Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 05, Issue: 06 (NOV-DEC, 2025)
Available online at http://www.agriarticles.com
©Agri Articles, ISSN: 2582-9882

Eco-Conscious Textile Production: Green Materials, Technologies, and Industry Practices

*Tanisha Sherawat and Dr. Rupal Babel
ATS Department, CCAS, MPUAT, Udaipur, Rajasthan, India
*Corresponding Author's email: tanishasherawat5255@gmail.com

The textile sector is under increasing scrutiny for its environmental footprint, spanning raw material sourcing, chemical-intensive processing, high water and energy usage, waste generation, and end-of-life disposal. There is a growing imperative for eco-conscious textile production that spans green materials, sustainable technologies, and industry practices aligned with circular economy and low-impact frameworks. This review synthesises current research on (i) green materials such as organic fibres, recycled and bio-based fibres; (ii) process technologies and manufacturing approaches that reduce resource consumption and pollution; and (iii) industry practice innovations including certifications, supply-chain transparency, circular models, and regulatory frameworks. The paper identifies key progress areas, remaining challenges such as scalability and cost, and offers perspectives for future research and industry transition.

Keywords: sustainable textiles; green materials; textile processing technologies; circular economy; supply-chain practices.

Introduction

Historically, the worldwide textile and garment industry has been resource-intensive and detrimental to the environment. Common manufacturing processes include the cultivation or synthesis of raw materials (usually cotton or synthetic fibers), chemical treatments (finishing, dyeing), excessive water and energy consumption, and often inadequate waste management and end-of-life procedures. For instance, according to one assessment, the production of textiles requires a lot of water, dangerous chemicals for pre-treatment, dyeing, and finishing, and produces a lot of solid waste and effluent. The need for more environmentally friendly, sustainable textile manufacturing has increased recently due to pressure from customers, businesses, and environmental authorities. Therefore, three broad but interconnected pillars must be integrated into eco-conscious textile production: (a) green materials (renewable, recycled, or low-impact fibers); (b) green technologies (processes that reduce water, energy, or chemical footprint); and (c) industry practices (supply-chain management, certifications, circular economy models). In order to create a more sustainable textile value chain, this review paper looks at each pillar separately, reviews current developments, identifies important case studies or innovations, and talks about how material, technology, and practice interact.

Green Materials for Textile Production

Natural fibers that are renewable and advancements

Textiles made from natural fibers like cotton, linen, hemp, and jute have been around for a while. However, "conventional" cotton farming has come under fire for degrading soil, using a lot of water, and requiring fertilizer and pesticides. One consumer-facing guide, for instance, said that cotton utilizes a disproportionately high percentage of pesticides worldwide and requires enormous amounts of irrigation. A number of tactics have been

developed to increase the sustainability of natural fibers, including regenerative agriculture (which restores soil and biodiversity), organic cotton (which doesn't include synthetic pesticides or genetically modified organisms), and alternative natural fibers like hemp and linen that use less water and inputs. Natural fibers still have sustainability issues (land usage, water use, transport, processing), notwithstanding these advancements. As a consequence, recycled or bio-based fibers are often the next frontier.

Secondary and recycled fibers

Pre- and post-consumer textile waste is a continually expanding issue. Waste recovery and recycling of textile-derived fibers, particularly in composites, were highlighted in a study on textile manufacturing. However, the same concepts apply to textile production, including the use of recovered cotton, polyester, blends, and waste textile fibers. Reduced dependency on virgin fibers, decreased needs for water, energy, and land, and garbage diverted from landfills are the advantages. Nowadays, recycled nylon and polyester (rPET) are widely used in sports and fashion fabrics. A blog post claims that compared to the production of virgin polyester, recycled polyester lowers greenhouse gas emissions by over 70%. There are still issues with the recycled fiber's quality (length and strength), mixed-fiber textile sorting, color and contamination, and cost.

Bio-based and regenerated fibers

Regenerated cellulosic fibers (like lyocell and modal) and newly developed biotech-derived materials (like mycelium leather and pineapple-leaf leather) provide low-impact substitutes for mechanical recycling. One blog, for example, highlighted plant-based leathers (Piñatex from pineapple leaves, mycelium leather) and wood-pulp-derived textiles (lyocell/Tencel) as viable substitutes. These materials seek to give biodegradable end-of-life solutions, minimize reliance on fossil fuels and carbon, and cut supply chain lengths. However, there is still room for improvement in their comprehensive life-cycle evaluations, cost competitiveness, and commercial scale.

Evaluation of material implications in comparison

However, choosing the right materials by itself does not ensure sustainability. "Natural materials ultimately make the most sustainable fabrics because they are both renewable and biodegradable; however, the degree of eco-friendliness is much more complicated," one guide warns. Water usage, chemical use, transportation, finishing treatments, and end-of-life disposal all have a substantial influence on the total impact, according to life-cycle analysis (LCA). In fact, synthetic materials like polyester, acrylic, and nylon continue to be troublesome because to their extended landfill half-lives, microplastic release after washing, and fossil fuel origin. Therefore, a fundamental takeaway is that choosing greener materials is important, but it's not enough; integration with supply-chain, processing, and end-of-life strategies is crucial.

