Journal of Textiles, Coloration and Polymer Science
https://jtcps.journals.ekb.eg/

Egyptian Society for Textile Science and Technology
الجمعية المصرية لعلوم وتكنولوجيا النسيج

Recycling and Sustainability Innovations in the Textile Industry

Abdullah E. Fahmy [a], Mai A. Mohammed [a], Esraa A. Ahmed [a] and Ahmed G. Hassabo [b]*

[a] *Textile Spinning, Weaving, and Knitting Department, Faculty of Applied Arts, Benha University, Benha, Egypt.*

[b] *National Research Centre (Scopus affiliation ID 60014618), Textile Research and Technology Institute, Pre-treatment, and Finishing of Cellulose-based Textiles Department, 33 El-Behouth St. (former El-Tahrir str.), Dokki, P.O 12622, Giza, Egypt.*

Abstract

The textile industry produces a significant amount of waste, with 92 million tons estimated globally each year. Textile waste is the second largest contributor to plastic waste, and it is often disposed of in landfills or burned. The recycling of textiles helps reduce the use of virgin raw materials and the amount of waste going to landfills. Textile recycling involves collecting, sorting, disassembling or dissolving, reprocessing, and integrating the recycled materials into the supply chain. There are different types of textile recycling, including closed-loop, open-loop, down-loop, and upcycling. Chemical recycling is a method where fibers are chemically processed to create recycled yarn, fabrics, and fibers. Recycled textile products can be used in various industries, and although the quality is usually lower than virgin fibers, they can be turned into items such as rags, insulation materials, and upholstery. Textile recycling is crucial for reducing the negative environmental impact of the textile industry, which is one of the most polluting industries globally.

Keywords: Recycling, textile fibers, fabric, cotton, environment, circular economy.

Introduction

One of the fastest-growing industrial sectors in the world is the textile industry. The textile industry is one of the most important sectors of the domestic economy, acting as a locomotive for the development of regions, creating production facilities in rural areas, providing employment for the population, as well as increasing exports. And the expansion of clothing and textile industry and the fast fashion trend among consumers have caused a rapid global increase in textile waste in the municipal solid waste all of which have a negative influence on the environment. That made textile material recycling is becoming more and more important in this setting.

Recycling is the process of repurposing a product or its parts to make something new, reducing the quantity of waste produced and the need for further resource exploitation. Four categories of recycling technologies exist and include primary (recycling material in its original form for recovery of equal value), secondary (mechanical recycling), tertiary (chemical recycling) and quaternary approaches (waste-to energy conversion processes). [1-6]

The aim of this review study is to understand the current state and practice of sustainability innovation in the textile industry in this article we will talk about the impact of recycling and using renewable materials in fabric manufacturing form environmental and economic aspects. And recycling and converting textile waste into value-added products with enhanced functional properties pave the way toward a circular economy for sustainability

The textile industry is one of the fastest-growing industrial sectors globally. One of the most significant sectors of the domestic economy is the textile industry, which boosts exports while generating job opportunities, manufacturing facilities in rural areas, and regional development. Additionally, the fast fashion trend among consumers and the growth of the apparel and textile industries have led to a sharp rise in the amount of textile waste entering municipal solid waste worldwide, all of which have a detrimental effect on the environment. Because of this, recycling textile materials is becoming increasingly crucial in this context. Repurposing a product or its

* Corresponding author: Ahmed G. Hassabo, E-mail: aga.hassabo@hotmail.com, Tel. 00201102255513
Received date: 29 December 2023, **Revise Date**: 06 February 2024, **Accept Date**: 23 February 2024
DOI: 10.21608/jtcps.2024.259259.1300

pieces to create something new is known as recycling, and it helps to reduce the amount of garbage that is created.

