Development and Characterization of Sustainable Functional Textiles from Recycled Cotton Textile Waste and Temple Flower Waste

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ABSTRACT

The rapid growth of the textile and apparel sector, together with the continuous accumulation of temple flower waste, has increased the need for sustainable waste management strategies. Recycled cotton textile waste and temple flower waste represent valuable renewable resources that can be utilized to develop environmentally friendly functional textiles. Recycled cotton waste offers opportunities for the production of sustainable textile materials, while temple flower waste contains naturally occurring aromatic compounds and bioactive constituents that can be explored for textile finishing applications. This review examines the available literature on the sources, characteristics, processing methods, and potential textile applications of these two waste materials. It also discusses fragrance extraction techniques, eco-friendly finishing methods, material characterization, and the functional properties of treated textiles. Furthermore, the review identifies current research gaps, including the limited integration of recycled cotton textile waste and temple flower waste into multifunctional textile systems and the need for improved durability and large-scale application methods. The findings highlight the potential of combining these waste resources to support circular economy practices, reduce environmental impacts, and encourage the development of sustainable functional textiles for future industrial applications.

Keywords: Recycled cotton textile waste, Temple flower waste, Sustainable functional textiles, Circular economy, Natural fragrance finishing

INTRODUCTION

The textile and apparel industry is one of the largest manufacturing sectors worldwide and plays a significant role in economic development. However, the industry also generates substantial quantities of textile waste during fibre processing, fabric manufacturing, garment production, and post-consumer disposal. World fibre production has been steadily increasing in the past few decades, now exceeding 64 million tons per year [1]. Cotton textile waste constitutes a major portion of this waste because of its extensive use in clothing and household textiles. Although cotton is a biodegradable natural fibre, the improper disposal of cotton textile waste contributes to landfill accumulation, resource depletion, and environmental pollution. Recycling cotton textile waste into value-added textile materials has therefore become an important strategy for promoting sustainable manufacturing and supporting circular economy principles. Temple flower waste is another major organic waste generated daily in countries such as India, where flowers are extensively used for religious and cultural activities. After rituals, large quantities of flowers are discarded into open dumping sites or water bodies, leading to unpleasant odours, microbial growth, and environmental contamination. The potential environmental benefits of various systems of textile reuse and recycling have been assessed in the literature, using methods like life cycle assessment [2]. Despite being considered waste, temple flowers contain valuable natural aromatic compounds, pigments, antioxidants, and bioactive constituents that can be recovered and utilized in various applications. The effective utilization of temple flower waste can reduce environmental pollution while creating opportunities for sustainable product development. The systematic waste management and different valorisation techniques for

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handling textile waste are of prime concern [3]. In recent years, increasing attention has been given to the development of environmentally friendly textile materials by utilizing renewable and recycled resources. Recycled cotton textile waste has been investigated for the production of nonwoven materials, insulation products, home textiles, and composite structures because of its biodegradability, comfort, and availability. Conventional methods employed in textile and apparel industry for managing these waste materials include landfilling and incineration [4]. Similarly, natural extracts obtained from plant and flower sources have gained importance as eco-friendly alternatives to synthetic textile finishes due to their fragrance, antimicrobial potential, and reduced environmental impact. Reuse refers to the repurposing of end-of-life products or components for continued use in subsequent life cycles, typically through second-hand stores, flea markets, and charities [5]. The combination of recycled textile materials with natural finishing agents represents a promising approach for developing sustainable functional textiles.

Cotton Textile Waste

Cotton textile waste is generated during fibre processing, spinning, weaving, knitting, garment manufacturing, and post-consumer disposal. Due to the increasing demand for cotton products, large quantities of textile waste are produced every year, creating environmental and economic challenges. Recycling cotton textile waste helps reduce landfill disposal, conserves natural resources, and supports sustainable textile production. Recycled cotton fibres can be used in nonwoven fabrics, home textiles, insulation materials, composites, and other value-added textile products. Cotton fibres are among the most widely discarded textile waste materials. Regenerating textile waste as resources has become a global focus, not only to create extraordinary economic opportunities but also to tackle environmental pollution [6]. The utilization of recycled cotton textile waste contributes to waste reduction and promotes circular economy practices within the textile industry. Fig.1 shows the cotton textile waste.

