range was created with structural and applied design features appropriate for children with ASD that can address the issues of sensory sensitivities and stimming behavior.

Keywords: *Autism Spectrum Disorder (ASD), functional clothing, motor skills, sensory processing, social need*

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1. Introduction

Clothes represent one of the necessities for human existence [1]. Humans are satisfied when their clothes meet a range of needs. Fashion designer Michael Kors famously said, "Clothes are like a good meal, a good movie, and a good piece of music." This comment perfectly demonstrates how clothes are intrinsically connected to our identities on a psychological as well as a physical level [2]. Children's attire is usually more casual than adult wear. Children should wear comfortable clothing with protective characteristics appropriate for their activities because they are very active and energetic [1]. Children with autism may have certain preferences or sensitivities regarding apparel. It is critical to recognize and respect these unique children's preferences to ensure that they feel at ease and comfortable.

Autistic children have certain preferences and sensitivities regarding clothes, such as materials and textures, seamless and tag-less designs, and adaptable clothing options [3]. Adaptive clothing can enhance the comfort and overall well-being of children with autism by considering their clothing preferences and issues related to sensory processing. Children with autism frequently struggle with sensory processing dysfunction. As a result, they could be sensitive to certain fabrics, colors, or patterns. It might be difficult to find clothing that is stylish, comfortable, and functional for those with autism.

Children with autism may experience clothing as harsh or stiff, particularly if they have heightened sensory sensitivities. For some, even minor irritants such as tags and seams can be problematic, leading to discomfort or skin irritation. Given the spectrum of sensory experiences, individuals with hyper-sensitivity may find such features particularly distressing. Therefore, for those with autism, it is crucial to use clothing that is soft and free from potentially bothersome seams or tags, to ensure comfort and minimize irritation [4].

A neurological and developmental condition, ASD affects a person's behavior, ability to learn, and social relationships [5]. Autism Spectrum Disorder affects a person's perceptions and interactions with others, which can cause difficulties with social interaction and communication. The disorder is also associated with limited and recurring behavioral patterns/stimming behavior [6].

The term "spectrum" refers to the wide range of symptoms and severity levels associated with autism spectrum disorder [7, 8]. ASD can affect a person for their entire life, even though it often develops initially in early childhood [9, 10]. Autism may become apparent in early childhood, but the condition is frequently not diagnosed until much later [11]. Even though autism can be diagnosed at any age, it is classified as a "developmental disorder". This is because most symptoms appear within the first two years of life [5].

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This number rises to 1 in 125 among children aged 2 to 6 across five states in north and west India, and 1 in 80 among children aged 6 to 9 [12]. ASD is a broad category that includes a variety of challenges that are characterized by varying degrees of difficulty in social engagement and communication. Additional features include unusual activities and behavior patterns, such as difficulties transitioning between activities, attention to detail, and unique responses to sensations. People with autism frequently co-occur with emotional and behavioral disorders (EBPs), such as sadness, anxiety, hyperactivity and inattention, violent behaviors, and difficulties sleeping or self-harm [11, 13 & 14]. When developing and implementing interventions for individuals with autism and other developmental disabilities, their perspectives must be considered. Community and social activities must be combined with care to improve accessibility, inclusivity, and support [11]. Autism affects daily functioning in a variety of ways. The impact of autism on daily life can vary greatly depending on the unique challenges and strengths of each individual. By identifying and addressing these problems, one can assist individuals with autism in leading happy, meaningful lives. Regardless of a person's neurodiversity, one may create a more accepting and inclusive society by raising awareness, empathetic responses, and supportive measures [15].

1.1 Autism Spectrum Disorder (ASD)

It is a neuro-developmental disorder marked by persistent difficulties with speech, nonverbal communication, social interaction, and repetitive/restrictive behavior [16, 17 & 18]. It has an impact on the neurological system in addition to the person's overall health - mental, emotional, physical, and social. Unfavorable prenatal, perinatal, and neonatal circumstances, such as advanced maternal age and birth before 32 weeks of gestation, are connected to an increased risk of ASD. The prevalence of ASD, which is currently estimated to be between 1% and 2% worldwide, has increased in recent years as awareness has expanded and diagnostics have improved [19]. Being autistic does not mean that a person is ill or suffers from a particular condition; rather, it simply means that their brain processes differently than other individuals. The National Autistic Society states that although autism cannot be cured, it can be improved. Autism is a developmental disability that affects people throughout their lives [20].

1.2 Areas of Development affected by ASD are as follows

- *Social Awareness and Interaction*
  Autism spectrum disorders are characterized by differences in language, understanding, and communication abilities. They have a unique perspective when interacting with others. This results in differences in the way the person interacts with people and builds relationships.

- *Integration and Processing of Sensations*
  Sensory changes can impact not only the eight senses of sight, hearing, touch, taste, and smell, but also vestibular (balance), proprioception (body awareness), and interoception (internal sensations). These variances will vary from person to person, and a variety of factors, such as the surroundings or the time of day, may affect how receptive they are.

- *Thinking Flexibly, Processing Information and Interpreting*
  There are differences in the attention span, interests, and learning styles of people with autism. One method to do this is to be deeply committed to a certain activity. They usually feel safer and more at ease with regularity and structure since it lessens uncertainty, as they are not as adaptive as others.
  Although individuals with autism spectrum disorders are not alike, there are some traits that they share. A person diagnosed with autism spectrum disorder may have behavioral and social difficulties like making eye contact, asking meaningful questions about their interests, initiating, or continuing a conversation, reacting to people appropriately, and using facial expressions suited for the situation, understanding the perspective of others. The individual may also exhibit behaviors like withdrawing from other people; engaging in repeated or stimming activities like rocking back and forth or repeating words; becoming very interested in a specific topic; or finding it difficult to adapt to changes in their environment or daily schedule, varying from neurotypical people in terms of sensitivity to sensory input, such as loud noises, finding it difficult to go asleep.

A person's balance, coordination, and motor abilities can occasionally be affected by autism [21]. Though all autistic people have certain characteristics in common; they are all different because autism is considered a spectrum disorder. The autism spectrum is not a linear range that runs from high to low; rather, it is a spectrum that encompasses all possible differences between people [22].

1.3 ASD can be classified into three levels

Level 1: Needs assistance

A Level 1 person may have social challenges that necessitate help.

They might find it difficult to start discussions with strangers, behave in a way that other people would expect, and stay involved in the conversation. As a result, making friends can be difficult, especially without the right support. In addition, the person may feel uncomfortable in unfamiliar or shifting situations, need help with planning and organizing, or feel compelled to follow rigid behavioral standards.

Level 2: Necessitates significant assistance

Compared to level 1, level 2 individuals need more help.

The person may have trouble speaking effectively even with assistance, and they are more prone to respond in ways that may surprise or be unacceptable for neurotypical people. They may be very wordy, restrict their conversation to highly specific topics, and struggle to read or understand nonverbal signs like facial expressions. One of their actions could be to turn away from the person they are speaking to. It can also be difficult for people with level 2 autism to go about their daily lives since they struggle with change adjustment. When faced with change, they could experience an immense amount of pain.

Level 3: Necessitates extremely strong assistance

Level 3 autism needs the most assistance. They may avoid or restrict social connection, find it difficult to play with friends, show little interest in friends, and find it difficult to form new ones. Both verbal and nonverbal communication will be very difficult for them to utilize or understand. They may find it difficult to change their routines or activities, engage in repetitive actions (such as flipping objects) to the point where it interferes with their ability to function, and become quite agitated if they must shift their focus or job [21].

1.4 The brain of ASD individuals and Sensory disorders

Several changes in the brain have been identified in individuals diagnosed with autism. The brain's overall size as well as the characteristics and skills of different brain regions can vary [23]. One of the earliest indicators of abnormal brain growth during ASD development is head circumference measurements in newborns and early children with autism [9].

The brain's cerebellum is a small, spherical area that sits behind the cerebral cortex. It regulates certain cognitive functions like language, attention, balance, and mobility. Large, abnormal cerebella are commonly seen in people with autism. Along with difficulties with cognition, social connection, and communication, these abnormalities may lead to problems with balance, coordination, and motor abilities [23, 24].

A smaller amygdala in autistic individuals may be associated with increased levels of anxiety and terror. This may contribute to the understanding of why certain autistic people avoid social situations or become quite upset when their routines are disturbed [23, 25]. The cortex lies in the outermost layer of the brain and is involved in higher-order thinking skills such as planning and decision-making. It is also responsible for processing data from the body's sensory organs, such as sight, hearing, and touch [23, 26]. People with autism usually have thicker cortical layers than people without autism. This discrepancy may help to explain why social interaction and communication are often difficult for people with autism. The thicker brain may also be connected to autism's repetitive/stimming behavior and limited interests [23].

To make decisions on how to react to sensory input, the brain can access information stored in memory [27]. Sensory processing is the capacity to process and respond to sensory input. To process information, the body makes use of the following eight sensory systems: Visual (sight), Auditory (sound), Gustatory (taste), Olfactory (smell), Tactile (touch) Interoception (internal sensors for physiological conditions), Proprioceptive (input from muscles and joints), and Vestibular (balance) [28, 29]. Many children with autism do not process information in the same ways as their typically developing peers. Participation problems can arise when a person's sensory processing pattern and their environment do not align and they may exhibit variations in their sensory processing, such as hyperresponsivity (more sensitivity) or hypo-responsivity (lower sensitivity) to specific environmental signals [30, 31].

Color is one of the elements that probably influence human psychology greatly; this is especially true when attempting to comprehend how people with ASD perceive things. According to some studies, color significantly affects children's visual stress. The study by Paron-Wildes, 2005, discovered that 85% of children with ASD had more vivid color vision than typical children and that they are aroused by environments that are vibrant with color. People with autism suffer psychological effects from color because of their sensitivity to it. Soft hues are generally calming and bright colors fascinating to people with autism [20, 32].

Touch sensitivity is a common concern among people with sensory processing disorders, regardless of age. Occupational therapists who have received training in sensory integration would commonly label this issue with touch perception as "tactile defensiveness", "over-responsivity to touch" or "touch sensitivity" [33]. The brain filters out a lot of moderate sensory stimuli, such as touch, background noise, and the sensation of clothing against our skin and a person usually continues without any difficulty or second thought. In the case of individuals with tactile defensiveness, there is no filter. These so-called "non-threatening sensations" turn into a serious problem that can cause tension and worry, making it difficult for them to perform regular tasks [34].

Self-stimulatory behaviors such as repetitive motions or noises are referred to as stimming [35] which could be a whole-body or an isolated stimming activity. Sometimes these activities might be distracting and get in the way of learning or work [34]. Under some conditions, they can be disturbing and interfere with emotional self-control [35].

Children with ASD are more likely than typically developing children to have delays in both the gross and fine motor skills [16]. Poor balance, aberrant posture during movements, and coordination problems with both gross and fine motor abilities can be some of the challenges [36]. According to test findings (Movement Assessment Battery for Children 2 (M-ABC2) and Test of Gross Motor Development-2 (TGMD-2), children aged 3 to 16 claimed that up to 80% of them had a definite impairment in their overall motor skills; similarly, 80% of children with an ASD diagnosis also reported having gross motor delay [16].

When faced with challenges and problems, people with autism can draw strength from their various abilities. Autism does not make someone less than or discourage them from doing anything. They may demonstrate different points of view in response to questions, a strong eye for detail, or a preference for topics that bring them joy [22].

Like all people, for children with autism, clothes have a significant impact on their everyday lives. It is a basic physiological and psychological need because it provides comfort and protection from undesirable outside effects [3]. The ability to be independent, secure, and comfortable while minimizing the difficult components of dressing, such as buttons, zippers, and closing openings, makes clothes even more critical in determining the quality of life for children with autism.

Based on the observations and data gathered from the sources, parents, and caregivers of children with autism must assist their children with dressing. 90% of children with autism, experience sensory difficulties, i.e., they either avoid or become anxious about certain sounds, textures, or smells [20].

Children with autism spectrum disorders frequently experience difficulties with their motor abilities, especially when it comes to dressing themselves [20]. In the current paper, this issue has been thoroughly addressed by including self-help features that allow children with ASD to dress up with psychological and physical comfort.

1.5 Common Clothing Sensitivities among Autistic Individuals

For individuals with autism, some garment components may trigger sensitivity. Each person may have varying levels of sensitivity hence it is important to highlight the key factors that affect their comfort, sensory needs, and overall well-being.

a) Understanding Sensory Sensitivities

- Hyper or Hyposensitivity: Children with ASD may be extremely sensitive to certain textures, seams, or tags in clothing.
- Textures: Soft, seamless, and tag-less clothing is often preferred. Natural fibers like cotton are breathable, absorb moisture, and can be more comfortable than synthetic materials.
- Avoiding Irritation: Clothing should avoid tight fits, rough fabrics, or labels that might cause discomfort or distractions.

b) Ease of Dressing/ Self-Help Garments

- Simple Fastenings: Elastic waistbands, large buttons, magnetic fasteners, etc., can help children dress independently.
- Adaptability: Clothes should be easy to put on and take off, especially for children who struggle with fine motor skills.
- Elastic and Adjustable: Consider clothing that can be self-reliant, such as elastic and adjustable waistbands.

c) Safety Considerations

- Non-toxic Materials: Clothing should be made from materials that are safe and free from harmful chemicals, as children with ASD might have heightened sensitivities.
- Avoidance of Hazards: No loose strings or cords that could pose strangulation risk, especially for younger children.

d) Comfort and Movement

- Flexible Fabrics: Clothing should allow for a full range of motion, as many children with ASD benefit from physical activity.
- Layering Options: Provide the ability to add or remove layers easily, as children with ASD might have difficulty regulating their body temperature.

e) Clothing Options

- Compression Clothing: Some children with ASD find comfort in wearing compression garments, which can have a calming effect.
- Control of Temperature: Individuals with ASD may have difficulties regulating their body temperature due to differences in sensory processing, autonomic function, sweating responses, and difficulty in communicating discomfort, which makes them more vulnerable to clothing that traps heat or restricts airflow. Comfort could be improved by using breathable, moisture-absorbing, and moisture-wicking fabrics [37].

f) Style and Social Considerations

- Age-appropriate Fashion: Ensuring that clothing is not only comfortable but also aligned with the child's age and social context can help them feel more included in peer group and society.

- Avoid Over-stimulation: Choose clothing with simple designs and patterns to avoid overwhelming children who may be sensitive to visual stimuli.

2. Significance of the study

The project intends to develop clothing that is adaptive and functional keeping sensory sensitivity, stimming behavior, and ease of dressing with self-help features as essential factors of consideration. Functional apparel is designed to improve the quality of life for children with autism, whose skills and gross and fine motor skills development are different from those of children with typical development. Children with ASD also experience clothing sensitivity hence, the creation of clothing that is specifically customized to meet their needs is essential. Throughout the design process, consideration is given to social needs, psychological aspects, and physical limitations. For children with ASD, the clothing should be simple to put on, cozy, secure, and incorporate self-reliant elements. The clothing developed is expected to have psychological advantages in addition to aiding in improved sensory and social integration with society.

3. Objectives of the study

1. To identify the clothing needs and challenges experienced while dressing by children with ASD
2. To understand the sensory sensitivities concerning clothing in children with ASD.
3. To understand the aspects that influence stimming behavior in children with ASD
4. To develop a range of clothing that is suitable to provide comfort from sensory sensitivities and stimming behavior.

4. Materials and Methods

To learn more about the clothing requirements, preferred colors and textures, and variables influencing stimming activity in children with ASD, the study used an exploratory and descriptive research methodology. Close observation of the children's individual and group behaviors, as well as in-depth semi-structured and structured interviews, were used to collect data. To evaluate the wearability, usefulness, and aesthetics of the clothing, a range of top and bottom wear was made following content analysis and used in subject pilot testing. With structural and applied design appropriate for children with ASD, a final range was created based on the test results.

Area Selection: Two special schools for autistic children were chosen as the research locations.

Sample selection: Five occupational therapists, three speech therapists, seven special educators and caregivers, and 30 autistic children in the age range of 6-10 years old comprise the sample.

Tools of Data collection included in-person observations, expert opinions, a sample of autistic children, and extensive semi-structured and structured interviews with therapists (occupational therapists, speech therapists), special educators, and caregivers.