Population growth, improvement of living standards, an increasing assortment of textile materials, and the decreasing life cycle time of textile products contributed to global fibers consumption that generates a significant amount of post-industrial and post-consumer fibers waste. Globalization has made the apparel industry produce more clothing at lower costs, and many consumers have adapted a ‘fast fashion’ trend that considers clothing to be a disposable product Fast fashion characterized by mass production, variety, agility, and affordability has brought about a surge of apparel consumption[7, 8] One category of municipal solid trash that has been expanding quickly in recent years is textile waste. Rich sources of textile waste, such as waste from the production of textiles and apparel, commercial services, and consumption, have sparked worries about creating innovative circular textile solutions across the globe. In actuality, in recent years, management and disposal of textile waste have become more and more pressing global issues..[9] The definition of recycling is the conversion of waste into new products with or without damaging the previous one. Specifically, textile recycling is related to the reprocessing of pre- or post-consumer textile waste for utilization in new textile or non-textile products. The recycling of textiles can be regarded as a route to socioeconomic benefits and wherewithal to boosting a nation's economy Besides, it can be included in the concept of “circular economy”, in which materials keep circulating in the economic system in a cascade of reuse and recycling, and that has been gaining strength in the policy, business and civil society sectors [7] Therefore, using recyclable, natural, and renewable materials is a feature of many suggested solutions. One effective example being researched and used in industry over the last ten years is the utilization of natural fibers and their wastes. Particularly, it is becoming more and more common to think of lingo-cellulosic fibers made from plants as natural, eco-friendly fiber applications. These fibers, which combine textile, fiber, and particle structures, are predicted to have a major beneficial environmental impact. The availability of natural eco-friendly production technology and the product's high socioeconomic worth are strong factors in favor of its further growth. It can be widely used as a replacement for non-biodegradable or non-ecological products. [8, 10] . According to estimates, the textile industry can recycle up to 93-55% of its waste into various valuable goods without producing any additional hazardous waste or unpleasant by products. Recycling is still happening at a comparatively low rate, though. For example, only approximately 25% of textiles in Europe are recycled. The textile recycling rate in the US is 16.2%, which is considerably lower. Millions of tons of textiles are dumped in landfills worldwide as a result of inadequate textile recycling. The variety of fiber waste and its structure (colour, type, content, and characteristics), which impedes the recycling process, may be the cause of this poor recycling rate. Given the low recycling rate that exists today, there is a great deal of room for growth in recycling.[7]

Type of fibers

Plant based fibers

The majority of plant fibers, including cotton, ramie, jute, hemp, flax, and sisal, are cellulose-based fibers. Paper and cloth are made from fibers derived from cellulose. A natural fiber is made up of hundreds of polymer chains that combine to create intricate patterns and highly specialized layered structures that give the fiber most of its characteristics. Natural fibers can be as short as a few centimeters for cotton, as long as several hundred meters for silk, and as short as one decimeter for wool. shorter fibers. [11, 12]

Cotton

The most commonly manufactured natural textile fiber is cotton. Cotton is a staple fiber that typically has a length of 22 to 32 mm and grows around the cotton seed as seed hairs.

Between 5000 and 20,000 fibers can be produced from a single cotton seed. 88–97% of cotton fibers are made of cellulose, with the other ingredients being waxes, proteins, and pectinid acid. Following harvesting, the lint fibers are extracted from the seed and used to make yarn. After that, no cellulosic chemicals are removed from the cotton linters by bleaching them, which lowers the DP. Sustainable cotton production has recently been under scrutiny due to environmental issue such the usage of arable land, excessive water use fertilizers and insecticides, as well as high energy use. Relevant environmental pollutants and consequences are linked to these practices. As a result, initiatives have been made to produce cotton in a more sustainable manner, which includes using less agrochemicals and conserving energy and water. Additionally, cotton textile recycling offers substitutes to reduce the need for new raw materials. [7, 12]

Jute Fiber

The second-most-used natural fiber in industrial settings is jute.

At the moment, 3.2 million kg of jute fiber are processed per year. When it comes to mechanical qualities, jute fiber is superior to several other natural fibers including sisal, coir, and ramie. Jute fiber has a porous structure as well, and its heat conductivity is determined by the arrangement and form of its voids. Jute fiber thus offers a great deal of promise for use as an effective thermal and acoustic insulation material. A significant portion processed jute fiber is still wasted and dumped in landfills, showing that recovering jute fiber can help increase its market value and promote more sustainably produced material.[7, 12-17]

Wool

Because it is permeable, warm, and moisture-wicking, wool is one of the most widely used animal protein fibers worldwide for thermal insulation. Global production of wool fiber reached 1.2 million kg in 2017. Long chains of various amino acids make up wool most of the time. Wool's molecular chain's coiled springs enhance fiber toughness and make it appropriate for sound absorption Wool is a good material for mechanical recycling because of its long fiber length. Wool is regarded as one of the most recyclable fibers and has been recycled for more than 200 years. [7, 12]

Synthetic textile fibers

Man-made fibers are formed by extruding the melted or dissolved polymer through the small openings of a spinneret. This method can be used to create spun yarns, which are made up of shorter fibers that are spun together, as well as filament yarns, which are made up of a single, infinitely long fiber [9].