Technologies & Manufacturing Approaches for Eco-Conscious Production

Processing energy, chemical, and water reduction

Wet processing (scouring, bleaching, dyeing, and finishing) is one of the biggest environmental burdens in textile manufacturing. It takes a lot of energy and water and often involves dangerous chemicals. For instance, an evaluation of wastewater treatment in the textile sector concentrated on using green technology to remove indigo hues. Supercritical CO_2 dyeing, low-liquor and waterless dyeing systems, ozone bleaching, enzyme processing (such as enzyme washing denim), and plasma treatment (dry process finishing) are some specific methods that lessen the effect since they use less water, energy, and chemicals. Reusing washing water and improving energy efficiency with AI forecasting decreased power use and costs, according to one study that examined a Turkish textile plant. (MDPI) These examples show how technology and data analytics may be used to lessen the environmental impact of textile manufacturing.

Integration of recycling and circular processes

Circular manufacturing includes closed-loop systems, textile fiber recycling, and process water reuse. Eco-design, reuse, recycling, and industrial symbiosis (waste from one process

used as input to another) are important enablers, according to a 2023 thorough assessment of circular economy practices in the textile sector. In a similar vein, a study of green textile production mapped green practices across the cutting, sewing, washing, and finishing steps of the garment manufacturing process, pointing out that while there are many green approaches, they are not well studied in poor nations.

Green industry and manufacturing technology Enablers 4.0/5.0

According to research, digitization, automation, sensors, artificial intelligence, and sustainable manufacturing—also known as Industry 4.0/5.0—are increasingly coming together in the textile industry. Environmental impact assessment, life-cycle assessment, sustainable design, sustainable fashion, and circular fashion supply chains are the five main study topics that were identified by a bibliometric evaluation. In order to minimize resource consumption, these enablers provide process optimization, waste reduction, traceability, and predictive maintenance.

Ecolabels, certifications, and standards

Sustainability cannot be ensured by technology alone; industrial practices must include sustainability. Restricted-substance lists (RSLs), fiber requirements, ecolabel criteria, and the need of design and manufacturing transparency were all considered in a 2023 assessment of sustainability standards and ecolabelling in textiles. For example, the OEKO TEX Association certification group (Standard 100, Made in Green) establishes requirements for traceability and safe chemicals. By offering reliable validation, these frameworks encourage the use of environmentally friendly materials and technology.

Industry Practices and Value-Chain Innovations

Certification and transparency in the supply chain

Fiber cultivation and manufacturing, yarn and fabric production, garment assembly, logistics, retail, usage, and end-of-life comprise the worldwide and intricate textile value chain. There are chances to lessen the negative effects on the environment and society at every level. Evaluations highlight the need of standards, auditability, and openness to guarantee that sustainability objectives are legitimately fulfilled. Brands and customers may now obtain information about the origin, processing, and certification of materials thanks to the increasing prevalence of traceability (via digital product passports and blockchain).

Business models for the circular economy

It is crucial to switch from linear "take-make-dispose" models to circular ones. According to evaluations of the circular economy, these practices include upcycling, modular product design, rental or subscription models, take-back programs (garments returned for recycling), and industrial symbiosis (textile waste as feedstock for other sectors). Waste from the textile sector, for instance, might be used to make composites or construction materials. Economic feasibility, post-recycling product quality, customer behavior, sorting, and logistics are among the difficulties.

Regional, policy, and regulatory issues

The green transition is hampered in many textile-producing regions (such as Asia and Africa) by factors like high technology costs, inadequate recycling infrastructure, lax enforcement of regulations, and low consumer willingness to pay for high-end green products. A recent research on the textile industry in Kenya found obstacles to using green technology and highlighted the need of just-transition principles (equity, employment) in conjunction with green development. Industrial clusters with common services (e.g., wastewater treatment, renewable energy) and policies (tax/incentives, EPR – Extended Producer Responsibility) might hasten adoption.

Brand strategy and consumer behavior

In the end, brand strategy and customer demand are crucial. Sustainable collections, recycled material, product-life extension tactics, and transparency are all being promoted by brands more and more. But "greenwashing" is still a possibility since claims might be overstated in the absence of strong verification systems. Thus, labeling, certifications, and consumer education play a crucial role.

Synthesis: Interplay of Materials, Technologies and Practices

Coordinated advancements in value-chain procedures, manufacturing technology, and materials are necessary for environmentally responsible textile production. If clothing is thrown away after one or two uses, or if processing involves the use of strong chemicals and a lot of energy, a greener fiber (such organic cotton) by itself will fall short. Similarly, if the fiber's origin is unsustainable, high-efficiency dyeing is pointless. The comprehensive approach includes: • Material innovation, such as the use of recycled, regenerable, low-impact fibers.