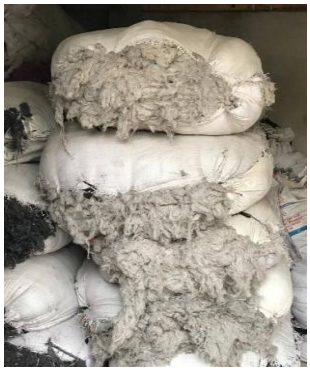

Figure 1: Cotton Textile Waste

Sources of Cotton Textile Waste

Cotton textile waste is generated at various stages of the textile supply chain, including fibre processing, spinning, weaving, knitting, garment manufacturing, and post-consumer disposal. During spinning, short fibres and fibre fly are produced as waste. Current waste cotton recycling methods mainly consist of mechanical, chemical, and biological recycling [7]. Fabric production generates selvedge waste, off-cuts, and defective materials. Garment manufacturing contributes a large amount of cutting waste, sewing waste, and rejected garments. After consumer use, worn-out or damaged cotton clothing and household textiles also become post-consumer textile waste.

Types of Cotton Textile Waste

Cotton textile waste is generally classified into pre-consumer and post-consumer waste. Pre-consumer waste is generated during textile manufacturing before the product reaches the consumer and includes spinning waste, weaving waste, knitting waste, cutting scraps, and defective garments. Post-consumer waste consists of used cotton garments and household textiles that are discarded after their useful life. Compared with post-consumer waste, pre-consumer waste is usually cleaner and easier to recycle because it contains fewer contaminants.

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Environmental Impact

Improper disposal of cotton textile waste creates several environmental challenges. Large quantities of textile waste are sent to landfills, occupying valuable land and increasing solid waste generation. Incineration of textile waste may contribute to greenhouse gas emissions and air pollution. Although cotton is biodegradable, the large volume of discarded textiles results in the unnecessary loss of natural fibres, water, energy, and other resources used during cotton cultivation and textile production. Recycling cotton textile waste can reduce environmental pollution, conserve natural resources, and promote sustainable waste management.

Recycling Methods

Several recycling methods have been developed to utilize cotton textile waste effectively. Mechanical recycling is the most widely used method, in which waste textiles are sorted, cleaned, shredded, and converted into recycled fibres for producing yarns, nonwoven fabrics, and insulation materials. Chemical recycling involves dissolving cellulose fibres and regenerating them into new textile fibres with improved quality. Textile waste generation and the fraction of textile waste in MSW is increasing with time [8]. Other emerging recycling technologies combine mechanical and chemical processes to improve fibre recovery while maintaining material performance. The selection of the recycling method depends on fibre quality, contamination level, and the intended application.

Applications of Recycled Cotton Textile Waste

Recycled cotton textile waste has a wide range of applications in the textile and non-textile industries. It is commonly used in the production of nonwoven fabrics, home textiles, insulation materials, automotive interiors, composite materials, packaging products, and cleaning cloths. The extent to which each circular strategy is evaluated in the literature does not reflect the hierarchy of the preferred strategies established within the circular economy. [9]. In recent years, recycled cotton has also been explored for developing sustainable functional textiles through the application of eco-friendly finishes and advanced textile technologies. Fig.2 Recycle of shows the cotton textile waste. Finally, lower-grade or heavily damaged cotton fibers that cannot be re-spun are diverted from landfills to serve industrial purposes; these fibers are heavily compressed and treated to manufacture automotive acoustics, building insulation, furniture padding, and highly absorbent industrial wiping cloths. Within the textile circular economy, mechanical processing breaks down scrap material back into a fibrous state, allowing facilities to generate secondary raw materials without the heavy agricultural impacts of cultivating virgin cotton crops. This structural degradation makes the resulting fiber mass weak, requiring facilities to blend it with longer virgin cotton or synthetic polyester fibers to achieve the tensile strength needed for high-speed industrial weaving looms.