Polyester, polyacrylic, polyamide, elastane, and polypropylene are the primary synthetic polymers utilized in textile products. Polyesters are the same as poly(ethylene terephthalate) (PET), which is also utilized to make packing containers (bottles). Compared to PET used to make bottles, polyester used in textiles has a higher crystallinity and a lower molecular weight. [11, 12]

Polyester

The most common fiber used in clothing and textiles is polyester. The manufacturing of polyester fiber has expanded globally since 1990 by more than five times. About 53.7 million kg of polyester fiber were produced globally in 2017, accounting for 51% of all fiber produced worldwide. Despite being the most wasteful material produced by the apparel industry, virtually little of it is recycled. Only 14% of garbage was recycled in 2017, and a significant portion of this synthetic fiber was thrown away as waste in landfills. Researchers are looking into ways to recycle polyester waste into new products, such as thermal and acoustic insulation materials, in order to lessen the environmental impact of polyester production.[7]

Acrylic

Acrylonitrile comonomers must make up at least 85% of the mass of the polymer chain for a fiber to be classified as acrylic. The bulkiness and strong elastic qualities of acrylic fiber, which is categorized as artificial wool fiber, allow it to substitute wool fiber, particularly in hand-knitted and hosiery clothing. Additional noteworthy physical attributes include a high resistance to sunlight, chemicals, and microbes, a moderate flammability, and a high electrical resistance. Additionally, these fibers have amazing insulating qualities. The creation of thermal and acoustic insulating materials from discarded acrylic fibers is the subject of several ongoing investigations. Since the 1980s, the use of acrylic fibers in the production of carpet yarns has significantly decreased as nylon and polypropylene yarns have taken the lead.[7]

Fibers of regenerated cellulose

The majority of regenerated cellulose fibers (RCF) come from wood pulp, with cotton linters being a less common source. The two most notable regenerated cellulose fibers are lyocell and viscose, which is also referred to as rayon. The principal stages in RCF production can be summarized as dissolution, fiber spinning, and regeneration. According to, the resultant viscose and lyocell fibers are both nearly 100% cellulose fibers. A number of factors affect the mechanical properties of RCF, the most important of which is the degree of polymerization (DP). Higher DP is known to result in higher tensile characteristics.[7]

In 2017, apparel and textiles accounted for 6% of global manufactured goods exports. The top two export destinations for apparel and textiles are China and the European Union (EU) . Around 23.9 million metric tons of textile fibers were produced globally in 1975; by 2017, that number had risen to 98.5 MMT, and by 2019, it had reached approximately 111 MMT. The demand for polyester outgrew that of cotton fiber for a considerable amount of time, but in 2002 the demand for polyester outgrew that of cotton fiber, and it has since continued to increase at a faster rate. The two most widely used fibers in the world are polyester and cotton. Furthermore, 40% of the world's fiber consumption in 2017 was made up of synthetic fibers or polyester/cotton blends, and 60% was made up of other materials. [7, 8]

Textile waste

The textile industry generates a significant amount of waste annually, the most of which is currently disposed of as municipal solid waste (MSW).The global textile waste output is estimated to be 92 million tons per year. With 42 million tons of plastic trash produced annually, the textile industry is the second largest contributor to plastic waste behind the packaging industry. In the US, five percent of landfill area is occupied by textile waste. The two countries that produce the most textile waste are China and the US, with 20 million and 17 million tons, respectively.