Personal interviews were done for the research project involving occupational therapists, speech therapists, special educators, and caretakers. Additionally, observational, and experimental studies on preferred textures, colours, and designs were carried out with children who have ASD. To do this, a sample of 30 children, comprising 10 from level I, 12 from level II, and 8 from level III ASD, were chosen using purposive sampling techniques.

Children with ASD completed three different kinds of tasks: one involving fabric texture, while the other two involved color preferences and motor development.
The activities were carried out under the direction and supervision of qualified occupational therapists and special educators.

5. Results & Discussion

The study was carried out to analyze the clothing-related challenges faced by children with ASD. The content analysis of the interviews and observations provided data on the clothing needs of children with ASD, fabric, and color preferences, and sensory and motor developmental deficiencies that impact their daily life.

The factors that affect the sensory behavior were categorized [Table 1 and 2] and the results provide directions for modifications that can be implemented in the garments made for children with autism.

Table 1 reveals that children's preferences for cool and smooth denim were 33%, followed by 23% for knit and corduroy and 30% of children liked blue and 23.33% favored pink and green.

Table 2 shows the analysis of the gap between market-available clothes and the needs of children with ASD. The dressing-related issues faced can be resolved by considering the needs and requirements of children with ASD like using cotton-based fabrics, preferred colors, seamless construction, minimal trims, no tags, elastic waistbands, magnetic fasteners, and zippers in place of buttons, flexible front and back garments and smart opening methods keeping in mind the sensory sensitivities which are described in greater depth below.

Table 1 – Distribution of the respondents according to their preferred clothing attributes (n=30)

Sr. No.	Attribute	Category	No. of Respondent	%
1.	Fabric/Textile function	Denim Corduroy Knit Rubber print Felt Un-cut pile	10 07 07 01 02 03	33.33 23.33 23.33 3.33 6.66 10
2.	Colour	Blur Green Red Yellow White Black Pink	09 07 01 03 02 01 07	30 23.33 3.33 10 6.66 3.33 23.33

Table 2 – Analysis of clothing needs for autistic children and their implementation methods

Requirements of design implementations	Findings	General aspect in context to children with ASD	Observation	Design implementation
Standard criteria for creating collections for individuals with special needs.	Delayed motor development	**Physical attribute**	Gap analysis-Lack of availability of special clothing for ASD children	Functional & aesthetic garments with features added as per the requirements of ASD children
Design modification based on the needs of children with ASD	Slow mind and academic growth due to brain development	**Psychological**	Difficulties in wearability	Easy to wear clothing with self-help features
Latest garment design collection for kids	Fashion trends for children wear	**Design**	No specific implementation for sensory difficulties	Including sensory integration details in garments
Suitable fabric	Fabric and material theory	**Material**	No specific material being used based on ASD requirements	Comfortable & breathable material to enhance ASD children's activities
Clothing with a multipurpose design concept	Functional features	**Functional**	Limited functionality in clothing for ASD children	Incorporation of functional features
Color implementation	Color theory	**Color**	No color specification with regards to the children with ASD	Specific colors used based on ASD children's preferences

5.1 Clothing requirements

Children with ASD have unique physiological and psychological needs that influence their clothing preferences, some key considerations are sensory sensitivities from fabric and color, stimming behavior, motor development, safety, temperature regulation, and ease of use.

Sensory issues with clothes can be problematic for children who are uncomfortable wearing certain types of clothing due to their sensory sensitivities [38]. Developing independence and confidence in dressing skills through suitable approaches and techniques can improve the daily routine and quality of life for children with ASD. The features added were easy-to-wear clothing such as pull-on/elasticated bottoms, flexible front, and back bottoms because they get confused between front and back, garments without labels and tags (printed labels), and clothing with flat seams, which are ideal for all three levels of autism [Fig. 1].

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labels), and clothing with flat seams, which are ideal for all three levels of autism [Fig. 1].

Figure 1: #Style 1 for Age Group 6-10 years

Fabric

Many individuals with autism have unique anticipation in response to touch, certain clothing items, or labels and tags on clothing. People with autism experience anxiety and distress when they come across certain unpleasant stimuli, or undesirable textures in their environment [39, 40]. Depending on their texture, fabrics can be either calming or aggravating. This ability is simply enhanced for many individuals and children who have higher sensitivity and ASD [41]. It has been observed that children with autism tend to feel happy and comfortable when they are wearing smooth and soft fabrics [Table 1].

An experimental study comprising of 30 children from all three ASD levels i.e. 10 from level I, 12 from level II, and 8 from level III—was carried out for this research. Different

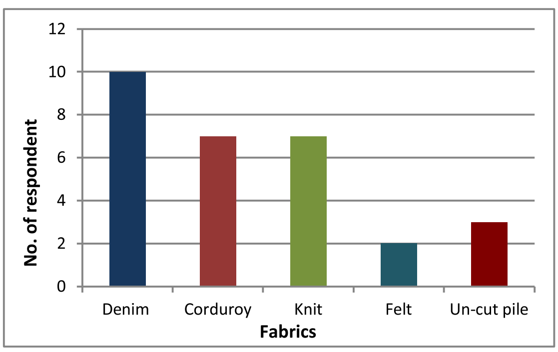

Figure 2: Fabric preferences by children with autism of level I, II and III

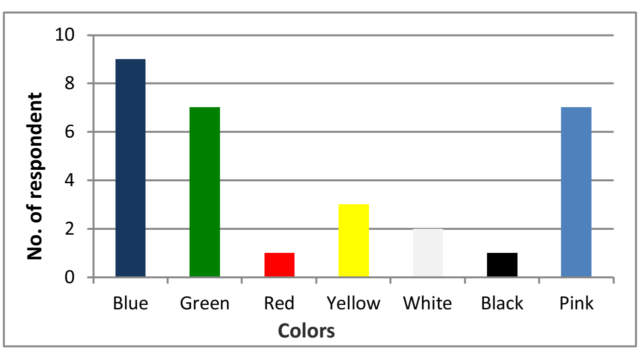

Figure 3: Color preferences by children with autism of level I, II and III

fabrics including knits, uncut pile textiles, fur, felt, velvet, denim, and corduroy, were introduced to each child. A greater inclination for knits, corduroy, and denim was indicated by 80% of children across all three levels [Fig. 2]. Additionally, since fur fabric can cause children to become distracted from their work and engage in stimming behavior, instructors do not recommend it.

Breathability

Sensory sensitivity is common in people with autism spectrum disorder (ASD), which may interfere with their ability to regulate body temperature [42, 43]. Therefore, this element was taken into consideration when choosing the materials, and no interlinings were used in the development of the clothing. Cotton-based materials were utilized like cotton-based knit fabric, as preferred by all 3 levels of children with features such as softness, stretchability, air permeability, and wrinkle and tear resistance. Denim is durable and strong, whereas corduroy's thick weave makes it resistant to wear and tear, and the ribbed structure hides stains and other flaws. Depending on the thickness, these three textiles are suitable for both summer and winter use.

Touch Sensitivity

Children with autism are not comfortable with rough textures, so they are introduced to new textures at an early age (6-8 years) to get familiarized. As a result, touch sensitivity develops earlier than later in life. Textures in the form of applique (using felt, uncut pile, etc.), patchwork, and embroidery were used in the garments to develop touch sensitivity [Fig. 4].

Figure 4: Different Textures to develop touch sensitivity

Color

As discussed, children with ASD see colors more intensely than other children and are aroused by color-rich environments. People with autism suffer psychological effects because of their color sensitivity. Bright colors fascinate people with autism, whereas soft colors calm them. The same sample of ASD children was used for the color activity. In this exercise, thumb and hand impressions were obtained to determine color preferences and fine motor skills. They were introduced to a variety of warm, cool, and bright colors, including blue, green, red, yellow, white, black, and pink. The results from all three levels reveal that 30% of children liked blue and 23.33% favored pink and green [Fig. 3].

5.2 Stimming Behavior

Under some conditions, children with ASD may stim. Stimming itself does not always provide an issue; it only does so when it interferes with learning, isolates a person from society, or becomes harmful [35].

Changes have been made to the clothes for children with ASD to decrease stimming behavior. The rib knit structure has been employed in place of woven cuffs and collars, which is an ideal feature for all three levels of autism. According to the data collected, cuffs, collars, strings, etc., are reported to activate the stimming activity. Typically, the length of ribs is two inches; however, to decrease stimming activity and give soft compression at the wrist and ankle areas, three inches of ribs were provided for children with ASD. Furthermore, as previously mentioned, stimming behavior also affects the vestibular (balance) sensory system of the body. To prevent potentially dangerous scenarios, knee and elbow paddings have been incorporated into the clothing, which is an ideal feature, particularly for level 3 children with ASD and for children in the age range of 6 to 8 years who require additional protection from falls in their clothing [Fig. 5 & Fig. 6].

Figure 5: #Style 2 for Age Group 6-10 years

Figure 6: #Style 3 for Age Group 6-10

5.3 Motor Development

Easy-to-wear clothing with pull-on bottoms and zipper openings is well-suited for children with all three levels of ASD, while for level 3 children, magnetic buttons can be considered. These modifications were made in consideration of the motor development delays observed in children with ASD. To enhance fine motor skills and build self-reliance in children aged 8-10 years, button openings were incorporated in certain cases [Fig.7 & Fig. 8].

Figure 7: #Style 4 for Age Group 10-12 years

Figure 8: #Style 5 for Age Group 10-12 years

6. Conclusion

Children with autism spectrum disorder have a variety of symptoms, but the majority exhibit sensory processing issues, particularly when it comes to clothing. Their unique apparel design requirements are critical to their social presence and quality of life. Autistic children have special needs. When developing clothing for children with autism, the current research focused on developing garments that were more functional and aesthetic, so fashion characteristics are embedded in clothing too. The emphasis was on bridging the gap between the limitations in the available apparel and the clothing requirements mentioned by caregivers, therapists, and children with autism. The criteria covered aspects such as safety, functionality, comfort, psychological, social, and aesthetics. The content analysis of interviews and observations with therapists, caregivers, special educators, and children with ASD resulted in a list of clothing requirements and issues that children with autism confront daily.

To meet the special needs of children with ASD, the range developed includes a set of upper and bottom garments designed with careful consideration of sensory sensitivities, ease of dressing, and comfort and movement. Fabrics such as cotton-based knits, denim, and corduroy were chosen for their softness and flexibility, while functional features like pull-on designs and flexible front-back bottoms enhance the ease of dressing. Safety considerations were addressed through the incorporation of padding and ribbing in place of cuffs and collars, reducing discomfort and potential hazards. Additionally, the inclusion of style and social considerations, such as applique work, patchwork, and embroideries, ensures that the clothing not only meets practical needs but also supports the child's social presence and self-expression. This comprehensive approach aimed to improve the overall experience of wearing clothing for children with autism, enhancing their quality of life and facilitating their social interactions.

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Incorporation of Nanotechnology in Textile and its Economic and Environmental Aspects

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Abstract:

The investigation of materials having a length between 1 and 100 nanometers is known as nanotechnology (NT). When a material's dimensions are reduced to the nanoscale range, its characteristics significantly change. The textile industry is currently investigating the use of nanotechnology. With the goal to alter the physical, chemical, and biological properties of materials (atoms, molecules, and bulk matter) for the purpose to produce new materials, devices, structures, and systems that are better, we can define nanotechnology in the textile industry as the process of understanding, manipulating, and controlling matter at the above-mentioned length. It is employed to create textiles with the desired attributes, including high tensile strength, a distinct surface structure, a soft hand, durability, water repellency, fire retardancy, antimicrobial properties, etc. The development of nanotechnology in the textile industry has created a number of opportunities and challenges for the sector, all of which are thoroughly discussed in this article. The summary of contemporary applications of nanotechnology to textile fibres, textiles, and yarns is the primary goal of this work.

Keywords: _Economic, Environmental, Fibres, Nanotechnology, Nanoparticles, Textile_

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1. Introduction

Due to the widespread perception that nanotechnology holds enormous promise for a diverse variety of end uses, it is gaining more and more attention on a global scale. Due to their enormous economic potential, businesses have been interested in nanomaterials due to their novel and distinctive features [1-3].

The use of nano textile materials for numerous cutting-edge applications has recently been considered as having a significant promise. Nanoscience is the study of objects with dimensions smaller than a nanometer, or 10-9 (one millionth of a millimetre) [4]. Utilising nanoparticles and nanomaterials within cutting-edge products is known as nanotechnology. One of the most widespread uses of nanotechnology is in textiles. By utilising nanotechnology in textiles, innovative finishes and materials can be created that can be used for high-end applications like filtration down to the nanoscale, breathable sportswear, and protective fabrics for chemical and medical professionals.

The nanofibers exhibit a variety of advantageous properties, as previously mentioned, making them crucial in a wide range of applications. The most adaptable technology used today to create nano-scale materials is electrospinning. On the textile substrate, it is also used to engineer nanoscale materials. The nanomaterial created with this technology is highly porous and has a higher surface area, which makes it suitable for cutting-edge uses. By using a few unique suitable additives during electrospinning, a superior product for a particular purpose can be created.

Textile goods are already finding uses in a variety of technical and sophisticated application fields. Still, nanotechnology and nanoscience have already shown their usefulness in producing some textile materials as small as a nanometer, showcasing highly porous fibres and high surface areas that demonstrate the appropriateness for cutting-edge applications. The majority of nanoscale textile products come in the type of nanomembranes or nanofibres. Due to their precisely designed structures and nanoscopic size, these materials have extraordinary capabilities that offer exceptional electrical, magnetic, optical, biological, thermal, and mechanical qualities.

The nanofibers can be created using a variety of methods, including centrifugal spinning, electrospinning, melt blowing, drawing, template synthesis, phase separation, and extrusion of biocomponents [5]. The successful application of nanofibers for tissue engineering, thermal resistance, biomedical products, filtration down to the nanoscale scale, protective equipment for military, chemical, and healthcare workers, and breathable sportswear is possible. These cutting-edge application textiles can be produced with success by incorporating nanofiber, nanoparticle, and nanotechnology additives into textiles.

2. Nanomaterials Needs

The standard textile methods have some restrictions that limit their ability to produce filaments beyond the

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microdenier range. A fabric made from these filaments won't have pores with a nanometer-sized diameter. This material should have more layers if we want the pore size to decrease as we increase both mass and thickness per unit area; as a result, it becomes more difficult to use in some advanced applications.

For instance, in the case of an artificial kidney, the membrane should permit the passage of waste material but should not permit the passage of valuable proteins or blood particles. Furthermore, the mass membrane should not permit any hazardous gas or microorganisms to get through. A nano-membrane is a material that is permeable and exhibits persistent impermeability to gases and water vapour as well as to any liquid or water.

Nanotechnology can be used to develop advanced effects on common textile products, such as durability, softness, and breathability. It can also be used to develop advanced properties, such as antimicrobial resistance, fire retardancy, water repellency, and various advanced applications in the medical field. This feature makes it easier to use them to create protective gear for medical professionals that provides both the necessary level of comfort and protection from any infectious fluids. Additionally, blood can be repelled by nanocoating in order to prevent accumulation of blood on medical personnel' protective garments as well as penetration of the clothes with blood. Since a regular textile material is unable to fulfil all of the aforementioned conditions, a nanomaterial is therefore required.

3. Application in properties of textile materials

Water repellency, soil resistance, wrinkle resistance, anti-bacterial, anti-static, and UV protection, flame retardancy, improved dye capacity, self-cleaning materials, and other qualities can be added to textiles using nanotechnology [6].

Figure 1: Nanotechnology in textile

Among them important applications are described below

3.1 Water Repellence

Nano-whiskers, which are hydrocarbons that are 1/1000 the size of a conventional cotton fibre and are added to the fabric to generate a peach fuzz effect without reducing the strength of cotton, are created by Nano-Tex to increase the water-repellent ability of cloth. Water remains on atop of the whiskers as well as above the fabric's surface because the gaps between the whiskers are less than a typical water drop but still bigger than water molecules. If pressure is applied, yet, liquid can still travel through the fabric. While still able to breathe, the performance is ongoing [7].