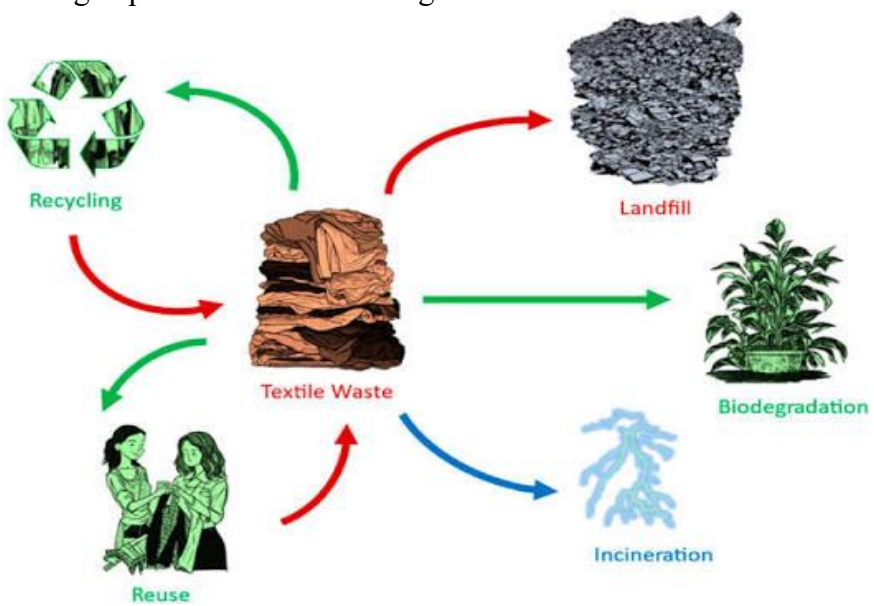

Figure 2: Recycle of Cotton Textile Waste

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Temple Flower Waste

Temple flower waste is one of the major biodegradable wastes generated from religious activities, temples, flower markets, festivals, and ceremonial events. Every day, large quantities of flowers are offered during worship and are discarded after use. Although these flowers are considered waste after religious rituals, they still contain valuable natural compounds such as essential oils, pigments, phenolic compounds, flavonoids, and antioxidants. Improper disposal of temple flower waste into landfills and water bodies contributes to environmental pollution, unpleasant odours, and organic waste accumulation. Therefore, the effective utilization of temple flower waste has gained increasing attention as a sustainable approach for resource recovery and value-added product development. Floral waste is produced by a variety of causes, including temple waste, wedding ceremonies, hotels, and other cultural and religious ceremonies [11]. Fig.3 shows the Temple Flower waste

Figure 3: Temple Flower Waste

Sources and Availability

Temple flower waste is generated from various religious and social activities where flowers are used for decoration and worship. Major sources include temples, flower markets, religious festivals, weddings, cultural events, and households. India produces a significant quantity of flower waste every day because flowers such as jasmine, rose, marigold, lotus, hibiscus, and chrysanthemum are widely used in religious offerings. Since these flowers are discarded shortly after use, they provide a continuous and easily available source of biodegradable raw material. Proper collection and segregation of temple flower waste are important to preserve its quality for further processing and utilization.

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Chemical Composition

Temple flower waste contains a wide range of naturally occurring bioactive compounds that can be utilized for sustainable textile applications. The major components include essential oils, aromatic compounds, phenolic compounds, flavonoids, natural pigments, carbohydrates, cellulose, lignin, and antioxidants. These compounds contribute to the fragrance, colour, and biological activity of flowers. The composition varies depending on the flower species, growing conditions, maturity, and storage period. The presence of natural aromatic compounds makes temple flower waste a promising source for fragrance extraction and eco-friendly textile finishing.