In general, any unwanted or abandoned article of clothing or fabric that is unsuitable for its intended use is referred to as textile waste . It is split Depending on the sources, it can be separated into three sizable categories: pre-consumer, post-consumer, and post-industrial waste. Pre-consumer textile waste is viewed as ‘clean waste’ is produced when textiles are made, manufactured, or processed. It usually consists of yarns, fabric scraps, or returned or defective goods. When used textile items are thrown away before or at the end of their useful lives or outgrown of no value to consumers after their service life is created. Examples of this waste are the clothes, bedding, and curtains that homes and institutions discard. Other industries that employ textiles as inputs or outputs, such as abandoned medical, automotive, or packaging textiles, And is deemed as ‘dirty waste’ generated from commercial and industrial textile applications produce post-industrial textile waste.[8, 18]

In addition to using a lot of water, energy, and chemicals throughout the clothing-making process, the fashion sector alone has been found to be responsible for 10% of global greenhouse gas emissions and 20% of wastewater worldwide. Textile waste is frequently landfilled or burned, which uses landfill space and increases the amount of harmful materials or microplastics that are released into the air, water, and soil during the burning process. Economically, the textile sector loses money as a result of textile waste. Every year, an estimated USD 500 billion is lost as a result of inadequate recycling and underuse of garments. Moreover, there are costs associated with disposing of textile waste. Disposing of textile waste contributes to the social inequality that already exists. Before being sold in second-hand markets, used clothing is shipped from developed to low- and middle-income nations for sorting, categorization, and rebalancing. Low-wage workers frequently carry out these tasks. Unsold clothing is disposed of as solid waste, adding to the load on low- and middle-income nations' MSW systems and increasing health risks to the environment.

Consequently, efficient handling of textile waste may have favorable effects on the environment, the economy, and society. Nonetheless, there are a number of difficulties in managing textile waste. Particularly in poor nations, the collection of textile waste is frequently insufficient, ineffective, and disorganized, which causes streams of textile waste for the recycling sector to become unstable and unstable. The variety of blends, colors, treatments, and accessories on textiles contribute to the heterogeneity and complexity of textile waste, making trash sorting and separation challenging. Numerous technological, financial, and environmental obstacles must be overcome before textile waste may be recycled. For example, recycling techniques for natural fibers are unestablished, while those for synthetic fibers are typically energy-intensive and environmentally harmful. Due to restrictions on the sorting and recycling of textile waste, disposing of it in landfills is sometimes the only practical solution. This is not sustainable because it takes up valuable landfill area and generates leachates and greenhouse gases. Since synthetic fabrics are a primary source of microfibre, improper handling of textile waste, particularly synthetic textile waste, exacerbates the already concerning plastic pollution.[18]

Textile recycling

Reusing an item or its parts to create something new is known as recycling. It reduces the amount of virgin raw materials used and the amount of garbage that is disposed of in landfills or burned.[7, 19]

The five basic steps of recycling are

- Collecting;
- Sorting based on material, color, and structure;
- Disassembling, shredding, or dissolving;
- Reprocessing, restoring quality, or regenerating;
- Integrating into the forward supply chain.

The purpose of sorting is to help with the recycling process by separating the various kinds of textiles. The removal of bulky goods like coats and blankets is referred to as a crude sorting method. Next, pants are separated from blouses or dresses, for example. The sorting gets increasingly precise as it goes on. For instance, after every pair of pants is chosen, they are further arranged according to the fabric, quality, and condition for men or women. The recycled materials are graded to meet particular markets in addition to being sorted. The quality of the grading procedure is typically what distinguishes one rag sorter's competitive advantage over another.[7, 20]

Textile waste recycling is dependent on specific waste criteria. Since the contents of textile waste are so diverse, it is important to determine what the material is made of when thinking about recycling textiles. This includes items made from a particular kind of natural fiber or a blend of other fibers. Because it affects both the cost and the recycling process, the content of the textile is a crucial factor Despite these obstacles, the textile recycling sector is among the oldest in the world and has the capacity to treat waste without producing any more hazardous waste or hazardous by products.[20]

Chemical recycling is the term used to describe several procedures wherein the textile fiber is chemically processed to create recycled yarn, fabrics, and fibers that have been altered at the molecular level. In the case of synthetic polymer fiber, the polymers are depolymerized, while in the case of natural polymer fiber, they dissolve, generating monomers or oligomers that are then re-polymerized into new fibers In contrast to mechanical recycling, this method recovers more valuable products that can be easily reintroduced into the production cycle without experiencing market saturation. It also has the advantage of allowing the crude products of the chemical breakdown to be used without the need for additional purification.[21]