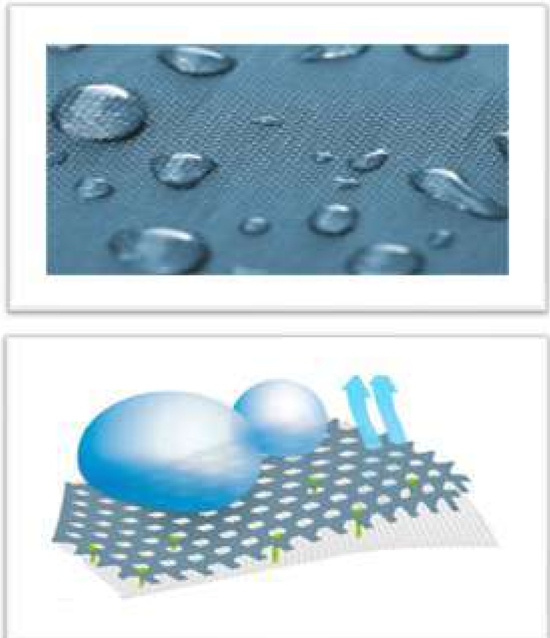


Figure 2: Water repellence in fabrics

3.2 UV Protective Finish

Protecting the wearer against the elements is one of the garment's most crucial tasks. However, it also serves to shield the wearer from the sun's damaging rays. The term "ultraviolet radiations" refers to light with a wavelength between 150 and 400 nm. A dye, pigment, delustrant, or ultraviolet absorber finish that absorbs ultraviolet radiation and prevents it from passing through a fabric to the skin improves a fabric's ability to block UV rays.

When opposed to organic UV-blocking compounds, metal oxides like ZnO are more stable. Nano ZnO will therefore significantly improve UV-blocking properties due to their increased surface area and high UV absorption. ZnO nanoparticles outperform nanosilver in terms of cost-effectiveness, whiteness, and UV-blocking ability for antibacterial finishing.

A person's exposure to UV rays is reduced and their skin is protected from potential damage by clothing made of fabric coated with UV absorbers to ensure that the garments reflect the sun's harmful ultraviolet radiation. The level of skin protection needed for various human skin types depends on the intensity & distribution of UV radiation in relation to geographic location, time of day, and season. SPF (Sun Protection Factor) is a measure of this protection; the greater the SPF value, the better the UV radiation protection [9-12].

Figure 3: Representation of UV protective finish

3.3 Self-cleaning Fabrics

Since 1990, stain-resistant jeans and khakis have been readily available, as have self-cleaning cotton fabrics known as nano-care and Nanotex. By altering the cylindrical structure of the cotton fibres that make up the fabric, nanocare textiles are produced. Cotton threads resemble tree trunks when viewed at the nanoscale. These tree trunks are covered in a fuzz of tiny whiskers made using nanotechnology, which surrounds the fibre with an air cushion. Water beading on the whiskers' points creates extra buoyancy by compressing the air in the spaces between the hairs as it contacts the cloth. Technically speaking, the cloth has been either extremely waterproof or extremely hydrophobic. There are fewer places of contact for dirt because of the whiskers. When water is put to filthy fabric, the dirt is transported away with the water as it beads up and rolls off the surface of the fabric because the dirt sticks to the water far better than it sticks to the textile surface. Thus, the lotus plant's leaves serve as the foundation for the idea of soil-cleaning [13].

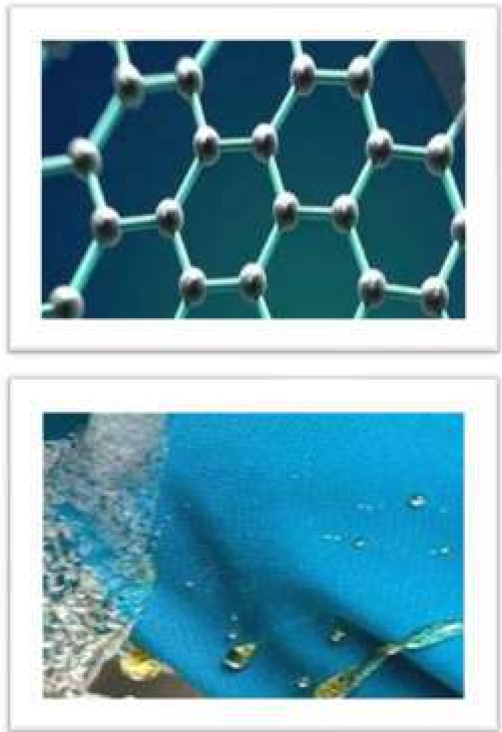


Figure 4: View of self-cleaning fabrics

3.4 Anti-static Finishes

Because synthetic fibres like nylon and polyester absorb little water, static charge typically accumulates in these materials. As a result, no static charge can build up since cellulosic fibres have more water in them that carries away static charges. Due to the poor anti-static qualities of synthetic fibres, research was done on how to improve the anti-static properties of textiles using nanotechnology. It was shown that synthetic fibres might acquire anti-static qualities by incorporating nano-sized titanium dioxide, zinc oxide whiskers, antimony-doped tin oxide (ATO), and silane nano sol. TiO2, ZnO, and ATO are electrically conductive materials that have anti-static properties. This type of material effectively dissipates the static charge that has built up on the fabric. On the other hand, silane nano sol enhances anti-static qualities because the silane gel particles on the fibre absorb moisture from the air through amino and hydroxyl groups as well as bound water [14, 15].

Figure 5: Effect of anti- static finishes

3.5 Nano Technology for Wrinkle Free Treatment

In an effort to give an alternative to abrasive conventional methods, Nano-Tex has introduced a novel wrinkle-free treatment based on nanotechnology that promises to improve performance while maintaining the strength and integrity of the fabric. A fabric's rip and tensile strength are decreased by chemicals and processing techniques. This means that some fabrics and clothing items, including lightweight fabrics or slim-fitting clothing, are traditionally not candidates for wrinkle-free technology, despite the fact that they are popular and handy for consumers who are short on time. In other cases, materials must be over-engineered or strengthened in order to withstand the fibre deterioration

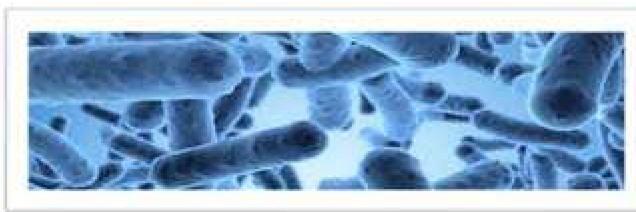
Figure 6: Before and after wrinkle free treatment view

brought on by conventional wrinkle-free techniques. Either way, present technologies are ineffective for all materials or the brand/retailer must spend more money to account for the damaging effects of wrinkle-free chemistry.

The new Fortify DP technology from Nano-Tex uses a molecular structure at the nanoscale to permeate the fibre more deeply and enhance wrinkle-free performance. It also makes use of a longer and more flexible cross-linking chain, which lowers the tensional load on the fibre and, consequently, the major strength loss connected to conventional wrinkle-free chemistry [16-18].

3.6 Anti-bacterial Finishes

Nano-sized zinc oxide, titanium dioxide, and silver are employed to provide anti-bacterial characteristics. Metallic ions and metallic compounds have certain sterilizing properties. According to this theory, a portion of the oxygen



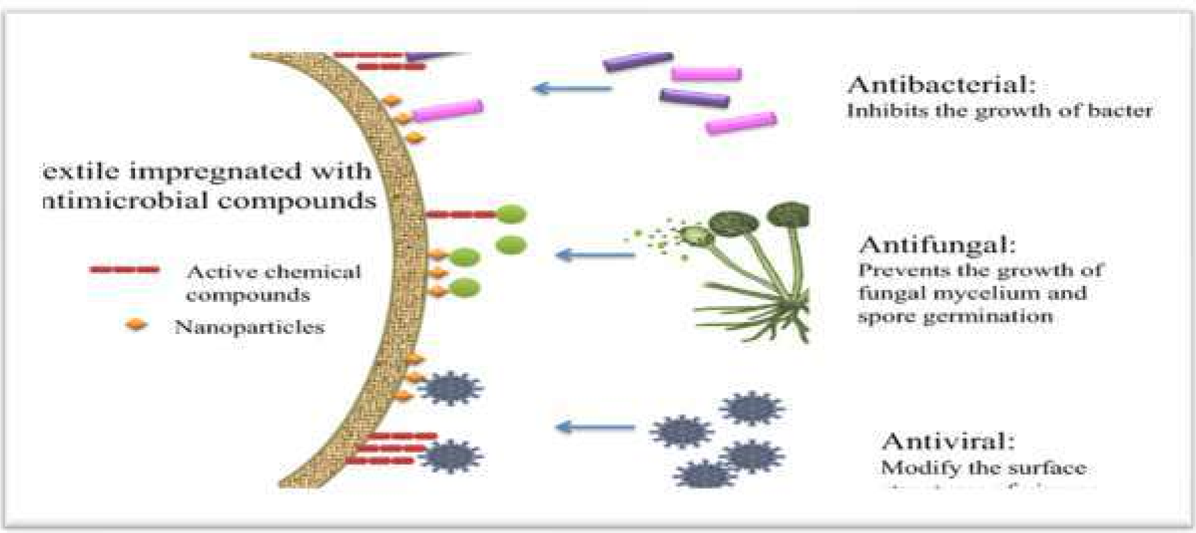


Figure 7: Effect of moisture regains on the refractive index of fibers

in the air or water is catalyzed by the metallic ion to become active oxygen, which dissolves the organic material to have a sterilizing effect. The number of particles per unit area is increased when nanoscale particles are used, maximizing the antibacterial effects [19-21].

3.7 Market needs of nanomaterials

Because of their enormous economic potential, nonmaterials' distinctive features have drawn not just scientists and researchers, but also corporations. The market for products inspired by nanotechnology is being driven by society's rising acceptance of the technology. This emphasises the need to comprehend the potential effects these items may have on the environment, the eco-system, animals, and people. The global market for nanomaterials was valued at 8.5 billion US dollars in 2019; from 2020 to 2027, it is expected to increase at a rate of 13.1% annually. The rapid acceptance and adoption of nanostructures in the aerospace applications, medical and health sectors, food and packaging industry, agriculture and farming, sports, cosmetics, constructions, paints and coatings, electronics, environmental remediation, power and energy sectors, etc. is credited with this increase in nanotechnology's market share. The distinctive physical, chemical, and biological features of metal nanoparticles are the driving force behind this expanding industry for nanomaterials. Many different consumer items use copper, silver, platinum, gold, aluminium, palladium, zinc, tellurium, titanium metals, as well as their oxide-based nanoparticles and carbon-based nanostructures.

Table 1: Estimated growth rate of whole world and USA

Revenues in $ billions	Annual growth rate 2000 – 2010	Annual growth rate 2010 – 2013	Estimated growth for year 2020	Estimated growth for year 2030
World	25%	48%	3000	30,000
USA	24%	38%	750	7500

Source: data from Roco et al. and from Lux Research

The USA and China are at the top of the list of nations investing in nanotechnology, which is a global phenomenon. The process of incorporating produced nanomaterials into the final market product is being rendered by this influx of cash. The market for nanotechnology is predicted to expand with a 17% CAG rate in the seven years between 2018 and 2025 with this interest and funding. The upbeat market trend is a result of the thoughtful partnerships between science, business, and society [22, 23].

4. The Environmental Impact of Nanotechnology

Global environmental concerns include raising the standard of the air, soil, and water. Industry is currently concentrating on locating pollutants (from chemical spills, fertiliser runoff, and pesticide runoff), enhancing industrial and mining sites, treating toxins, and halting further pollution. Nanomaterials could be a viable answer to these issues. Nanomaterials can be utilised to help clean the environment and even offer effective energy solutions, like solar cells made of nanomaterials. Additionally, nanoparticles contribute to the enhancement of numerous consumer goods' functionality and quality. As a result, produced nanoparticles are being exposed to more people every day. However, nanotechnology has both beneficial and harmful effects on the environment [24-27].

4.1 Positive Impacts

Water quality can be enhanced with the aid of nanotechnology. Carbon nanotubes (CNTs), zeolites, nanoparticles of zero valent iron (ZVI), silver nanoparticles, and other nanomaterials are a few examples of nanomaterials that can be employed for water remediation. Other nanomaterials, such as tungsten oxide, titanium dioxide, and zinc oxide, act as photocatalysts. These photocatalysts have the ability to oxidise organic contaminants into inert substances. Due to its strong photostability, high photoconductivity, availability, affordability, and non-toxicity, TiO_2 is the material of choice. Nanoscale silver has an antibacterial effect. Additionally, a lot of polymeric nanoparticles are employed to treat wastewater.

Nanofiltration is another cutting-edge technology that can be used to clean water in homes, businesses, and other industrial settings. An energy-efficient membrane that filters five times as much water as traditional ones is made of molybdenum disulphide (MoS_2). A paper towel made of nanofabric that is woven from small wires of potassium manganese oxide that can absorb oil 20 times its weight has been created to clean up oil spills in water bodies. Nanotechnology thus offers a way to treat the polluted water and stop further pollution.

Nanotechnology can be used to purify airborne hazardous gases. But first, we need to use precise sensors to locate the pollutants at the molecular level. Heavy metal ions and radioactive elements can both be detected by a sensor known as a nanocontact sensor. These sensors are portable, affordable, and simple to use on-site. Currently, NO_2 and NH_3 gas detection is done using single-walled nanotubes (SWNTs). In addition, compared to conventional sensors, which operate between 200 and 600 °C, SWNTs sensors may achieve high sensing activity at room temperature. For the detection of pesticides, heavy metals, and VOCs, cantilever sensors have been created. Toxic gases including NO_x, SO_2, and CO_2 can be adsorbed using a mixture of CNTs and gold particles. Another porous nanomaterial manganese oxide has better adsorption of toxic gases due to its large surface area.

Therefore, we may contribute to the sustainability of both human health and the environment by identifying contaminants using particular sensors. As a result, nanotechnology offers us a fresh method for reducing waste generation, greenhouse gas emissions, and the release of harmful chemicals into waterways.

4.2 Negative Impacts

Nanomaterials may potentially be detrimental. The relative environmental danger of the produced nanomaterials is now poorly understood. There are no precise standards to measure the impacts, and only a few studies have been done to determine the direct and indirect exposure to nanomaterials. The National Science Foundation and the US Environmental Protection Agency recently organised a workshop to determine the crucial risk concerns relating to nanoparticles. Determine exposure and toxicity of produced nanoparticles, ability to extrapolate toxicity of made nanoparticles using current particle and fibre toxicology database, and recyclability and overall sustainability of the created nanomaterials were the specific goals of the workshop.

4.3 Green Technology

Utilising green technology or green production is a corrective measure. This technique was created with the environment in mind and is employed to preserve natural resources. With the use of fewer raw materials, less energy, and less waste, this method promises to produce nanomaterials. Every manufacturing process is known to produce a significant quantity of trash. Green production, which employs environmentally friendly chemicals and energy-saving techniques, reduces this to a minimum. Green technology includes microemulsions, which are utilised in place of VOCs in the cleaning sector.

As a result, scientists are keeping an eye on the different nanoparticles that are created and employed, as well as the effects that follow. This is done to strike a balance between the advantages of the technology and any potential negative effects [28].

5. Nanotechnology's Future Potential in the Textile Industry

As an enabling technology, nanotechnology improves the effectiveness and efficiency of the current applications. Nanomaterials have a huge future potential because they have the ability to be employed for a variety of cutting-edge applications across many industries. The companies are now concentrating on producing nano-textile goods that have conventional qualities and adhere to global standards for safety, health, and the environment. Given the increased consumer interest in nano-textiles and the stringent environmental regulations, it is crucial for textile producers to maintain high ethical standards in these goods. Technology has historically been incorporated into textiles, as is evident.

For example, efforts have been made to enhance clothes with sensing capabilities further. Companies are also working on developing textile-based nano-sensors, which opens up a wide range of opportunities for the nano-textile, including the development of clothing that is easily adaptable to changing weather conditions, monitoring wearers' vital signs, and creating specialised healthcare systems.

One of the issues with the development of nano-textiles is the high expenses of the technology. Thermos- or temperature-regulated clothing is a common appearance in the garment market, but customers avoid it because of the high cost. Despite some drawbacks, nanotechnology has a wide range of benefits, including the capacity to provide textile items improved corrosion-resistance capabilities while also making them more durable, lighter, and stronger. The future of nanotechnology in the textile industry is looking bright, according to research that focuses on enhancing its prospects or developing exceptional textile functions [29-32].