Existing Utilization

Several studies have explored the utilization of temple flower waste for the development of environmentally friendly products. Common applications include compost and vermicompost production, natural dye extraction, essential oil recovery, incense stick manufacturing, handmade paper, biofertilizers, and bioenergy production. In recent years, researchers have also investigated the extraction of natural fragrance compounds and bioactive substances from flower waste for cosmetic, pharmaceutical, and textile applications. Varanasi, situated in Uttar Pradesh state of India, is considered as one of the holy cities in the country, and thus, attracts a potential tourist attraction and ranks among the top ten tourism cities. However, the city is subjected to a severe challenge of managing its waste, including significant portions of floral refuse, generated from its hundreds of temples on a daily basis [13].

Challenges in Waste Management

Despite its potential, the utilization of temple flower waste faces several challenges. Flowers are highly biodegradable and begin to decompose rapidly after disposal, leading to a loss of fragrance and bioactive compounds. The lack of organized collection systems, improper segregation, seasonal variation in flower availability, and limited large-scale processing facilities further restrict the efficient utilization of this waste. In addition, the preservation of natural fragrance and maintaining consistent quality during processing remain important challenges. Addressing these issues through improved collection, storage, extraction, and processing techniques will enhance the commercial utilization of temple flower waste in sustainable textile and allied industries. Millions of waste pickers that recover materials under unsafe conditions an without formal institutional supports and coordination to be reduce an wastage . Fig.4 shows the different products that can be carved out of flower waste.

Figure 4: Different products that can be carved out of flower waste

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Natural Fragrance Technique

Natural fragrance extraction is an important process for recovering aromatic compounds from temple flower waste and converting them into valuable materials for textile finishing. Various extraction techniques have been developed to preserve the natural fragrance while maintaining the quality and stability of the extracted compounds. The selection of an extraction method depends on factors such as the flower species, fragrance yield, extraction efficiency, cost, and intended application. Conventional techniques, including steam distillation, hydrodistillation, and solvent extraction, are widely employed because of their simplicity and effectiveness, whereas advanced methods such as supercritical carbon dioxide extraction provide higher purity and better preservation of heat-sensitive compounds. The extracted natural fragrance can be incorporated into textile materials through suitable finishing techniques, enabling the development of sustainable functional textiles with controlled fragrance release. Being an offering to God, flowers do not find their way to the conventional waste disposal system. The techniques for their proper disposal should be identified, such as vermicomposting, dyeing, paper manufacturing, etc [12]. Selecting an appropriate extraction technique is therefore essential for improving fragrance quality, durability, and the overall performance of naturally finished textile products.

Steam Distillation

Steam distillation is one of the most widely used methods for extracting essential oils and aromatic compounds from flowers. In this technique, steam passes through the flower material, causing the volatile fragrance compounds to evaporate. The vapour mixture is then condensed and separated to obtain the essential oil. Steam distillation is preferred because it produces high-quality fragrance extracts without the use of harmful solvents and is suitable for large-scale industrial applications.

Hydro distillation and solvent extraction

Hydro distillation involves immersing flower materials directly in water and heating the mixture until the volatile aromatic compounds evaporate with the steam. After condensation, the essential oil is separated from the water. This method is simple, economical, and commonly used for laboratory-scale extraction, although prolonged heating may reduce the quality of heat-sensitive fragrance compounds. Solvent extraction uses organic solvents to dissolve aromatic compounds from flower materials. After extraction, the solvent is removed to obtain concentrated fragrance extracts. This method is particularly suitable for delicate flowers with low essential oil content and generally provides a higher fragrance yield than distillation methods. However, careful solvent removal is required to ensure the safety and purity of the final extract.

Function Textile Finishing Method

Functional textile finishing has become an important area of research for improving the performance, durability, and value of textile materials while meeting the growing demand for sustainable products. Unlike conventional finishing, functional finishing aims to impart specific properties such as fragrance release, antimicrobial activity, ultraviolet protection, moisture management, wrinkle resistance, and improved comfort without adversely affecting the fabric's physical characteristics. Besides the temple, people also offer flowers directly to the Ganga River, which have a negative impact on the river ecology and are also a threat to living aquatic organisms [14]. In recent years, increasing attention has been given to the use of natural extracts derived from plant-based materials and agricultural waste as environmentally friendly alternatives to synthetic finishing agents. Temple flower waste is considered a promising source of natural aromatic compounds because it contains essential oils and other bioactive constituents that can be incorporated into textile materials through suitable finishing techniques. Various application methods, including pad–dry–cure, exhaust, spray coating, and microencapsulation, have been investigated to improve the adhesion, durability, and controlled release of natural finishes on textile substrates. Among these techniques, microencapsulation has gained significant interest due to its ability to protect volatile fragrance compounds and gradually release them during use, thereby extending fragrance longevity. The effectiveness of textile finishing is influenced by several factors, including the type of fabric,