In contrast to mechanical recycling, this method recovers more valuable products that can be easily reintroduced into the production cycle without creating issues with market saturation. It also has the advantage of allowing the crude products of the chemical breakdown to be used without the need for additional purification [7, 21, 22]

Furthermore, there are four types of textile recycling: closed-loop, open-loop, down-loop, and upcycling. "Upcycling" refers to the process of creating a product from recycled materials that is more valuable or of higher quality than the original product; "downcycling" is the opposite of this. Reusing a product's material to create a nearly identical product is known as closed-loop recycling. Open-loop recycling, on the other hand, involves recycling a material from one product and using it in another. The closed-loop recycling method recovers the raw material that was used to make a polymer product and reprocesses it to create a product that is just as high-quality as the original material and this figure show the process of textile recycling and classification of textile reuse and recycling routes, re .[8, 23, 24]

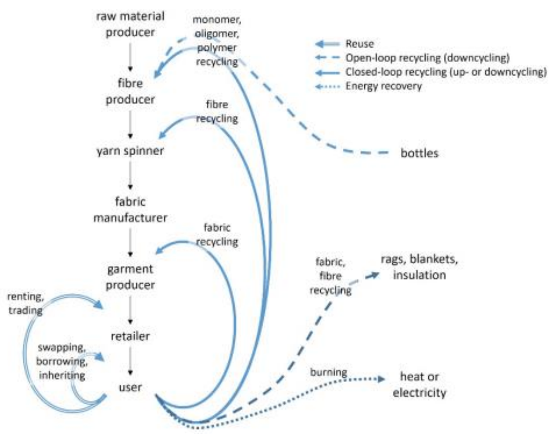

Figure 1: Recycled textile products

Since wear and laundry shorten the length of the fibers and the molecular components, fiber recycling typically results in materials of lower quality than materials made from virgin fibres. Therefore, fiber recycling is considered to be downcycling

Clothing and home textiles can be downcycled into, for instance, industrial rags, low-grade blankets, insulation materials, geo-fleece, carpet underlay, stuffed toys, shoe insoles and upholstery[25, 26] Moreover, the recycled materials can be used in the sailing, furniture, and automobile industries. Additionally, some of the waste produced by the spinning and weaving industries can be recycled (through the fiber recovery process), adding to the textile and apparel industry's resource pool in a way that is comparable to that of natural fibers like cotton or linen. This adds value to the waste because it can be used as a raw material to create new products.[8, 27, 28]

An increase in the rate of textile recycling can lessen the harm that new textile production and landfill space consumption do to the environment. According to estimates, the annual environmental impact of a family's non-recycled clothing is comparable to the water needed to fill nearly 1000 bathtubs and the amount of carbon dioxide released by a modern car traveling 6000 miles. But first, it's important to grasp the precise impact that textile production has on the environment and natural resources in order to appreciate why recycling is so important to the textile industry.

One of the most polluting industries in the world, the textile sector has a number of detrimental effects on the environment, including the depletion of natural resources, the excessive use of energy and water, the production of a large amount of wastewater and solid waste, worker exploitation, massive fuel consumption for transportation, and the use of toxic chemicals. It is projected that each year, 1200 million tons of greenhouse gas emissions , 93 billion cubic meters of water are used, 42 million tons of chemicals are used, and one million tons of dyestuffs are used. the textile industry is responsible for 20% of all industrial water pollution because of the dyeing and treatment of textiles demonstrated that recycling second hand clothes is able to diminish greenhouse gas emissions by 53%, pollution associated with chemical processing by 45%, and water eutrophication standards by 95%. Besides, it is necessary to link the textile recycling with the circulatory economy and with life

When only the production of natural fiber textile is considered, the scenario is not favourable also, principally the production of cotton. The environmental impacts associated with cotton-growing are heterogeneous and complex. Previous studies showed that water 15 consumption, land occupation, biodiversity loss owing to the usage of pesticides and other toxic substances, and use of chemicals during cotton manufacturing are the most serious features to be analysed during the cotton production step assessment of textile product. [7, 29]