6. Conclusion

Thanks to the development of technology for the manufacture of nanomaterials, a customised product can now be produced more quickly and with the required features. It is now simpler to use textile nanoparticles for cutting-edge applications. The use of nanotechnology in cutting-edge textile applications is already well known in the textile industry. The textile sector has a bright future for nanotechnology and will use it extensively.

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Kuchai Silk: A Traditional Craft

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Abstract:

Kuchai silk is produced by tussar silkworms cultivated on the trees of Asan and Arjun. It is a part of an ancient tradition of Jharkhand, which provides livelihood in rural areas. It was started in the small village of Seraikela-Kharsawan – 'Kuchai' and is now spread all over Jharkhand. Currently, 30,000 people are working in the production of Kuchai silk in Jharkhand. This traditional craft is becoming a light in darkness for many people and the Jharkhand tableau in the Republic Day 2024 parade shows the production of Kuchai silk by the tribal women. Tableau plays an integral part as it displays the nation's progress, historical significance and abundance of cultural heritage. Kuchai silk production involves long-term production processes, thus rural artisans rely on agriculture for day-to-day household management, as daily wages are insufficient.

Keywords: Jharkhand, Kuchai, Silk, Traditional, Tribes

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1. Introduction

Evolution has occurred with the change in time; people adapted different cultures and languages and migrated from one place to another. However, the ambition to create an artwork or an object for a need continues. The legacy of creating skilled work by hand from ancient times continues to inspire and influence contemporary cultures, reminding us of the timeless value of skills, commitment, and creativity in terms of functionality and elegance.

'The land of the forest'—Jharkhand is well-known for its tribal communities. Almost 32 tribal groups are in Jharkhand, representing 28% of the total state population. The primary cultures of these tribes are represented by their dance and music. The tribe or Adivasi community carry their cultural legacy and belief as they gather with the drums, make music and dance with their heart and soul with its rhythm, forgetting all the despair for a special occasion with all their communities [1]. The state is also known for its rich mineral resources, contributing 40% of the country's minerals. However, apart from these resources, one who visits this place will be amazed by the charm and enchanted beauty of nature, culture, temples, mountains, and waterfalls. Jharkhand was a part of Bihar before July 2000 [2]. It is situated in the northeastern part of India. Jharkhand shares its border with five states: Uttar Pradesh, Bihar, West Bengal, Chhattisgarh, and Odisha. This state is mixed with opportunities, challenges, and livelihoods through ongoing efforts to promote economic development, sustainability, and preservation of cultures. It has three well-defined seasons, i.e., the winter (November–February), then the summer (April–June), the hottest time and the rainy season (July to September). 'Basant Ritu', or spring season, is seen from March to April and autumn from September to October.

In the state of Jharkhand, tussar sericulture has cultural significance. It also has the potential for entrepreneurship development amongst rural people and contributes to India's tradition of silk production through innovation. The researcher addressed the impact of tussar sericulture in empowering rural entrepreneurs despite the challenges faced by the industry [3]. Jharkhand is one of the bio-diversity states in India, and most locals depend on forest resources. Forest plays an integral part in their economic, cultural and societal livelihood. The unnecessary use of plants, lack of scientific knowledge and over-grazing are some threats endangering the existing populations of important plants. Therefore, a detailed investigation is required on the geographical distribution and habitat utilisation patterns, feeding ecology, and impact of herbivores on important plant populations [4]. The researcher also assesses the efficiency of farmers in enhancing their livelihood through tussar sericulture in the Bastar district [5]. The researchers framed a structured questionnaire to get an unbiased opinion from artisans regarding their working conditions and various steps required for better productivity. The main hurdles found in the survey are quality and quantity production, the supply of quality cocoons for reeling, continuous electricity supply during weaving, proper wage structure for the artisan, and the need for improved machinery [6]. The tussar silk has the

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potential to provide employment and also raise income levels in the rural sector in Jharkhand. The researcher found that knowledge of technology positively impacts the productivity of tussar silk fabric so that the tussar silk garment Industry grows and benefits its stakeholders [7].

2. The common crafts of Jharkhand

Bamboo and cane are the most commonly used by the villagers of Jharkhand in their daily lives, as they are lightweight and easy to carry. Bamboo has inherent antibacterial properties, which makes it excellent for food storage. The ornaments worn by the tribals are made of bell metal, brass, bamboo, or terracotta. Sohrai and Khovar paintings, tussar silk weaving, wood carving, sabai grass crafts, and dokra metal crafts are some important crafts in Jharkhand.

3. Kuchai silk

A small village, 'Kuchai', in the Kharsawan Block of the Seraikela-Kharsawan District, is well-known for cultivating silkworms and making silk sarees. This wild silk spreads all over the Seraikela-Kharsawan District of Jharkhand. Kuchai silk, also known as 'Tussar silk,' unfolds a timeless facet of cultural legacy among indigenous communities, primarily in the Santhal Parganas district.

The silkworms grow on Sal, Arjun, and Asan trees. The disease in the caterpillar spread during the larvae stage before forming a cocoon, and the caterpillar died. This was the worst period for the farmers and weavers, especially the ones who had taken on loan debt. Pebrine is the most common disease in caterpillars, spreading rapidly among silkworms if not controlled on time. Pebrine is caused by a microsporidian parasite known as 'Nosema bombycis' that affects the silkworm's digestive system, leading to discolouration and preventing them from growing. Figure 1 shows a dead caterpillar due to this disease. Bacterial diseases are mainly caused by the 'Flacherie' virus and predominantly occur in the rainy season. In mycosis, the larva becomes rigid and inactive about 12 h after infection. These diseases cause total crop failure; if the mother is infected, her eggs will also carry that infection. To get disease-free laying, proper hygiene in the field and the grainage room needs to be maintained, and the disinfection of worms and feeding the larvae with healthy nutrition leaves are provided. The production of Kuchai silk revived after 2000 with more scientific processes and people adopted the scientific method, leaving behind the traditional process so that the caterpillars are disease-free.

Figure 1: Dead caterpillar due to pebrine disease

4. Tussar (Antheraea mylitta) silkworm

Jharkhand produces three types of silk i.e., mulberry, eri, and tussar. Jharkhand is mainly renowned for tussar silk production and the villagers who do sericulture in the Seraikela Kharsawan district produce tussar silk, known as 'Kosa silk or Vanya silk'. Antheraea mylitta, the Indian tussar silkworm, is widely spread across tropical regions of the country due to its insect species polyphagia, resulting in extensive population variation.

Almost nineteen eco-races, depending upon the geo-ecological conditions, have been found in Antheraea mylitta. They primarily feed on 'Terminalia' species (Arjun tree) and 'Shorea robusta' (Sal tree) but also have other secondary food plants. The dominant eco-race, which is spread all over Kuchai and the district, is bivoltine DABA that has two life cycles or generations per year reared in the forest on arjuna and asan, usually results in higher-quality silk than a uni-voltine (single-generation) silkworms [8]. Figures 2 and 3 show Antheraea mylitta and tussar moth.

Figure 2: Antheraea mylitta Figure 3: Tussar moths

4.1 Pre-cocoon activities

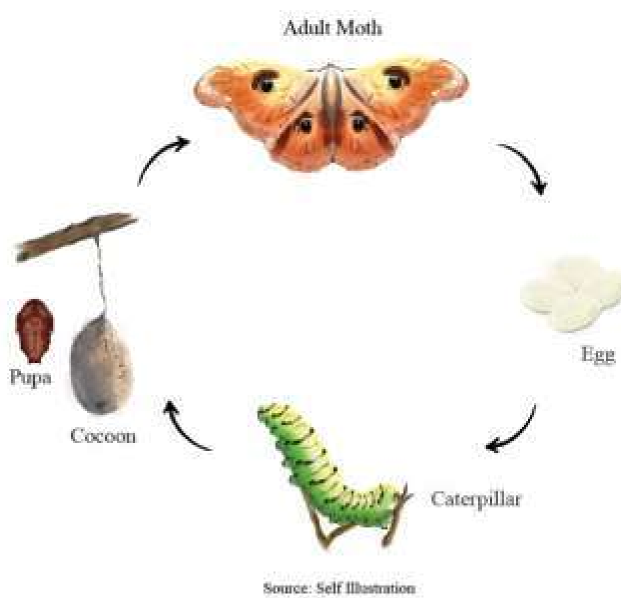


Figure 4: illustrates the life cycle of silkworms

4.1.1 Tree for sericulture

- Indian Laurel (Terminalia Tomentosa)

Generic name/ Local name: Asan ka ped

Indian laurel (Figure 5a) produces wide-spreading leaves. It's a primary source of food for caterpillars and is easily available in tropical evergreen forests.

- Arjuna Tree (Terminalia arjuna)

Generic name/Local name: Arjun ka ped

Terminalia arjuna (Figure 5b) leaves help silkworms grow by providing them with the required nutrition. Apart from this, Terminalia arjuna is a deciduous tree traditionally used as a medicine for pain.

Figure 5: a) Indian laurel and b) Terminalia arjuna

4.1.2 Equipment used for sericulture

Earthen pot

It is locally called Matka and is made of clay which is baked at a high temperature to make it hard. It is used for keeping the moths to lay their eggs.

Hygrometer

It is used to measure humidity or moisture and monitor the grainage room temperature and humidity for the eggs of the moth and the cocoon.

Microscope

It is used to detect the disease of moths or caterpillars. If any moth or caterpillar is infected, it is buried immediately to avoid spreading the disease.

Dyprotex

It is locally called Dawai and acts as a steriliser to protect it from contaminants or bodily fluids. It is used to disinfect the eggs of the moth.

Sickle

Locally it is called Hasua. It's a tool which has a sharp curved metal blade to cut grass and is used to cut the stem and detach the cocoon from the stem.

Jute rope

Jute rope is easy to splice, and handle, and is very durable. It is used to form garlands of cocoons where cocoons are loosely tied with the jute rope. Figure 6 shows equipment used during sericulture.

Figure 6: Various equipment used in sericulture

4.2 Pre-cocoon process

Stage 1: Egg

An egg laid by the female moth is the first stage of the silkworm's life cycle. A female moth can lay up to 150 to 300 eggs. Each moth is separated into a 'cylinder earthen pot' or 'matka'. They lay the eggs entirely in 2 to 3 days in cool and humid conditions where a temperature of 28oC to 30oC is maintained using a hygrometer. After laying eggs, each female moth is checked under the microscope to see if they are infected with any disease; if infected, they are removed immediately along with the eggs and buried so they do not infect others. The trained villagers can quickly detect any disease in the caterpillar. After a proper examination, the DFLs (disease-free laying) or eggs are washed and disinfected with a Dyprotex sterilizer to remove any remaining infection. In the traditional method, villagers used turmeric to disinfect the eggs. The eggs are dipped in the turmeric solution for 10 to 15 minutes and dried under the shed.

Stage 2: Silkworms

It's the most critical time for the farmers; the eggs are hatched, and now a dull brownish-yellow caterpillar with its black head peak from the egg is ready to meet a new world. The hatched larvae change their colour from dull brownish yellow to green and black head into brown within the day. For the next few days, their mission is to eat and increase by 12 times in size. In the larvae stage, they undergo the most painful process of shedding their skin. In their five-instar larval period, they moult four times in 30 to 35 days. The farmers feed the caterpillars on Arjun and Asan trees and take care of them so they are not out of food. The tree height would be 10 ft to 14 ft, which would be easy for farmers to handle. In a few days, caterpillars will eat all the leaves and the farmer has to transfer them from one tree to another.

Another thing that farmers have to take care of is predators. They have to take care of the birds and insects. Some villagers use the net to take care of them. To keep the caterpillar free from disease, farmers take some prophylactic measures in the rearing field using a disinfectant on the caterpillar, as shown in Figure 7, so the caterpillar is disease-free.

Figure 7: Applying disinfectant on the caterpillar

Stage 3: Pupa

In the final moult stage, the caterpillar stops eating and secretes a filament of fine, protein-rich saliva for 8 to 10 days without a break. They spin cocoons around them. The caterpillar rotates around 300,000 times to create a durable, beautiful, and robust habitat. The female caterpillar spins a bigger cocoon than the male silkworm. They use the two salivary glands on their heads to produce a protein gum called sericin. Sericin binds the silk threads together, which gives protection until it turns into a brown pupa (Figure 8a).

To attach the cocoon to the stem, the stalk is made by the silkworm, which is very strong and securely attached to the stem. Once the cocoon (Figure 8b) is formed, the silk thread is almost 1 km long within 40 days, the caterpillar retires from the buzzing forest, and it's time to take a long nap. During metamorphosis, nearly 15 to 20 days are taken for the change from pupa to adult moth. A week later, the cocoon becomes hard and compact. The farmers remove it by cutting the stem without damaging the stalk with Hasua (sickle) (Figure 8c). The colour of the cocoon, like grey, white or golden yellow, depends upon what the caterpillar has eaten

Stage 4: Moth

Lumang, lugum, goti, and koyi are some local names for cocoons used by the 'Santhalis' and other tribal communities in the village. After detaching the cocoons from their host plant, they are ready to form a garland of cocoons loosely tied with a rassi or rope (Figure 8d) and hung in the grainage room (Figure 8e). Each garland has 100 cocoons, and each grainage house contains one lakh cocoons. The grainage house size is made with proper planning. The exact temperature is maintained up to 28OC to 30OC. Depending upon the temperature, humidity, and environmental conditions, the moth will come out of the cocoon, usually after 20 to 30 days. In a few days, the pupa changes into an adult moth, and the adult moth will pierce one end of the cocoon and emerge.

The adult moths (male and female) will perform the most important task in their life cycle: they begin to mate, mostly at night, and the process is called 'coupling'. The female moth is dull yellow, and the male moths are brown. They have characteristic mirror-like circles on their wings. The female moth mates once in a lifetime, and the male will mate more than twice, but soon after, he dies. The following day, after mating, the moth has to decouple; the female's wings are clipped to prevent disease transmission and to ensure that the eggs remain uncontaminated during collection. The female moth lays eggs, and once again, the life cycle of the silkworm begins. The grainage room for the fertility of egg and moth is shown in Figure 9.

The male Antheraea mylitta moth has prominently bushy and feathery antennae, which are highly sensitive and specialised for detecting pheromones emitted by females from long distances, aiding in successful mating. On the other hand, the female's antennae are less feathery and comparatively finer, as their primary role is not to seek mates but to lay eggs. .

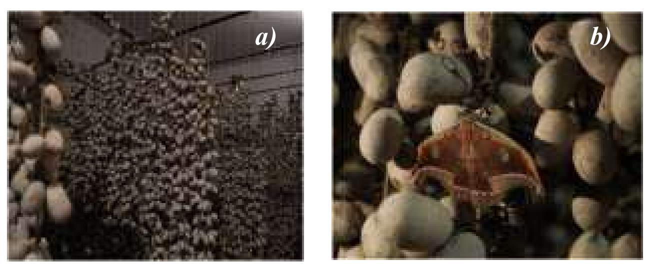


Figure 9: Grainage room for the fertility of a) eggs and b) moth

a) b) c) d) e)

Figure 8: a) pupa, b) cocoon, c) women cutting stems of eaten leaves d) garland of cocoons, e) cocoons are hung in drainage room

4.3 Post-cocoon activities

4.3.1 Stifling

For high-quality silk without fibre breakage, it is necessary to kill the pupa, which has not yet come out of the cocoon. The process of stifling is used, through which pupa in the cocoon is killed by applying hot air or steaming for 10 to 15 min. This will also preserve the silk for a long period. The villagers eat the dead pupa left out after reeling, a good source of protein, minerals, and vitamins. It is also used in medicine and healthcare products for humans and animals.

4.3.2 Cooking

Cocoon cooking is a process of removing the sericin to make it soft by penetration of hot water outside to inside of the cocoon and vice-versa. This will help unwind the continuous filament without breakage. For cooking, 100 cocoons of similar sizes and hardness are selected. In a cooker, 'eenta,' i.e. brick is placed inside a cooker as a base so the cocoons are not burned. For 100 cocoons 1.5 litre of water, 10 ml of H_2O_2 and 10 g of sunlight soap are needed. Hydrogen peroxide and sunlight soap remove a small quantity of sericin and provide a better spinning and elongation of the silk, making it easier to reel. When the water is boiling, the cocoons are packed in plastic bags and dipped in water. After half an hour, the plastic is turned to the opposite side and covered with the plate. On top of the plate, the brick is placed so that proper steaming and boiling of the cocoon is done.