- Process innovations include the use of low-water, chemical, and energy technologies, the integration of circularity, and the audacious embrace of digital technology.
- System innovations include the creation of transparent supply chains, reliable certifications, circular business models, and laws and regulations that encourage them.

The research highlights that while there are several technologies and materials available, scale, integration, and cost-effectiveness in mainstream production—particularly in developing economies—are the true challenges. For instance, an examination of 138 articles on the manufacture of green clothing revealed a lot of research being done in wealthy nations, but little empirical evidence from production environments in poor nations.

Key Challenges & Barriers

Despite positive momentum, several hurdles remain:

- Scalability and economic limitations: Many green fibers, recycling technologies, and effective processing methods are more expensive up front; smaller businesses find it difficult to get funding.
- Trade-offs between quality and performance: New bio-based materials may have durability or lifespan problems; recycled fibers may have shorter fiber lengths, which might decrease yarn strength.
- Complexity of mixed fiber textiles and recycling: Blended textiles, such as cotton/polyester and elastane mixes, make separation and recycling more difficult.
- Data and measurement gaps: There is a lack of standardized measurements and comparability, and life-cycle data for many innovative materials and processes is still scarce.
- Regional differences and infrastructure: Although the majority of textile production occurs in poor nations, many of them lack adequate infrastructure for recycling, wastewater treatment, energy efficiency, or regulatory supervision.
- Consumer behavior and end-of-life disposal: Business models that prolong use-life and behavioral interventions are necessary since even well-made sustainable clothing cannot assist the environment if it ends up in a landfill too soon.
- Credibility of certification and greenwashing: In the absence of reliable standards, labels might be deceptive; a 2023 study revealed questions about the transparency and audit reliability of ecolabels.

Future Directions

Based on the review of literature, the following directions stand out for research, policy and industry:

- Life-Cycle Assessment (LCA) of innovative materials and technologies: To measure the advantages (such as embodied GHG, water, and chemicals) of new fibers and processes, more thorough, peer-reviewed LCA studies are needed.
- Scale-up and cost-reduction studies: Particularly in manufacturing centers in developing nations, pilot green technologies need transition routes to industrial-scale, cost-competitive production.
- Circular design for product life extension and end-of-life: Studying modular design, clothing that can be repaired or upgraded, take-back programs, and business strategies that encourage durability and reuse.

- Digitalization and traceability: Increased use of blockchain, IoT sensors, digital product passports, and AI analytics for supply chain transparency and process optimization.
- Policy, incentives, and regional support: research comparing national policy frameworks, green investment incentives, and SMEs' capacity development in textile areas.
- Social aspects and a fair transition: ensuring that workers are not unjustly displaced by the shift to eco-friendly textiles; investigating skills, career paths, and fair supply networks.
- Research on consumer behavior: Gaining insight into how customers react to promises about sustainable textiles, their willingness to pay, how long clothing lasts, and how they support circular business models.
- Integration and systems thinking: Research that treats textile manufacturing as a system rooted in an economic, social, and environmental context and integrates advancements in materials, processes, and systems rather than seeing them as discrete enhancements.

Conclusion

The transition to environmentally friendly textile manufacture is both necessary and doable. Green materials (organic, recycled, and bio-based fibers), more effective and low-impact manufacturing technologies (water, chemical, and energy reduction, recycling integration, digital optimization), and changing industry practices (certification, transparency, circular business models) all show promise. The key obstacle, meanwhile, is integrating these innovations into standard practice and expanding them across the mostly international, cost-sensitive textile value chain, particularly in manufacturing centers in poor nations. The three pillars—materials, technology, and practices—must cooperate for significant change; there is no one-size-fits-all solution. There are roles for producers, consumers, governments, researchers, and brands. According to the literature, the textile industry of the future will need a redesigned value chain that is inclusive by ethos, transparent by necessity, circular by default, and sustainable by design, in addition to new fabric types and machinery.

References

1. Patti A., Cicala G., Acierno D. Eco-Sustainability of the Textile Production: Waste Recovery and Current Recycling in the Composites World. *Materials* 2022; (PMC) PMC7796070.
2. Plakantonaki S., Kiskira K., Zacharopoulos N., Chronis I., Coelho F., Togiani A., Kalkanis K., Priniotakis G. A Review of Sustainability Standards and Ecolabeling in the Textile Industry. *Sustainability* 2023, 15, 11589.
3. Rahaman M.T., et al. Green production and consumption of textiles and apparel. *Journal of Cleaner Production* 2024.
4. Jain S., Kalapurackal J.J. A Systematic Review of Green Apparel Manufacturing. *Environmental Research, Engineering and Management* 2023.
5. Castillo-Suárez L.A., et al. A critical review of textile industry wastewater: green technologies for the removal of indigo dyes. *International Journal of Environmental Science and Technology* 2023, 20, 10553–10590.
6. Yılmaz K. Sustainable Textile Manufacturing with Revolutionizing Production Management. *Sustainability* 2024, 16(18):8152.