Economic aspects of textile recycling

Textile recycling has a positive effect on a variety of entities and makes a significant contribution to modern culture's social responsibility, which includes desire to support environmental causes, charitable causes, and disaster assistance. Furthermore, it causes a great deal of disruption in the international economy According to every phase of the textile waste recycling life cycle—that is, collecting, sorting, transport, and recycling—can generate employment and present chances for small or family-run enterprises.[30]

Particularly for the textile industry, a fully integrated fabric and fiber recycling system offers the potential to reduce resource requirements (water, fossil fuels, chemicals) and generate new employment opportunities throughout the entire clothing production chain (collection, sorting, and recycling). While there is a significant amount of accessible research, these socio-economic gains have only been partially forecasted[8, 31, 32]

Newly, the term called “Circular Economy”, which presents a model capable to dissociate economic growth from generating waste has gained popularity among global companies due to its environmental benefits and can be used to the recycling of textiles. According to this concept, it is possible to turn waste into beneficial resources for the manufacture of new products and to increase profits and competitiveness of companies. It is a process that does not generate industrial wastes, but instead reutilize natural resources repeatedly[7]

The circular economy has also the purpose of keeping products, components, and materials on its highest level of usefulness and value all the. Then, there is a huge potential for the textile recycling sector to collaborate with the circular economy. As main economic aspects, it can decrease the manufacturing of new textiles from virgin materials and consequently decrease the usage of water, energy, and chemicals in the production chain. the figure exhibits the concept of Circular Economy in the textile industry.[23, 33]

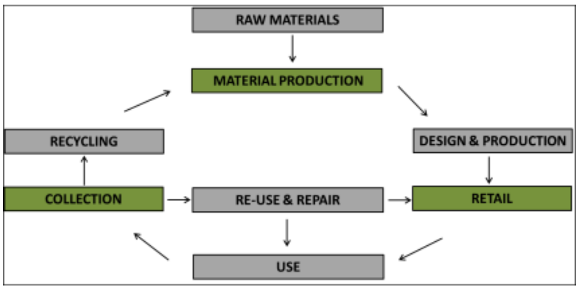

Figure 2: [7]

Innovative recycling technologies for textiles – A potential solution

A potential solution is the development of innovative recycling technologies for textile materials. In this sense, technical textiles are a field envisaged by the European strategy, and consist of textile materials with technical applications, in fields like industry or agriculture. To improve and reach a significant valorisation, integrated processes for proper separation, detection and classification of textile waste from industrial and commercial packaging waste are promoted. In this sense, several research and industrial approach suggest the proposed technical solution, as a strategy for textile waste recovery from the disposal in landfills, with a great potential in treating textile waste and facilitating the recovery of natural textile wastes as value–added products into natural fibre reinforced composites.[34-36]

In the past ten years, there has been a huge increase in interest in textile wastes, and this interest will only grow in the future as researchers work to develop a recycling technology that will make it possible to gather, separate, and process low-value blended textiles into new raw materials that can be used as composite reinforcement. One of the valorisation approaches is the growing applications of these materials (fibre and textile recycling, with a focus on natural and synthetic textile fabrics that make up a significant portion of textile waste) as reinforcements in the creation of natural fiber reinforced composites. Cellulosic material, which makes up the majority of natural fiber, can be utilized as a resource to create fiber-based goods like composites. The biggest obstacle to using different types of textile waste is figuring out how to recover it for use as composites reinforcement. A further intriguing addition about the usage of geo-polymers in agriculture is put forth. The qualities of textile materials (lightweightness, flexibility, resistance) are included in this category of new high-added value textile products, which also provides suitable solutions for the particular technological purpose.

Consequently, creating markets for the lowest quality textiles can have broader advantages, such as assisting in the production of composites reinforced with natural fibers. Additionally, innovations involving composite materials may offer a workable way to valorize textile waste, and textile wastes made up of different ratios of natural and synthetic textile fibers or fabrics may be utilized as inexpensive raw materials for high-value goods.

There have been partnerships between innovative enterprises and brands in recent years. The general goal of creating recycling technology to address the issue of textile waste. More fabrics, some of which have hardly been worn, are being thrown out as a result of rising garment consumption. Along with technological advancement, knowledge of the markets regarded as inputs (textile wastes) and outputs (natural fiber reinforced composites) for the recycling process has been quantified to determine the entire opportunity.[9, 10]

Summary

In summary, recycling textiles is essential to achieving sustainable development and the idea of a circular economy. But in order to become a practical choice in the future, textile recycling methods need to be less costly, less polluting, and more energy-efficient than traditional methods that use virgin materials as their raw materials.