4.3.3 Deflossing

There are three layers in the cocoon i.e., outer (cocoon coat), middle (cocoon layer), and inner (cocoon lining). The outermost layer is rough and has a coarser surface because sericin is present in large amounts. On the other hand, the inner layer of the cocoon contains finer silk; that is why the outer layer of envelopes of silkworm cocoons is removed. Therefore, removing the outermost layer of the cocoon's rough and loose envelopes is called deflossing; this increases the silk's quality and price. In the village, it is hand-operated by the women. 5 to 6 women sit together and defloss the cocoon using a brush with care so that the inner layer is not damaged. Figure 10 shows the deflossing process of the cooked cocoon by a villager.

Figure 10: a) Cooked cocoon, b) Deflossing of cooked cocoon

4.4 Traditional method of reeling

Before adopting the scientific method and instrument, villagers of Kuchai, Seraikela Kharsawan district used different methods for reeling silk, i.e. unwinding the silk fibres from softened cocoons. Traditionally, the wild tussar is divided into many sub-categories, two of which are Ghicha and Katia silk. They are both made of damaged, leftover, cut, or pierced cocoons, preventing the natural reeling of the silk. It promotes sustainability in the textile industry. Gicha and Katia silk is spun yarn, which is reeled manually by the women of the village.

Ghicha silk

Ghicha is derived from the word 'ghichha', which means 'waste'. The origin of tussar ghicha silk can be traced back to the Jharkhand tribal communities. It is also produced in Bihar by Bhagalpur and Chhattisgarh weavers. It does not require a regular process of reeling. Gicha silk sarees are lightweight, breathable, and softer than Katia silk, as the minimal twist is given; during weaving, threads can be untwisted in a localised area. This gives softness to the fabric with a beautiful texture and earthy feel and makes it ideal for warm weather. Tribal women are practised enough in weaving Ghicha silk and can produce plain silk saree in 3 days.

Ghicha silk yarns are a by-product of the tussar silk production process and are often spun by hand. It is generally coarser and less shiny compared to Katia silk. It has an uneven and slubby textured and somewhat rustic feel with a matte finish. The fabric tends to be thicker and stronger, making it more durable and mainly used for traditional wear like sarees, stoles, etc.

However, these days, there is minimal production of ghicha silk in the Kuchai Kharsawan District because of less funding and support from the government. Figure 11 and Figure 12 depict illustrations of reeling ghicha silk.

Figure 11: Illustration of reeling of ghicha silk

Figure 12: Traditional method of reeling ghicha silk yarn

Katia silk

'Katia silk' is also called 'tar silk,' and it is made from 'phuki' or pierced cocoon. Katia is a unique handwoven made from wild tussar silk, which is soft and thick with distinctive textures. It is spun with short tussar silk waste filaments. The name 'tar' was given because of its thick and strong yarn formation after twisting the fibres. Katia silk saree is known for its durability and good abrasion resistance without losing its lustre. Figure 13 shows the reeling process of Katia silk and Katia silk yarn.

Katia silk is more uniform and known for its lustrous shine and smooth texture. It has a softer and lighter feel compared to Ghicha silk and is mainly used for producing formal wear, sarees, and dupattas.

Figure 13: a) Reeling of Katia silk, b) Katia silk yarn

Reeled silk

Reeling is a process of getting fine silk yarn from the cocoons, much finer than spun yarn. The yarn produced by this process is called reeled silk. It is a high-quality silk reeled with continuous filament from the different cocoons into a yarn. It is rich in lustre, smooth and bright. After 2006, when an organisation called Jharcraft was set up in Jharkhand, they trained villagers to produce a reeled yarn using a reeling-cum-twisting-machine (Figure 14b) developed by CSTRI Bangalore, but this needed water at 40OC to 45OC, which required a boiler. Then, in 2011, Jharcraft developed its solar-powered reeling machine, 'Samriddhi'. Several solar panels are placed on the terrace where the reeling machine is operated. This semi-automatic machine is 5 to 6 times more effective than a manual and reduces labour. Figure 15 shows the cocoon and reeled yarn produced as depicted in Figure 14.

Figure 14: a) Solar panels, b) Reeling-cum-twisting-machine, c) Reeled yarn making, d) Re-reeling machine

Figure 15: a) Cocoons, b) reeled yarn

4.5 Weaving

The exact origin of weaving is difficult to trace in Jharkhand. However, the basic principles of weaving were used to make baskets or fences by interlacing twigs and branches during Neolithic times. From ancient times, handloom weaving has played an important role in shaping the economies and culture of Jharkhand and is passed down from generation to generation. The weaving of Kuchai silk is done in a normal treadle loom. Converting yarn into fabric has to go through several phases: winding, creeling, warping, drawing-in, and weaving.

4.5.1 Winding (Suta ghumetna)

The transfer of the hank into the bobbin is called winding. A spinning wheel machine carries out this process. The hank is placed on a stand, and the bobbin is placed on the spindle blade. With one hand, the paddle is operated, and with the other hand, tension is given to the yarn for winding. Figure 16 illustrates the winding operation of a spinning wheel.

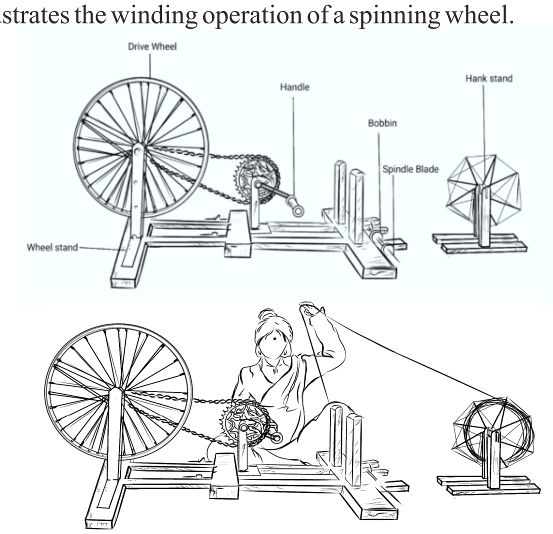


Figure 16: Illustration of winding using a spinning wheel machine

4.5.2 Creeling and warping

Creeling and warping are performed together. The weavers of Kuchai silk perform sectional warping because all the threads are arranged uniformly in less time. In sectional warping, the yarns that are passed through the reed during creeling will be placed on a wooden drum and then the drum is rotated, this will organize the yarns into several bands. Then, the yarn sheet will be transferred to the weaver's beam and the process is called warping.

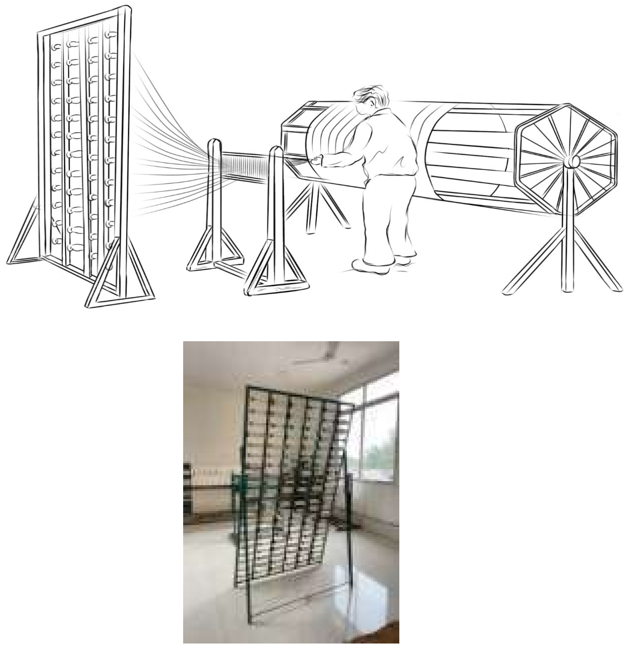


Figure 17: Illustration of creeling and warping of yarn

4.5.3 Drawing-in

This process comes after the sheet of yarn is placed on a weaver's beam. Drawing-in consists of two processes: drafting and denting.

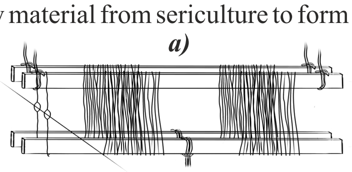
4.5.4 Drafting

The order of passing the warp thread through the heald of the heald shaft in a particular order is called drafting. In the Kuchai silk saree, weavers do a plain weave, which requires two heald shafts (Figure 18a). The single thread is passed through each heald eye of a shaft with the help of a hook.

4.5.5 Denting

Drawing the warp thread to the dent of the reed is known as denting. They use 100s and 120s reeds to make silk fabric.

After the loom is set, weavers are ready to weave, and the operation of handloom is easy to understand. With daily practice, weavers of Kuchai form a rhythm of pressing a treadle, throwing a shuttle (Figure 18b), etc. Weavers can weave eight meters of silk saree in three days of hard work and dedication. The extra weft is also used to make geometric or small designs using an extra shuttle inserted manually. The silk saree formed is not just a piece of cloth; it is the conscientiousness and commitment of all the villagers who produced raw material from sericulture to form a cloth.



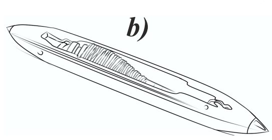


Figure 18: a) Two heald shafts for plain weave, b) Shuttle

5. Coloration

After weaving, the silk fabric is boiled with soap and water to remove the gum or sericin from the fabric. This process is also called 'dhulaye' or 'degumming'. However, after dhulaye, the fabric is sent for surface embellishment or to the dyeing sector, where dyeing, printing, and finishing are done. In Seraikela Kharsawan, the fabrics are sent to the village women for embroidery. The craftsmen of that place only process raw silk fabric. However, silk fabric is sent to Ranchi or Hazaribagh for the dyeing process, where natural and synthetic dyes are used for manufacturing products. Earlier, only natural dyes were the source of dyeing. However, at present people are trained to use synthetic and natural dyes with mordents. A different pattern of the block is carved by artisans and supplied to the block printing sector, where women in the village print the fabric according to the design. In the end, to improve the appearance and feel of the cloth, they apply textile finishing to Kuchai silk fabrics.

6. Motifs

Traditionally, stripes and geometric shapes were used in dresses. But to stand within the competition in the market, people started decorating the fabric with different motifs inspired by leaves, flowers, birds and human figures. Figure 19 shows some motifs on the final fabrics.

Figure 19: a) Tribal motifs, b) Floral motifs, c) Block printing with geometric patterns

7. Embroidery

Different embroidery is used to decorate the saree such as the 'Santha' embroidery of Jharkhand which visualises various phases of the Santhal lifestyle other than the 'Kantha' stitch of West Bengal, 'Chikankari' of Uttar Pradesh and 'Zardozi'. Women of villagers decorate the fabrics with vibrant colour threads and intricate designs using stitches like satin and chain (Figure 20).

Figure 20: Embroidery on silk sarees

8. Specification and Pricing

Table 1 shows the price of the final products along with the material used.

Table 1: Product specification and pricing

Product (Local name)	Usual size	Fabric used	Price (₹)
Kuchai Silk Saree	8 m	Silk, Silk-Cotton	6,000 - 15,000
Tassar Running fabric	1 m	Silk	700 - 5,000
Ladies Kurti	L: 45 in, W: 20in	Silk, Silk-Cotton	900 - 1,500
Men's Shirt	L:30 in, W:21in	Silk, Silk-Cotton	900 - 1,500
Men's Kurta	L: 40in, W: 23 in	Silk, Silk-Cotton	700 - 1,500
Men's Bandis	L: 28in: W: 21in	Silk, Silk-Cotton, Silk-Viscose	1,000 - 3,000

9. Marketing Channels

In Jharkhand, the local bazaars, such as Ranchi Market, Jamshedpur, Dhanbad, and smaller towns, are important spaces where traditional textiles like *Kuchai* silk are marketed. These markets attract both residents and tourists. Participating in local craft fairs or exhibitions in Jharkhand (like the Jharkhand State Handicraft & Handloom Exhibition) allows artisans to showcase *Kuchai* silk products. These events help build awareness and attract buyers interested in authentic handcrafted textiles. The flowchart of the movement of silk production in Jharkhand is described in Figure 21.

Retail

Jharcraft has showrooms in Jharkhand, Bihar, New Delhi, Ahmedabad, Bangalore, and Mumbai, selling Kuchai silk products.

Export

The state's organic silk is in high demand in the USA, Sweden, the UK, Germany, London, Turkey, Brazil, China, Cambodia, and Lithuania. These are the major importers associated with Jharcraft.

Urban and rural haats

The concept of '*Haat*' is unique to itself as it is established based on the nation's ancient culture. It is a 'Bazar' or '*Haat*' where various business merchants sell the products on particular weekdays. Large areas are marked, and small huts are made in Jharkhand to sell the products. The urban '*Haat*' mainly takes place in Hazaribagh and Mysore. In contrast, the rural haats are in the nearby village areas. This supports the artisans in living a settled life by providing them with a livelihood.

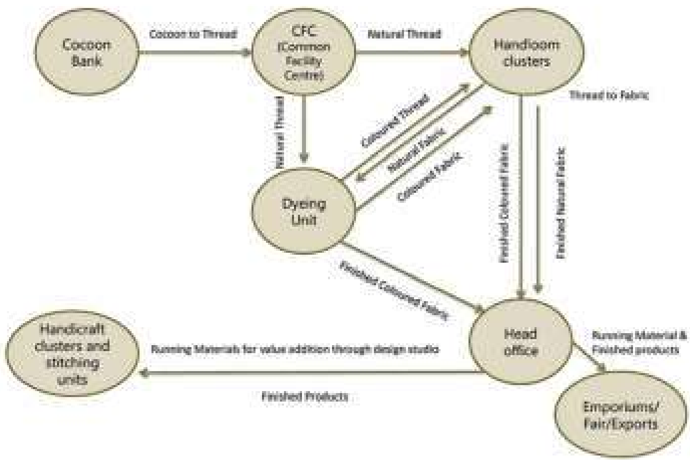


Figure 21: Flowchart of the movement of silk production in Jharkhand

10. Conclusion

Kuchai silk, an ancient tradition of Jharkhand, is a livelihood in rural areas, produced by tussar silkworms on Asan and Arjun trees, starting in Seraikela-Kharsawan. Presently to sustain in the competitive market, apart from sarees, the artisans in the Seraikela region produce products like kurtis, skirts, shirts, and many other dresses. With the help of government and non-profit organisations, Kuchai silk has gained its name nationally and internationally. The growth in the economy of Jharkhand as the demand for Kuchai silk has increased in recent years (Figure 22). Apart from Seraikela-Kharsawan, different regions of Jharkhand, like Ranchi, Dumka, Godda, and Hazaribagh, are the primary producers of Kuchai silk.

Many people in Kuchai silk production have another source of income, i.e. agriculture, to fulfil their daily needs (Figure 23). Not all craftsmen are into this craft; men are involved in other work in different sectors, and women work in training centres from 11 am to 4 pm or in their respective homes. Women of the village feel independent and proud to earn for their families. Although silk production has allowed women weavers to be satisfied, they need to get a better amount for their hard work and dedication that they deserve for making fabric due to business-to-business transactions. Middlemen buy the products at meagre cost and sell them at very high prices.