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concentration of finishing agent, binder selection, curing conditions. The adoption of eco-friendly finishing technologies not only reduces the consumption of hazardous chemicals but also supports sustainable textile manufacturing by promoting the utilization of renewable resources and minimizing environmental impacts. Therefore, the development of efficient functional finishing methods is essential for producing high-performance, durable, and environmentally responsible textile materials suitable for future sustainable textile applications.

Table 1. Sustainable Waste Resources for Textile Applications

Waste Materia	Key Component	Textile Application
Cotton Textile Waste	Textile and garment industries	Fibre recovery, sustainable textile
Temple Flower Waste	Temple, Flower market, festivals	Natural extract, fragrance, dyes
Food Waste	Domestic sources, restaurant and food processing units	Bio based materials, compost
Agricultural Waste	Farm and agro processing industries	Natural extract, fragrance, dyes

Characterization Technique

Characterization techniques are essential for evaluating the structural, physical, mechanical, chemical, and functional performance of sustainable textiles developed from recycled cotton textile waste and temple flower waste. These techniques help determine the effectiveness of recycling processes, fragrance finishing treatments, and the overall quality of the developed textile materials. Open dumping of flower waste (or any kind of organic waste) can cause many environmental problems, as its decomposition will promote the genesis of pathogens [15].

Chemical Characterization

Chemical characterization is performed to identify the chemical composition and functional groups present in recycled cotton fibres and temple flower extracts. Fourier Transform Infrared Spectroscopy (FTIR) is widely used to confirm the presence of cellulose, aromatic compounds, and the interaction between natural fragrance compounds and textile fibres. Gas Chromatography–Mass Spectrometry (GC–MS) is commonly employed to identify volatile compounds responsible for the fragrance profile of temple flower waste. These analytical techniques provide valuable information regarding the chemical stability and compatibility of the finishing materials and it promotes an waste into an recycle into usable garments to be finish into an ecofriendly products. Functional characterization further determines fragrance retention, wash durability, antimicrobial activity, and UV protection. Together, these characterization techniques provide comprehensive information on the performance and suitability of recycled cotton textiles finished with temple flower waste for sustainable textile applications.

Surface Morphology and Physical Characterization

The surface characteristics of textile fibres are commonly examined using Scanning Electron Microscopy (SEM). SEM analysis provides detailed images of the fibre surface before and after finishing treatment, allowing researchers to evaluate fibre damage, surface roughness, and the distribution of fragrance compounds or finishing agents. Waste gets generated from each and every activity of humans, which eventually degrades the quality of human health and accelerates the environmental degradation at an alarming rate [16]. Morphological analysis also helps determine the effectiveness of coating and microencapsulation techniques used for fragrance application. Physical characterization is carried out to evaluate important fabric properties, including thickness, fabric weight (GSM), air permeability, moisture absorption, water vapour permeability, and dimensional stability. These properties influence fabric comfort, breathability, flexibility, and overall usability. The

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application of natural fragrance finishes should not adversely affect the physical performance of the recycled textile substrate.

Mechanical Characterization and Functional Performance Evaluation

Mechanical properties determine the durability and serviceability of recycled textile materials. Common tests include tensile strength, tear strength, abrasion resistance, bursting strength, and fabric flexibility. These evaluations are important because recycled cotton fibres may exhibit reduced fibre length and strength compared with virgin fibres. Mechanical testing ensures that the developed textiles maintain adequate performance during practical use. Functional characterization assesses the effectiveness of the applied natural fragrance finish. Important parameters include fragrance retention, controlled fragrance release, wash durability, user comfort, and, where applicable, antimicrobial activity. Long-term performance studies are necessary to evaluate the stability of fragrance compounds after repeated washing and storage. These tests determine the suitability of fragrance-finished recycled textiles for commercial applications.