In order to achieve the environmental, economic, and social benefits of a textile recycling chain, it is also crucial to find a way to support the scale-up and potential lifecycle impacts of new and existing recycling processes to commercialization. Additionally, collaborative industry endeavours from raw materials, design, collection, and recovery technologies must be created.

Conflict of Interest

There is no conflict of interest in the publication of this article.

Acknowledgment

The authors thank to the National Research Centre, Giza, Egypt for the financial support of this work and also gratefully grateful to the Faculty of Applied Arts, Benha University

Funds

There in no funding

References

1. Sturgess, D.J. A spectrum of missed opportunity. , *Brandweek* **49**(15) 29 (2008).

2. Hassabo, A.G., Salama, M., Mohamed, A.L. and Popescu, C. Ultrafine wool and cotton powder and their characteristics, *J. Nat. Fiber*, **12**(2) 141-153 (2015).

3. Hassabo, A.G., Salama, M. and Popescu, C. Characterizations of pva composites based on recycled ultrafine cotton and wool powders, *Res. Rev. BioSci.*, **10**(14) 147-158 (2015).

4. Salama, M., Hassabo, A.G., El-Sayed, A.A., Salem, T. and Popescu, C. Reinforcement of polypropylene composites based on recycled wool or cotton powders, *J. Nat. Fiber*, 1-14 (2017).

5. Abdel Wahab, S.S.M., Atallah, H.A.A., Saleh, Y.D.M., Glal El-Den, R.E. and Hassabo, A.G. Challenges and unsustainable practices in the apparel sector, *J. Text. Color. Polym. Sci.*, - (2024).

6. Fahmy, A.E., Mohammed, M.A., Ahmed, E.a. and Hassabo, A.G. Recycling and sustainability innovations in the textile industry, *J. Text. Color. Polym. Sci.*, - (2024).

7. Candido, R. Recycling of textiles and its economic aspects, pp. 599-624, (2021).

8. Labayen, J., Labayen, I. and Yuan, Q. A review on textile recycling practices and challenges, *Textiles*, **2** 174-188 (2022).

9. Todor, M., Bulei, C., Kiss, I. and Alexa, V. Recycling of textile wastes into textile composites based on natural fibres: The valorisation potential, *IOP Conference Series: Materials Science and Engineering*, **477** 012004 (2019).

10. Bhuiyan, M.A.R., Ali, A., Mohebbullah, M., Hossain, F., Khan, A. and Wang, L. Recycling of cotton apparel waste and its utilization as a thermal insulation layer in high performance clothing, *Fashion and Textiles*, **10** (2023).

11. Bianchi, S., Bartoli, F., Bruni, C., Fernandez-Avila, C., Rodriguez-Turienzo, L., Mellado-Carretero, J., Spinelli, D. and Coltelli, M. Opportunities and limitations in recycling fossil polymers from textiles, *Macromol*, **3** 120-148 (2023).

12. Thapliyal, D., Arya, R., Verros, G. and Tiwari, A. Natural fibers composites: Origin, importance, consumption pattern, and challenges, *Journal of Composites Science*, **7** 507 (2023).

13. Nada, A.A., Hassabo, A.G., Mohamed, A.L., Mounier, M.M. and Abou Zeid, N.Y. Liposomal microencapsulation of rodent-repelling agents onto jute burlaps: Assessment of cytotoxicity and rat behavioral test, *JAPS*, **6**(8) 142-150 (2016).

14. Mohamed, A.L., Hassabo, A.G., Nada, A.A. and Abou-Zeid, N.Y. Properties of cellulosic fabrics treated by water-repellent emulsions, *Indian J. Fibre Text. Res.*, **42**(June) 223-229 (2017).

15. El-Sayed, G.A., Othman, H. and Hassabo, A.G. An overview on the eco-friendly printing of jute fabrics using natural dyes, *J. Text. Color. Polym. Sci.*, **18**(2) 239-245 (2021).