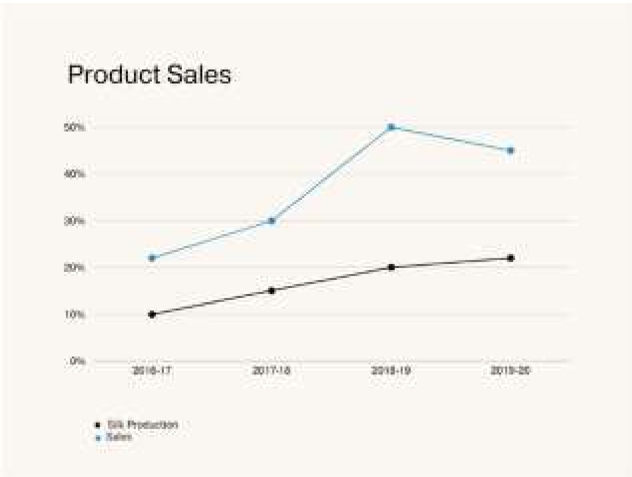


Figure 22: Growth of Kuchai silk

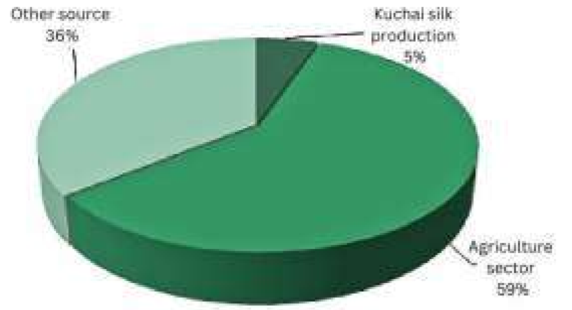


Figure 23: Source of income

11. Acknowledgement

It was an immensely great experience to explore the villages of Seraikela-Kharsawan, Jharkhand and understand the craft of Kuchai Silk. Authors are thankful to many people who were part of the journey of documenting the traditional craft. The authors want to acknowledge Mr. Kamal Dev Kumar Das, Mrs. Santi Mahato and her family, Mrs. Socheri Oraon, Mrs. Seema Tirkey and Mr. Narayan Munda. Without their support, this document would not have been possible. It was a great pleasure to have this opportunity to be a part of their culture.

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An Expert Perspective on Recent Innovative Developments that Took Place in Fibre, Polymer & Textile Industries and their Impact on the Global Industry

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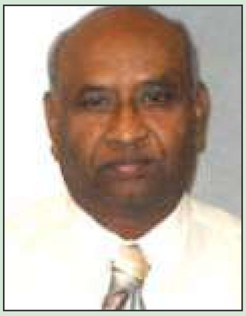

Dr. Radhakrishnaiah Parachuru

Dr. Radhakrishnaiah Parachuru possesses BS, MS, and PhD degrees in textile engineering/technology and an MS degree in Applied Statistics/Decision Sciences. He is a multidisciplinary scientist with more than 38 years of teaching, research, and industrial experience in polymer, fiber, textile, apparel, carpet, and other related disciplines. He taught almost all the dry manufacturing courses offered to textile engineers at Georgia Tech.

Dr. Radhakrishnaiah is serving as the 'Coordinator of Industry and Public Support Activities' of his own School at Georgia Tech, He has completed more than 220 applied research projects for the benefit of all segments of the textile & allied industries. He has completed several important projects.

Dr. Radhakrishnaiah conducted basic research in textile manufacturing and served as the main adviser of several graduate students who completed MS and PhD degrees. He has published more than 60 refereed research papers in international journals, dozens of technical articles, several books including e-books, book chapters, and 100s of industry reports. He made more than 180 presentations in national and international conferences.

Dr. Radhakrishnaniah was an active member of the Fiber Society, AATCC, ASTM, and TQCA. He continues to play a leadership role in several AATCC technical committees, including as the Chairman of the AATCC Committee on Statistics (since 2005). He is an active member of the Textile Association (Manchester) and life member of the Textile Association (India) and the Institution of Engineers, India.

Over a period of 35 years, Dr. Radhakrishnaniah actively extended technical consultation services to the manufacturers of polymers, fibers, yarns, fabrics, garments, carpets, and other miscellaneous fiber-based products, including nonwovens and technical textiles. He had also participated as 'Expert Witness' in over 50 litigations involving fiber-based products and processes. Experience covers federal, state, and county courts in multiple states within the US.

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Major Impactful Innovations of the Last Two Decades

Representation of a smart garment that continually monitors the vital functions of the body

Representation of a smart garment that continually monitors the vital functions of the body

1. Sustainable and Bio-Based Fibers

The rise of bio-based polymers like polylactic acid (PLA) and fibers from renewable resources such as bamboo, hemp, and algae has revolutionized the industry. These materials significantly reduce reliance on fossil fuels and address consumer demand for eco-friendly products. This innovation underscores a critical shift toward circular economy models, mitigating environmental impacts and aligning with global sustainability goals.

Significance

These fibers reduce reliance on non-renewable resources like petroleum and help combat the environmental issues associated with traditional textile production, such as pollution and carbon emissions. Bio-based fibers like PLA are biodegradable under industrial composting conditions, making them ideal for reducing plastic waste.

Future Potential

The development of advanced bio-refining techniques could lower production costs and expand applications beyond textiles, such as composites and packaging. Continued research into genetically engineered crops and algae could produce fibers with superior properties, offering a sustainable alternative to synthetic polymers.

2. Smart and Functional Textiles

Advances in conductive fibers and nanotechnology have enabled the development of smart textiles capable of sensing, responding, and adapting to environmental stimuli. Applications range from health monitoring garments with embedded sensors to temperature-regulating fabrics. These developments are crucial in industries such as healthcare, sports, and defense, transforming textiles from passive materials to active participants in human-machine interactions.

Significance

Smart textiles enhance user experience by integrating electronics and advanced materials into fabrics. These textiles are critical in healthcare (monitoring vital signs and body functioning), sports (performance tracking and performance enhancement), and defense (adaptive camouflage). Their multi-functionality supports the trend toward wearable technology.

Future Potential

Advances in energy harvesting (flexible solar panels and triboelectric generators) could enable textiles that are self-powered. Wider adoption of smart textiles in consumer and industrial markets will depend on breakthroughs achieved in terms of costeffective production and improved washability and durability.

3. High-Performance Fibers

Innovations in high-strength fibers like Dyneema (ultra-high molecular weight polyethylene) and advancements in aramids such as Kevlar have pushed boundaries in protective gear, aerospace, and industrial applications. These materials provide unparalleled strength-to-weight ratios, thermal stability, and chemical resistance, making them indispensable for safety and performance-critical sectors.

Significance

High-strength, lightweight fibers have revolutionized industries requiring extreme performance, such as aerospace, automotive, and defense. For instance, aramids like Kevlar provide protection against bullets, while Dyneema's lightweight properties reduce fuel consumption in transportation applications.

Future Potential

Research into bio-inspired materials (spider silk) and advances in carbon nanofibers could lead to next-generation high-performance fibers with enhanced properties such as self-healing, higher thermal resistance, and sustainability.

4. 3D and Additive Textile Manufacturing

The adoption of 3D knitting and digital weaving technologies has enabled on-demand manufacturing, waste reduction, and complex design capabilities. These advancements are transforming traditional supply chains by offering customization and enhancing production efficiency. Applications in fashion, medical textiles, and footwear demonstrate how this technology empowers creativity while reducing resource usage.

Significance

3D knitting and additive manufacturing minimize waste by using precise amounts of material, enabling "zero-waste" production. These technologies allow for highly customizable designs, reducing overproduction and unsold inventory in the fashion industry while creating seamless, functional garments. Future Potential

The integration of AI and machine learning with 3D textile manufacturing could enable fully automated design-to-production pipelines. Enhanced capabilities in multi-material printing could open up applications in medical prosthetics, advanced composites, and even space exploration.

5. Recycling Technologies for Closed-Loop Systems

Breakthroughs in chemical and mechanical recycling methods for synthetic and natural fibers, such as polyester and cotton, have accelerated the shift to closed-loop production systems. Technologies like Carbios' enzymatic recycling and textile-to-textile recycling platforms significantly reduce waste, extending the lifecycle of materials and reducing environmental footprints.

Significance

Recycling addresses the massive waste generated by fast fashion and short product lifecycles. Advanced recycling methods like Carbios' enzymatic technology can break down synthetic polymers like polyester into virgin-quality monomers, enabling true closed-loop production.

Future Potential

Widespread implementation of closed-loop systems could transform waste from a liability into a resource. Research into recycling blended textiles, which are currently challenging to process, could significantly expand recycling capabilities and adoption rates.

6. Graphene and Nanomaterials in Textiles

Integration of graphene and nanomaterials has enhanced properties like thermal conductivity, strength, and antibacterial performance in textiles. These materials open up new possibilities for lightweight, multifunctional products, critical for energy storage, wearable electronics, and extreme performance requirements in sectors like space exploration.

Significance

Nanomaterials like graphene impart unique properties such as conductivity, thermal regulation, and enhanced durability, enabling innovations in wearable electronics and extreme environments. For example, graphene-coated fabrics can provide lightweight thermal insulation.

Future Potential

Continued exploration of nanotechnology could lead to textiles with programmable properties, such as garments that adapt their structure or color in response to environmental stimuli. Graphene textiles could also find use in renewable energy applications, such as integrated solar cells.

7. Digital and AI-Driven Manufacturing

Adoption of AI and IoT in textile production has optimized processes through predictive maintenance, real-time monitoring, and quality assurance. Technologies like computer-aided design (CAD) and robotics have enhanced efficiency, reduced waste, and enabled mass customization. This digital transformation marks a shift toward Industry 4.0 in textiles.

Significance

Digital technologies improve productivity and precision while reducing waste and energy consumption. AI-powered predictive maintenance minimizes downtime, while IoT systems enable real-time monitoring for consistent quality control. These advances are crucial for meeting the demand for customization and rapid production.

Future Potential

The textile industry is moving toward full digitization, where AI-driven tools could autonomously design, prototype, and produce fabrics. Blockchain integration could enhance traceability and transparency across supply chains, meeting consumer and regulatory demands for ethical sourcing.

8. Waterless and Sustainable Dyeing Technologies

Innovations such as supercritical CO_2 dyeing and digital printing have drastically reduced water and chemical consumption in textile processing. These methods are game-changers for reducing the industry's environmental burden, particularly in water-stressed regions, while ensuring vibrant and durable fabric finishes.

Significance

Dyeing and finishing processes account for significant water pollution and energy use in textile production. Technologies like supercritical CO_2 dyeing eliminate water usage while improving colorfastness and reducing the need for harmful chemicals.

Future Potential

Scaling these technologies to make them economically viable for mass production remains a challenge. Integration of sustainable dyeing methods into decentralized and localized production models could greatly reduce the environmental impact of the global textile industry.

Each of these innovations represents a convergence of material science, technology, and sustainability, positioning the global fiber and textile industries to meet evolving consumer demands and regulatory challenges while addressing critical environmental concerns. Future growth will be driven by crossdisciplinary collaboration, integrating material science, data analytics, and green chemistry. The next wave of innovation will likely focus on automation, circularity, and personalization, positioning the textile industry as a key player in achieving global sustainability and technological advancement goals.

Late Shri M. K. Mehra

Shri M. K. Mehra, Textile Technocrat, graduated from The Technological Institute of Textiles and Sciences (TITS), Bhiwani, passed away on 06-12-2024 at Delhi.

After passing out he joined DCM Group and worked in SBM and Bara Hindu Rao Unit. Then he joined OGTC, Delhi as a Joint Director and worked for a long time.

Mr. Mehra was one of the Pillars of TAI (Delhi) Unit in getting registered way back in the year 1965. He was Hon. Secretary of TAI –Delhi Unit from 1968 to 1970 and also in 1973-74. He was out Spoken and always did his level best to see TAI (Delhi) on top.

Mr. Mehra served TAI – Central, shouldering various positions such as Vice Chairman 1979-85, Chairman 1985-87, Vice President 1987-89 and President 1989-93. He was a member of Board of the Trustees for the period 2011-23 of The Textile Association (India) - Central Office.

He was a recipient of the Service Gold Medal in 1980, Awarded with TAI RATNA at Indore and Life Time Achievement award in 2012 during 67th All India Textile Conference at Delhi.

Mr. Mehra was closely associated with FAPTA. He was the first FAPTA President in 1991 on behalf of TAI and organized the First Asian Textile Conference (ATC) in 1991 at Delhi. Then he was a member of the International Advisory Committee for FAPTA. During ATC-12 in 2005, Mr. M. K. Mehra, was honored with a Memento by FAPTA for his outstanding contribution to FAPTA.

Mr. Mehra was always open to new ideas and with his foresight understood the significance of various innovations in offering and was always logical, patient and the master minded. He was a great supporter of TAI Association with ISGP under which so many seminars on Science, Religion and Development (SRD) were organized in various units of TAI. His contribution to TAI is immense and was the most popular in every event of the textile industry. He was full of energy and enthusiasm to work for the betterment of the Textile industry and especially for TAI.

We will miss him and his valuable guidance which he used to give us as and when needed. TAI lost a gem of a person, which cannot be forgotten. We will always remember him for his contribution.

We pray to God to give his Noble Soul to rest in Peace.

International Conference on

"Automation and Robotics in Textile & Apparel Industry"

The Textile Association (India), Mumbai Unit organized an International Conference on "Automation and Robotics in Textile & Apparel Industry" on Friday, 15th November 2024 at Hotel the Lalit, Mumbai. The Conference received overwhelming response with 350 delegates in attendance. The theme of Conference, topics, presentations, and speakers were highly appreciated by one and all. Some of the highlights of the conference are described as under.

Chief Guest Ms. Roop Rashi, Textile Commissioner, Ministry of Textiles, Govt. of India and other dignitaries lighting the lamp

Mr. V. C. Gupte, Conference Convenor & Chairman, TAI, Mumbai Unit delivering the welcome address

Mr. V. C. Gupte, Chairman, TAI, Mumbai Unit and Convener of the Conference welcomed Chief Guest, Ms. Roop Rashi (IA &AS), Textile Commissioner, Ministry of Textiles, Govt. of India, Keynote Speaker, Mr. Navdeep S. Sodhi, Partner, Gherzi Textil Organization, Zurich, Awardee, Speakers, sponsors, Press, Media, and delegates. Mr. Gupte welcomed and congratulated the awardees Mr. Pradeep Dodhia. Managing Director, Dodhia Synthetics for "The Industrial Excellence Award". Mr. Gupte explained the programs organized by TAI Mumbai Unit over the past few years initiating with Industry 4.0 as the future needs of the textile trade and industry. He described that automation and robotics have become buzz words in the textile industry during the last decade and developing strategies for minimizing labour, enhancing productivity and quality.

He mentioned that TAI, Mumbai Unit has always selected contemporary & innovative topics in all the conferences organized and presentations by high profile speakers. This conference is also no exception to the set tradition especially the theme being of international importance.

Mr. Rajiv Ranjan, President, TAI, Mumbai Unit in his presidential address, described the role of automation and robotics in the future advancement of productivity and quality. Initiatives such as automation in the textile value chain adopted by the organized sectors have yielded the results and minimized labour intensive operations. However, MSMEs must pick up momentum to actively involve in technology upgradation and reap the benefits of automation. He also said the apparel industry due to induction of modern machines have adopted the Automation to a larger extent. In this pursuit, the present program organized by TAI, Mumbai unit, he said will, give an insight of the automation and robotics in achieving the higher level of productivity, reduction in manpower deployment and enhanced quality norms thereby achieving better cost benefit ratio.

Mr. Rajiv Ranjan, President, TAI, Mumbai Unit delivering the Presidential Address

Mr. G. V. Aras , Conference Chairman briefing about the conference

Mr. G. V. Aras, The Conference Chairman and Trustee, TAI, Mumbai Unit briefed about the details of the conference, including topics and speakers. He said every attempt has been made to address the theme from the perspectives of organized industry and MSMEs apart from international perspectives. He described that over the last more than a decade, Automation Technology has helped the Indian Textile Industry in increasing the productivity, improving efficiency, improving quality of the output, optimizing the resources and reduction of costs. Mechatronics and Artificial Intelligence has long been in use by the textile machinery industry while producing the state of the art textile machines. The apparel manufacturing industry has been one of the fastest amongst the textile value chain to use automation in the production lines. In the light of the above, this conference is organized in opt time to discourse on the need to adopt automation, Robotics and AI. He informed that the conference will be addressed by knowledgeable speakers and panelist from the related field who would bring their rich experience in sharing with the delegates.

Figure 11a, 11b : Final design outcome with printed fabrics

Mr. Navdeep S. Sodhi, Partner 'Gherzi Textil Organization, Zurich, in his keynote address described the changing dynamics of the textile value chain in the 21st century wherein the automation, Robotics, AI have far reaching implications on the operations and management of the textile and apparel Industry. In this regard, he discussed the journey of automation and robotics in the international perspectives in respect of future developments of textile and apparel industry. Since India is a potent manufacturing hub with conducive ecosystem and policy interventions, Indian textile and apparel industry is poised to make a quantum jump.