Significance of Characterization

Temple waste flowers are a type of biomass materials, and they are low-cost and easily available local raw materials [17]. Comprehensive characterization provides scientific evidence regarding the quality, durability, and functional performance of sustainable textile materials. The combined evaluation of chemical, physical, mechanical, and functional properties support process optimization, quality control, and product development. Proper characterization also facilitates the commercialization of recycled cotton textiles finished with natural fragrance extracted from temple flower waste while promoting sustainable textile manufacturing and circular economy practices.

Research Gap And Future Scope

Despite the increasing interest in sustainable textiles, several research gaps remain in the utilization of recycled cotton textile waste and temple flower waste for functional textile applications. Disposing of them on land or in nearby bodies of water causes significant pollution [18]. Most existing studies have investigated these materials separately, with limited attention given to their combined use in developing sustainable textile products. Research on the extraction and application of natural fragrance from temple flower waste is still in its early stages, particularly regarding its long-term stability and compatibility with recycled cotton textiles. Furthermore, there is limited information on the durability of fragrance finishes after repeated laundering, prolonged storage, and regular use. Standardized processing methods for fragrance extraction, textile finishing, and performance evaluation are also lacking, making it difficult to compare findings across different studies. When flowers are thrown in water bodies, they not only increase the biological oxygen demand but also bring in different unwanted pollutants in the water bodies due to the presence of pesticides in the flowers, thus severely affecting the quality of water [19]. In addition, most investigations have been conducted at laboratory scale, with relatively few reports addressing industrial-scale production, economic feasibility, and commercialization. Future research should focus on developing efficient and environmentally friendly extraction techniques to improve the yield and stability of natural fragrance compounds obtained from temple flower waste. Advanced finishing technologies, including microencapsulation and bio-based coating systems, should be explored to enhance fragrance retention and controlled release on recycled cotton textiles. Further studies are also required to evaluate the long-term durability, user comfort, biodegradability, and life cycle performance of fragrance-finished textile materials. The integration of sustainable recycling technologies with functional textile finishing can contribute to the development of innovative value-added textile products while supporting circular economy principles. Collaboration among researchers, textile industries, and waste management organizations will play an important role in translating laboratory research into commercially viable and environmentally sustainable textile solutions. Fig.5 shows the Reduce, Reuse, Recycle Process.

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Figure 5: Recycling in Waste Management

CONCLUSION

The increasing generation of recycled cotton textile waste and temple flower waste has highlighted the need for sustainable approaches to waste utilization and resource conservation. This review demonstrates that both waste materials possess significant potential for the development of environmentally friendly functional textiles. Recycled cotton textile waste serves as a sustainable textile substrate, while temple flower waste provides a valuable source of natural aromatic compounds that can be utilized for eco-friendly textile finishing. Various fragrance extraction techniques and functional finishing methods have been investigated to improve the performance, durability, and usability of these materials. Proper waste disposal is the need which is to be checked to avoid any kind of pollution arising just due to lack of proper knowledge and stringent laws by the acting authorities [20]. In addition, characterization techniques play a vital role in evaluating the chemical, physical, mechanical, and functional properties of the developed textiles. Although considerable progress has been achieved, several challenges remain regarding fragrance retention, process standardization, large-scale production, and commercial implementation. Addressing these challenges through advanced extraction technologies, sustainable finishing methods, and comprehensive performance evaluation will enhance the practical application of these renewable resources. The integration of recycled cotton textile waste and temple flower waste represents a promising strategy for promoting circular economy principles, reducing environmental pollution, and supporting the development of innovative sustainable textile products. Future research should focus on scalable manufacturing processes, long-term durability, and industrial adoption to facilitate the commercialization of eco-friendly functional textiles.

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