16. Hassabo, A.G., Shaker, S., Khaleed, N. and Ghazal, H. An observation on dyeing techniques of polyester/cotton blended fabrics using various dyes, *J. Text. Color. Polym. Sci.*, **21**(1) 205-220 (2024).

17. Othman, H., Reda, E.M., Mamdouh, F., Yousif, A.a.R., Ebrahim, S.A. and Hassabo, A.G. An eco-friendly trend of jute fabric in wet processes of textile manufacturing, *J. Text. Color. Polym. Sci.*, **21**(2) 435-442 (2024).

18. Kuok Ho, D.T. State of the art in textile waste management: A review, *Textiles*, **3** 454-467 (2023).

19. Wang, Y. Fiber and textile waste utilization, *Waste and Biomass Valorization*, **1**(1) 135-143 (2010).

20. Hawley, J.M. Textile recycling: A systems perspective, recycling in textiles, UK, Woodhead, (2006).

21. Zhang, Y.-Q., Lykaki, M., Alrajoula, M.T., Markiewicz, M., Kraas, C., Kolbe, S., Klinkhammer, K., Rabe, M., Klauer, R. and Bendt, E.J.G.C. Microplastics from textile origin–emission and reduction measures, **23**(15) 5247-5271 (2021).

22. COŞKUN, G. and BAŞARAN, F.N.J.J.o.S.R.i.S.S. Post-consumer textile waste minimization: A review, **5**(1) 1-18 (2019).

23. Sandin, G. and Peters, G.M. Environmental impact of textile reuse and recycling – a review, *Journal of Cleaner Production*, **184** 353-365 (2018).

24. Wang, H., Kaur, G., Pensupa, N., Uisan, K., Du, C., Yang, X. and Lin, C.S.K. Textile waste valorization using submerged filamentous fungal fermentation, *Process Safety and Environmental Protection*, **118** 143-151 (2018).

25. Palme, A., Idström, A., Nordstierna, L. and Brelid, H. Chemical and ultrastructural changes in cotton cellulose induced by laundering and textile use, *Cellulose*, **21**(6) 4681-4691 (2014).

26. Schmidt, A. Gaining benefits from discarded textiles: Lca of different treatment pathways, Nordic Council of Ministers, (2016).

27. Bartlett, C., McGill, I., Willis, P.J.W. and Resources Action Programme: Banbury, U. Textiles flow and market development opportunities in the uk, (2013).

28. Nunes, L.J.R., Godina, R., Matias, J.C.O. and Catalão, J.P.S. Economic and environmental benefits of using textile waste for the production of thermal energy, *Journal of Cleaner Production*, **171** 1353-1360 (2018).

29. Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G. and Gautam, R. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, *Ecological Economics*, **60**(1) 186-203 (2006).

30. Cuc, S. and Vidović, M.M. Environmental sustainability through clothing recycling, (2014).

31. Baloyi, R., Gbadeyan, O., Sithole, B. and Chunilall, V. Recent advances in recycling technologies for waste textile fabrics: A review, *Textile Research Journal*, (2023).

32. Filho, W., Tripathi, S., Andrade Guerra, J.B., Gine, R., Orlovic Lovren, V. and Willats, J. Using the sustainable development goals towards a better understanding of sustainability challenges, *The International Journal of Sustainable Development and World Ecology*, **26** 1-12 (2018).

33. Salvador Cesa, F., Turra, A. and Baruque-Ramos, J. Synthetic fibers as microplastics in the marine environment: A review from textile perspective with a focus on domestic washings, *The Science of the total environment*, **598** 1116-1129 (2017).

34. Faruk, O., Bledzki, A.K., Fink, H.-P. and Sain, M. Biocomposites reinforced with natural fibers: 2000–2010, *Progress in Polymer Science*, **37**(11) 1552-1596 (2012).

35. Pensupa, N., Leu, S.Y., Hu, Y., Du, C., Liu, H., Jing, H., Wang, H. and Lin, C.S.K. Recent trends in sustainable textile waste recycling methods: Current situation and future prospects, *Topics in current chemistry (Cham)*, **375**(5) 76 (2017).

36. Riedel, U. and Nickel, J. Activities in biocomposites, *materialstoday*, **6** 44-48 (2003).