He emphasized that automation can be adopted in all the sectors of the textile and apparel industry and is the need of the immediate future of the textile trade and industry

Guest of Honour, Mr. Priyavrata Mafatlal, Managing Director, Mafatlal Industries Ltd. addressing

Mr. Pradeep Dodhia, Managing Director, Dodhia Group receiving The Industrial Excellence Award by the hands of Chief Guest Ms. Roop Rashi

The Industrial Excellence Award

The Textile Association (India), Mumbai Unit has set a precedent by felicitating the textile professionals/industrialists for their outstanding contribution to the textile industry. In present Conference, the TAI, Mumbai Unit felicitated Mr. Pradeep Dodhia, Managing Director, Dodhia Group with "The Industrial Excellence Award" for his contribution in the field of textile and Apparel industry. Mr. Pradeep Dodhia in his remarks, emphasized the role of the textile and clothing sector in the light of international scenario. He thanked the TAI Mumbai Unit, for recognition and honouring him.

Mr. Priyavrata Mafatlal, Managing Director, Mafatlal Industries Ltd, who was the Guest of Honour, addressed the gathering. He expressed his appreciation for the chosen topic of the international conference by the TAI, Mumbai Unit. He emphasized that modern textile industry needs to adopt the technology and machineries with automation features for exhibiting competitiveness in terms of quality and productivity. It is an era of advanced technology driven enterprise which implies that the automated or robotics involved machineries-based technology in manufacture and other activities in the supply chain. He complimented the TAI Mumbai Unit, for organizing the conference on the topic of current interest to the textile trade and industry.

Ms. Roop Rashi, (IA &AS), Textile Commissioner, Ministry of Textiles, Govt. of India, the Chief Guest of the event addressed the delegates. She described the importance of the theme of the conference regarding holistic approach for the development of the textile and clothing sector. She highlighted the synergy of machinery development and promotion in achieving the

Release of Book of Papers by the hand of Chief Guest Ms. Roop Rashi and the dignitaries

Chief Guest Ms. Roop Rashi, Textile Commissioner, MoT, Govt. of India addressing the gathering

productivity and quality. She emphasized the importance of the automation and robotics in achieving high productivity and improved quality. She complimented the TAI, Mumbai Unit for choice of the topic and organizing the international conference as it is an important topic of current interest to the textile trade and industry.

Informative Technical Sessions

There were two Technical Sessions – each Session had 5 papers and a Panel Discussion.

Technical Session I

Technical Session I was chaired by Dr. G. S. Nadiger, Chairman, Professional Award Committee, Textile Association (India) who moderated the session. There were five papers, and oral presentation was made by the speakers.

Mr. S. Anandhakumar, Vice President-Sales (Exports), Mr. P. Satyanandan Vice President (Sales) and Mr. Ramanathan, Sieger Spintech Equipments Pvt. Ltd presented a paper on “Automation opportunities in the Textile industry”. The authors presented the potential scope in automation in the textile value chain including composite units. The paper was well received by the delegates as witnessed in the question answer session.

Mr. Sudhir Mehani, Chief Digitalization Officer, Marzoli, India, made a presentation on “Building Smarter Factories: AI and Path to predictive maintenance' 'Machine health Management '. Artificial Intelligence and ISO, IEC standards were discussed. Author brought home the ease of adopting AI and other tools in automation in textile machineries.

Mr. Fabian Altorfer, Sales Manager, Steinmann Central Vacuum Systems, Switzerland, made a presentation on “Steinmann Central Vacuum Systems- Automated Textile Waste Management Solutions” As one of the leading machinery manufacturers globally, presentation focused on automated textile waste management solutions in line with Steinmann Central Vacuum Systems. Presentation covered various types of textile waste and explores automated waste handling solutions across processes like air-jet spinning, open-end spinning, and winders. Key points included the benefits of Steinemann's Central Vacuum Systems, disposal logistics for different textile processes, and its global presence. The presentation also highlighted variations in disposal methods, demonstrating Steinemann's comprehensive approach to waste management in textile manufacturing.

Mr. Gilberto Loureiro, CEO and Co- Founder of Smartex ai, USA made presentation on “Automation in Action: The power of Smartex Inspected Fabric Towards Zero waste Textile Supply Chain” The presentation focused on the use of automated Smartex Inspected Fabric adopted in the manufacturing cycle which can reduce waste significantly at different levels of manufacturing including garmenting, knitting and Dyeing through AI enabled real time inspection of fabric. The quality assurance through automation can also lead to enhanced production and quality thereby better profit margins.

Mr. Victor Macovei, Area Sales Manager, Color Service s.r.l; Italy made presentation on “Automatic Dosing and Dispensing Systems”. Speaker highlighted the scope and goal of dye house automation through automotive dosing and dispensing systems, Presentation focused on saving of dyes, chemicals, labour and improvement in quality and productivity.

At the end of the technical session, the questions were welcome from the delegates. The clarifications/answers were provided by the respective authors. At the end, the chairman of technical session summed up briefly the deliberations in the session and thanked the authors who had prepared and presented their papers.

L to R: Mr. Gilberto Loureiro, Mr. Sathyanandan P., Mr. S. Anandhakumar, Dr. G. S. Nadiger, Mr. Victor Macovei, Mr. Sudhir Mehani and Mr. Fabian Altorfer

L to R: Mr. Harshavardhan, Mr. Thirupathi S., Mr. Umesh Prasad, Dr. Ashok Athalye, Mr. Navin P. Agrawal, Mr. Parag S. Kothari and Mr. Mangesh B. Raut

Technical Session II

Technical Session II was chaired by Professor (Dr.) Ashok Athalye, Department of Fibers and Textile Processing Technology, ICT, Mumbai, who moderated the session. Like Technical Session I, there were five papers, and oral presentation was made by the authors.

Mr. Umesh Prasad, Director, UV Hitech Pvt. Ltd, enlightened the audience on the importance & significance of "Storage Automation Opportunities for the textile Industry". He covered various aspects of inventory management and highlighted the resultant benefits in terms of value addition. A few industrial case studies enumerated the practical outcome and the resultant advantage of adequate and optimum storage automation. He emphasized that the tailer made solutions are needed in the automation of the storage as each situation is discreet.

Mr. T. Harshavardhan, CEO, Count AI Pvt. Ltd. and his associate from the affiliated organization Indo Texnology Pvt. Ltd. presented the 'Cascading benefits of Automatic Inspection of Textile Materials. The defects associated with the circular knitting process resulting in fabric construction damage causing significant wastage of material and financial loss. Online inspection linked with process control can automatically stop machine working to control the occurrence of fabric defects.

Mr. Navin P. Agrawal Sr, Vice President, Textile Engineering- Fabric Forming, A.T.E Enterprises Pvt. Ltd. made the presentation on "Machine Upgradation- Need of Time". In his presentation, he described automation or application of robotics in the machines is normally linked to modernization namely replacement of machines with automatic machines. This case leads to constraints in terms of budgetary limitations on the part of the textile or apparel unit. Instead of capital intensive proposition, the author proposes to upgrade the available machines to tune for automation. With his experience of implementing in different textile units as case studies, he illustrated the possibility of automation through machine upgradation, and automation that can be done economically. ATE team have been working on this hypothesis as an alternate development strategy for the textile and apparel industry.

Mr. Parag Kothari, Chairman and Managing Director, Jaysynth DyeChem Ltd. discussed 'Automation in Textile Printing', emphasising the developments in the fasted growing segment of Digital Printing. He elaborated on the features and benefits of using Pigment Ink-Jet printing and the advantages in terms of substantial reduction in water footprint, energy conservation enhanced productivity and the resultant Point of Sale usage. He described the conventional printing technique and digital printing and brought advantages of digital printing and some of the challenges involved. He brought . the theme of automatic printing through digital printing technology.

Mr. Mangesh Raut, Director- Sales and Marketing, Software Solutions Pvt. Ltd. made presentation on "Technology Transformation for Textile and Apparel Industry" . In his Presentation, he informed that the use of various Information Technology Based management tools such as SAP, IOT ERP pave path for automation. He emphasised the software developed by his company 'SOFTCORE'. A number of case studies wherein the company has worked in regard to textile and apparel units were showcased. The presentation impressed upon the technology transformation leading to integrated solutions in the overall enterprise management.

At the end of the technical session II, there were questions from the delegates and the clarifications/answers were provided by the respective authors. Prof. Athaley, Session Chairman, summed up briefly the deliberations in the session and thanked the authors who had prepared and presented their papers.

Panel Discussion Session

L to R: Mr. S. Rajendran, Mr. Amit Mittal, Mr. Rajesh Relekar, Mr. Rajiv Ranjan, Mr. K. B. Prasad and Mr. Kailash R. Lalpuria

The theme of the Panel Discussion was on "Automation and Robotics: Challenges and Opportunities" bringing together a diverse group of industry experts, technology innovators, and business leaders. The event drew an enthusiastic audience, reflecting the growing importance of technological transformation in one of India's most significant economic sectors.

The Panel Discussion was moderated by Mr. Rajiv Ranjan, President, The Textile Association (India),

The panel discussion served as a valuable platform for industry stakeholders to explore the impact of automation and robotics on the textile and apparel industry. The event highlighted the sector's readiness to embrace change while addressing the challenges that come with integrating advanced technologies into traditional workflows.

The panel included some of the most respected personalities from the industry:

1. Mr. Kailash R. Lalpuria, Executive Director and CEO, Indo Count Industries Ltd.
2. Mr. Rajesh Relekar, Vice President, Birla Cellulose, Grasim Industries Ltd.
3. Mr. S. Rajendran, Senior Vice President, Business Head- Textile Engineering Processing and Accessories, Zonal Head- South India, A.T.E. Enterprises Pvt. Ltd.
4. Mr. K.B. Prasad, Vice President, IIGM Pvt. Ltd.
5. Mr. Amit Mittal, Management Consultant & Advisor, Independent Director, Madasky Consulting

Mr. Rajiv Ranjan skillfully steered the discussion to cover a wide range of topics, from the technical advancements driving automation to the economic and social implications of robotics adoption in India's textile sector.

The panel discussion delved into several critical areas, offering valuable insights for all delegates. Below are the highlights:

1. Opportunities in Automation and Robotics

The panelists emphasized the potential of automation and robotics to revolutionize the textile industry by:

- Enhancing efficiency and productivity: Automated processes like robotic sewing, cutting, and fabric handling drastically reduce time and cost.
- Improving quality control: AI-driven systems ensure consistent product quality, minimizing defects and waste.
- Driving sustainability: Advanced technologies allow for precise resource utilization, reducing water and energy consumption.

2. Challenges in Implementation

Despite the promise of automation, the panel acknowledged several challenges:

- High Initial Costs: The adoption of robotics involves significant investment, making it inaccessible for many small and medium enterprises (SMEs).
- Skill Gap: There is a pressing need to upskill the workforce to operate and maintain advanced systems.
- Job Displacement Concerns: Automation raises concerns about labor displacement, particularly in India, where the textile industry is a significant employer.

3. Government Support and Policy Initiatives

The panelists called for stronger government policies to enable smoother transitions to automation. Key suggestions included:

- Expanding incentive schemes for automation investments.
- Creating training and upskilling programs for workers to bridge the skill gap.
- Strengthening support for SMEs to adopt robotics through subsidies or shared resources.

4. The Role of Collaboration

One of the recurring themes was the importance of collaboration between industry players, technology providers, and the government. Such partnerships can:

- Accelerate the adoption of cutting-edge technologies.
- Foster innovation tailored to India's unique needs and scale.
- Create a supportive ecosystem for both large and small manufacturers.

The discussion was followed by an interactive Q & A session, where attendees had the opportunity to pose questions to the panelists. Questions ranged from the technical feasibility of specific automation solutions to the socioeconomic impact of these technologies on India's textile workforce. The panelists provided thoughtful and comprehensive responses, further enriching the discussion.

The event was widely appreciated by attendees, who represented a broad spectrum of the industry, including manufacturers, exporters, designers, technology providers, and policy-makers. Participants lauded the panel for addressing the challenges of automation with a balanced perspective while highlighting opportunities that could drive growth and sustainability.

In closing the session, the moderator summarized the key takeaways, emphasizing the importance of:

- Investing in technology to stay competitive in the global market.
- Fostering innovation to address unique challenges in the Indian context.
- Prioritizing sustainability in all automation initiatives.
- Preparing the workforce for a technology-driven future.

The event concluded with a resounding message: while the path to automation in the Indian textile and apparel industry comes with challenges, it also presents unparalleled opportunities for growth, efficiency, and sustainability. Stakeholders must act collectively and decisively to harness the potential of these transformative technologies.

There was good interaction by speakers with the delegates during question answer sessions/Tea & Lunch break resulting thereon effective delivery of the thought sharing on the theme of conference "Automation and Robotics in Textile & Apparel Industry".

The Distinguished Audience

Mr. Haresh B. Parekh, Hon. Secretary, TAI, Mumbai Unit, proposing vote of thanks

Mr. Haresh B. Parekh, Hon. Secretary, TAI, Mumbai Unit proposed vote of the thanks to everyone who have contributed for the success of the international conference which was attended by around 350 participants.

Neelam Shami Rao appointed as Secretary, Ministry of Textiles

Smt. NEELAM SHAMI RAO has been appointed as the new Secretary, Ministry Of Textiles, Govt. of India led by Shri Giriraj Singh.

Smt. NEELAM SHAMI RAO

Prior to joining MoT, she has been the Secretary, National Commission for Minorities, Ministry of Minority Affairs. Smt. Rao has also served esteemed organizations like EPFO in senior position like Central Provident Fund Commissioner. She was the Director General of Training in the Ministry of Skill Development and Entrepreneurship in the rank of Additional Secretary. Early in her career, she served as District Collector in Guna and Koria Districts of Madhya Pradesh.

She brings in rich and varied experience as an IAS officer who held various administrative positions in different departments of Central and State Governments.

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She has been instrumental in many reforms in EPFO resulting in making it a more efficient, transparent and deliveryoriented organization.

She is IAS officer of 1992 batch of Madhya Pradesh Cadre and an alumni of Motilal Nehru National Institute of Technology, Allahabad with a B. Tech. degree in Electronics.

Rieter appoints Emmanuelle Gmür as Chief Human Resources Officer and Member of the Group

The Board of Directors of Rieter Holding Ltd. has appointed Emmanuelle Gmür to the Group Executive Committee of the Rieter Group with effect from January 1, 2025. As Chief Human Resources Officer, she succeeds Tom Ban, who has decided to pursue his career outside Rieter.

Emmanuelle Gmür has extensive knowledge in human resources and a proven track record in strategic leadership and organizational development, management consulting and change management. She has vast international experience and knowledge of the textile industry.

In the period from 2013 to 2024 Emmanuelle Gmür was active as Chief Human Resources Officer, Global Head of Communication and as a member of the global management board of the Triumph Group, Bad Zurzach (Switzerland). At the same time, she was a member of the Supervisory Board of Triumph France SA, Obernai (France) from 2020 to 2024 and deputy chairwoman of the Supervisory Board of Triumph Austria AG, Vienna/Wiener Neustadt (Austria) from 2015 to 2024. She previously worked as Global Head of Learning and Development for the Triumph Group in Bad Zurzach (Switzerland) from 2010 to 2013. From 2007 to 2010, she held the position of Head of Consulting at Qualintra SA, Geneva (Switzerland). From 1999 to 2006, she held various positions at British Telecom plc, London (United Kingdom), among others as a consultant for leadership and organizational development and as a business transformation consultant.

"Emmanuelle Gmür has extensive international expertise in all areas of human resources management. She is a respected expert and leader and will consistently drive forward the further development of the human resources department. As Chief Human Resources Officer, she will enrich the Rieter team with her expertise and profound business acumen and support the Group Executive Committee in implementing the new strategy," says Thomas Oetterli, Chairman of the Board of Directors and CEO of the Rieter Group.

Emmanuelle Gmür holds a Core MBA from the Helsinki University of Technology, Helsinki (Finland) and a Master of Science in Business from the École supérieure de commerce de Reims (France). She was born in 1976 and is a French citizen.

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ITMA ASIA CITME - Singapore 2025 Expands Exhibition Space to Accommodate Strong Response

Exhibition sector plan launched

12 December 2024 – ITMA ASIA + CITME, Singapore 2025 has received overwhelming support, surpassing the show owners' expectations with a 30 per cent increase in the number of applicants to date.

ITMA ASIA + CITME, Singapore 2025 is owned by CEMATEX (the European Committee of Textile Machinery Manufacturers), China Textile Machinery Association (CTMA) and the Sub-Council of Textile Industry, CCPIT (CCPIT TEX).

Scheduled to be held at the Singapore Expo from 28 to 31 October 2025, the exhibition has attracted over 770 technology and service providers from 33 countries and regions to apply for space. They include many international textile machinery manufacturers, as well as new technology providers. As a result of the increased demand, the show owners have expanded the booked hall space from 60,000 to 70,000 square metres.

Speaking on behalf of the owners, Alex Zucchi, president of CEMATEX said: "We are grateful to have the continued support of the industry. To accommodate all the eligible applicants, we have increased the booked hall space to allow more machinery manufacturers to showcase their latest products and solutions to the region's buyers who aspire to leverage technology to drive cost efficiency and remain competitive.

"The strong interest in the Singapore edition, despite being scheduled just a year after the Shanghai edition, highlights the need to penetrate deeper into emerging markets to sustain and grow our manufacturers' businesses."

Mr. Gu Ping, president of CTMA, concurred: "In recent years, digital technology has significantly influenced the development of the textile industry, with burgeoning new demand from regions such as South Asia, Southeast Asia and the Middle East. In response, we have added the Singapore edition between ITMA ASIA + CITME 2024 and 2026 exhibitions to meet the expectations of global exhibitors and visitors, hoping to bring them greater benefits."

At the close of space application on 12 November, almost all the booked exhibition space at Singapore Expo had been snapped up. Since then, applications have continued to stream in, prompting the show owners to expand space at the venue.

Hall sector plan

Spanning seven halls of the Singapore Expo, the sector plan features 19 product chapters of the complete textile and garment manufacturing chain. Based on the exhibition's unique selling proposition, the exhibits have been clustered in product sectors, enabling buyers to source more conveniently. The three biggest sectors based on space booked are finishing, followed by spinning and knitting.

Billed as The Leading Textile Technology Exhibition Driving Regional Growth, ITMA ASIA + CITME, Singapore 2025 will be held from 28 to 31 October 2025. The exhibition is organised by ITMA Services and co-organised by Beijing Textile Machinery International Exhibition Company. Japan Textile Machinery Association (JTMA) is a special partner of the exhibition.

For the latest updates, visit
www.itmaasiasingapore.com

55 years of collaboration: Parkdale and Trützschler's ongoing partnership

Parkdale is a top global provider of spun yarns – and a top partner for Trützschler too. Our collaboration stretches back more than 50 years and is now gathering momentum for the future, driven by our shared focus on continuous improvement for quality, innovation and sustainability. The latest step forward for this long customer relationship? Our SUPERTIP card clothing wire…

For over 108 years, Parkdale has proven to be a reliable full-service yarn supplier. Operation began at its first facility in Gastonia, North Carolina, producing 425 tons of thread yarn per year.

Since then, it has grown into the largest consumer of cotton in the US. Parkdale produces more than 8,000 tons per week at 21 manufacturing sites in the US, Mexico, Central America and South America. It supplies many industries worldwide with spun yarns consisting of fiber blends including cotton, polyester, rayon, nylon and acrylic.

Trützschler entered the US market in 1969 and almost immediately engaged in close cooperation with Parkdale. Together, the two companies have successfully identified and adapted to several big transformations within the textile industry. Those achievements are evidence of our shared

L-R: Charles Heilig, President and CEO of Parkdale, Greg Duncan, VP Spinning Machine Sales at ATR, Ivan Lami, VP Card Wire Sales at ATR and Stefan Engel, CEO at ATR

focus on exploring new technologies and continuously improving production processes. As the latest step forward in this pioneering partnership, Parkdale recently ordered 34 carding machines equipped with SUPERTIP wires from Trützschler on the licker-in, cylinder and doffer roller.

Taking clothings to the next level

SUPERTIP wires are the newest innovations in Trützschler's range of clothings. Parkdale selected these wires because they achieve big contributions to quality and precision. Specifically, the customer values the outstanding durability of SUPERTIP wires. All SUPERTIP offer a service lifetime that is up to 30 % longer than conventional solutions, which cuts maintenance requirements by up to 25 %. In this way, Parkdale can now minimize service disruptions and ensure smoother processes – with lower costs.

Parkdale uses a variety of SUPERTIP wires for its uniquely diverse range of applications and process parameters. In total, more than 300 versions of the SUPERTIP clothings are available – and our teams are constantly expanding that portfolio. This wide range of innovations makes certain that we always have the perfect wire for each customer's unique needs. It also eliminates the need to grind newly fitted clothings, which further extends intervals between maintenance tasks.

"Parkdale has trusted the Trützschler Card Clothing (TCC) team to be a full-service provider for our card clothing needs. They have exceeded our expectations for quality and performance throughout our entire manufacturing network, spanning throughout the Americas. TCC continually works with our team members, looking for innovative strategies to delight our customers," says Charles Heilig, President and CEO of Parkdale Textile Division.

Parts and people are always available

Parkdale's recent order for SUPERTIP card clothings is an important milestone in a partnership that now extends for over half a century. The customer can rely on fast availability of parts including stationary and revolving flats, licker-ins and more. And our technical specialists are always ready to visit Parkdale's sites and conduct full-service maintenance in line with the highest standards.

"We're incredibly proud of our longstanding partnership with this well-known industry leader," says Greg Duncan, Vice President Spinning Machine Sales American Trützschler (ATR). "Our companies have collaborated for more than five decades. Personally, I've worked with Parkdale for over thirty years.

I know how much Parkdale values the full maintenance service that our mechanics, engineers and technologists provide – as well as our pioneering solutions for card clothing."

HEBERLEIN
TECHNOLOGY FOR PROFESSIONALS

DTY Jet insert APe043 redefines low denier yarn processing

Record-small 0.65mm orifice launched during GTTES 2025

Heberlein Technology, a leader in air interlacing and texturing jets, is set to showcase its latest products at GTTES in Mumbai, India. Key highlights include the new housing generation HemaJet-LB06 and the DTY jet insert APe043, featuring a record-small 0.65 mm orifice for superior performance in extremely low denier yarns.

The Indian market drives demand for lightweight, premium fabrics using ultra-fine yarns, especially for activewear and luxury garments. The surge in synthetic fibre manufacturing positions Heberlein's innovations as essential tools for meeting these needs. Visitors at GTTES 2025 receive first-hand information at Heberlein and are warmly invited to come and see the Swiss company at booth D17 in hall 3.

APe043 Jet insert improves productivity and profitability

The APe043 Jet insert minimizes yarn displacement, preventing undeveloped knots and ensuring smooth production for ultra-fine yarns down to 20 denier. This new technical development aligns with the increasing demand for high-quality fabrics in global markets and supports the rapid growth of polyamide filament production capacity. On top, the APe043 jet insert features energy-efficient technology resulting in a positive impact on the mill's profit.

Heberlein HemaJet-LB06

Heberlein PolyJet-TG-3

HemaJet-LB06 – the economic solution for ATY

Heberlein, known for the production of high-quality jets for air texturing, offers the complete solution from a single source. The brand new robust HemaJet-LB06 jet housing is compatible with all Heberlein jet core series (T, A, and S).

This compatibility makes it an ideal solution for various air texturing process requirements. The distance between the impact body and the jet core can be easily adjusted using various gauges, allowing for precise control and optimization of the texturing process.

Heberlein jet cores are the reliable solution for the ATY industry for decades. Suiting a wide range of requirements like compact and uniform yarns from 30dtex up to 3,000dtex or softer, textile yarns achieved through a higher overfeed potential. In a nutshell, Heberlein provides the ideal solution for every application. Customers can choose from the great jet core portfolio and whatever jet core fits the needs, it fits – guaranteed – the housing too.

The new generation of spinning jet

Worldwide recognition receives the PolyJet-SP3 for spinning textile yarn. Producers of demanding technical yarns highly appreciate the PolyJet-TG-3-HP405A/WO70 (TopAir) achieving yarn with unmatched even and uniform interlacing density. Furthermore, this jet impresses customers with strong, reliable knots for high-tenacity yarns (HT and HMLS). Heberlein's PolyJet-TG-3 achieves more than 12 knots per meter with 1100f98dtex and 1670f98dtex. Additionally, yarn parameters of tensile strength, elongation, and elasticity show smaller variations, for ultimate quality benefits, as well as improved unwinding behaviour of the bobbins.

A typical Heberlein benefit comes with the PolyJet series SP-3 and TG-3. The high-performance air interlacing jets for textile and technical yarns offer a unique quick-release system, so jet packs can be exchanged within seconds, with just a single 180-degree turn. They also feature a compact, space-saving design and a roll bar to protect the ceramic surfaces.

About Heberlein

Heberlein Technology AG is the world's leading provider of air interlacing and air texturing jets for synthetic continuous filament yarns. Heberlein's core competence is the development and production of highly specialised key components for process-optimised treatment and finishing of synthetic yarns – especially filaments. Heberlein develops products for significant process improvements and energy savings, based on latest flow simulations and extensive trials at its headquarters in Switzerland.

Heberlein operates an in-house textile centre equipped with a range of cutting-edge filament processing machinery, and a laboratory for analysis and testing of filament yarns. A dedicated customer service centre is the focal point for the top-level support worldwide clients require for their individual solutions.

Since 1835, Heberlein products have been renowned for their innovative technology, durability and optimal cost-benefit performance.

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Digitalized production management for luxury fashion with tradition

Transformation of the production organization at Bonneterie with PPS powered by STOLL and KM.ON

*Kevin Strassburger_*

Products

Production

The Brazilian luxury knitwear manufacturer Bonneterie knits with love, tradition and innovation and creates sophisticated garments that fit comfortably around the body. It has been on the road to success since it was founded in 1987. Bonneterie products stand for quality, timeless elegance and comfort and are in demand worldwide. A considerable proportion of them are produced on flat knitting machines from STOLL. Bonneterie and STOLL have been working together for decades and the two partners also took one of the first steps towards the digitalization of production together: The knitting specialist has been using the Production Planning System (PPS) powered by STOLL and KM.ON for more than five years.

The decision in favor of the PPS was made as part of an expansion and modernization project in which Bonneterie was clearing up inefficient operating processes. Machine operators relied on manual notes for production and yarn management, leading to frequent miscommunication, errors, and increased setup times. With operators managing multiple machines, tracking production was time-consuming and prone to human error. As a result, downtime increased, and productivity decreased.

In order to streamline and digitalise its production processes, the company implemented the PPS alongside their ERP system. The PPS provides real-time insights, enables automation, eliminates the need of manual notes and thus offers real benefits.

"PPS has transformed how we manage production. Our efficiency has improved significantly, and we now have complete control and visibility over the entire process", says Kevin Strassburger, Marketing Manager at Bonneterie.

Efficiency Gains

The PPS led to a 20 % increase in efficiency. Operators now manage more machines with ease, and reduced setup time and errors contributed to a significant productivity boost.

Improved Organization

PPS replaced manual inputs, organizing production data in real time. Operators no longer need to walk around as much or take notes; they can view production data directly on their screens, allowing them to better manage timelines and machine assignments. The PPS enables remote access to production data, empowering operators and managers to oversee the entire process from anywhere, anytime.

Streamlined Production

With better timeline management, the system reduced stockpiling and aligned production more closely with demand. The system tracks when machines are running out of tickets, allowing for better workflow management.

Data-driven Control and Planning

PPS offers comprehensive reports on key machine and production data at both micro and macro levels, helping Bonneterie pinpoint inefficiencies and identify stop causes. The reports and access to historical data enhance decision-making and planning. Decisions are not only made more profoundly, but also more quickly and delays are reduced.

Bonneterie experienced remarkable improvements in production efficiency, organization, and overall control. The support and collaboration with STOLL have further empowered Bonneterie to continue delivering high-quality knitwear with precision and confidence.

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CII Recognizes NITRA as one of Top 5 Innovative Institutes in India

Confederation of Indian Industries (CII), biggest industry association of India recognized Northern India Textile Research Association (NITRA) on December 13, 2024, as one of the Top 5 Innovative Institutes in India for the year 2024. NITRA has done and is continually doing lot of R&D and Innovations in the field of technical textiles, unconventional natural fibres and sustainability. It's almost all developments and innovations have been commercialized and benefits are passed on to textile and apparel industry. Innovations are imbibed in NITRA culture.

NITRA was recognized by CII as one of the topmost Innovative Institutes in the year 2022 & 2023 also.

Birla Cellulose Achieves Top Ranking

Birla Cellulose Achieves Top Ranking in Canopy's Hot Button Report 2024

Birla Cellulose, the sustainability-focused Man-Made Cellulosic Fibres (MMCF) business of the Aditya Birla Group, has once again demonstrated its leadership in responsible wood sourcing by securing the Number One ranking in Canopy's Hot Button Report 2024. This marks the fifth consecutive year that Birla Cellulose has received the highest rating of 'Dark Green Shirt,' cementing its position as a global leader in sustainable practices.

The Hot Button Report, released annually by Canopy, a not-for-profit environmental organization, is a critical resource for fashion brands and retailers. The report independently assesses MMCF suppliers based on their forest fibre sourcing practices, enabling stakeholders to make informed choices that align with biodiversity conservation and deforestation-free supply chains.

Commenting on the achievement, Mr. H. K. Agarwal, Managing Director of Grasim Industries Ltd. and Business Director of Birla Cellulose, said, "Birla Cellulose is proud to be leading the collaborative effort for scaling up Next Gen solutions. This prestigious recognition affirms Birla Cellulose's unwavering dedication to enhancing sustainable wood sourcing practices, forest conservation, and maintaining transparency in the value chain."

Nicole Rycroft, Executive Director of Canopy, also commended the company's efforts: "Hearty congratulations to Aditya Birla Group for once again securing the top spot in Canopy's 2024 Hot Button Report. We commend their hard work to remove Ancient and Endangered Forests from the MMCF supply chain and are encouraged by their consistent progress in bringing Next Gen fibres to market at scale. We look forward to their continued leadership in 2025 in driving the sector's transition to low-carbon Next Gen production."

Birla Cellulose continues to invest heavily in research and development, focusing on Next Gen Solutions. Through lab and pilot-scale trials, the company explores a diverse range of feed stocks to reduce the impact on forests. These efforts are aimed at significantly scaling up the use of Next Gen Solutions to transform the MMCF industry sustainably.

With 11 sites for pulp and fibre manufacturing, Birla Cellulose leverages environmentally efficient closed-loop technologies to minimize resource consumption and carbon emissions. Its five advanced research centers, equipped with state-of-the-art facilities, further underscore its commitment to innovation and environmental conservation.

About Canopy's Hot Button Report

Canopy's Hot Button Report is a trusted resource for over 550 global fashion brands and retailers seeking to source sustainably. With combined annual revenues exceeding US $1 trillion, these brands play a pivotal role in promoting environmentally friendly practices within the textile industry. The 'Dark Green Shirt' rating represents the pinnacle of compliance with Canopy's requirements for Ancient and Endangered Forest conservation, transparency, traceability, and next-generation solutions.

The Textile Association (India) – Delhi Unit

UNT ACTIVITY

Educational Visit to Shri Hosiery Udyog, NOIDA

The Textile Association (India) - Delhi Unit organized an Educational Visit for the undergraduate and postgraduate students of the Department of Fabric and Apparel Science of Lady Irwin College, University of Delhi on 08th October, 2024. This visit was represented by Mr. Rajiv Pandey, Vice Chairman, TAI - Delhi Unit.

Shri Hosiery Udyog Limited, NOIDA warmly welcomed the faculty and about 40 students to their Knitting Unit.
Students were explained the working of various types of circular knitting machines. Students enthusiastically learnt and asked many questions which were attended to in detail by the factory personnel. Department of Fabric and Apparel Science, Lady Irwin College thanked TAI Delhi Unit and thanked Mr. and Mrs. Jain of Shri Hosiery Udyog Limited for providing such an enriching experience, knowledge to the students.

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