Circular Bioeconomy Approaches: Converting Food Waste into Sustainable Textile Materials

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Abstract

The rise in food waste and environmental issues in the textile sector have created a need for new and sustainable approaches. This paper discusses strategies for using circular bioeconomy technologies to transform food waste into textiles. It identifies the potential of different types of food waste such as crop residues, food processing waste, and the by-products of the agro-industry, as important feedstock containing valuable components such as cellulose, lignin, starch and protein. This research recapitulates the main processing technologies like mechanical, chemical, enzymatic and novel methods such as nanotechnology and electro spinning for biomass conversion. It also highlights the development of biodegradable fibres, biopolymers, and composite materials from these food wastes, and their implementation in agritech and food. The studies' environmental and economic impacts, such as waste minimization, greenhouse gas reduction, and improved rural incomes, are also discussed. While showing potential, issues such as cost of processing, standardization and regulatory frameworks need attention. Looking ahead, there is a focus on innovative biomaterials, technology upscaling and policy. This approach towards a circular bioeconomy in textiles creates a sustainable future for resource use, environmental harmony and innovation.

Introduction

The world's population and industrialization growth has greatly accelerated the production of food waste and textile waste, posing major environmental problems (Tang, 2023). The most recent estimates reveal that almost one-third of the world's food is wasted, leading to greenhouse gas emissions and a poor efficiency of resources (FAO, 2023; Dantas *et al.*, 2025). At the same time, the textile sector is one of the most resource-intensive and wasteful industries as it relies on synthetic materials, consumes large quantities of water and chemicals (Niinimäki *et al.*, 2020; Suen *et al.*, 2023). These issues point to the need for sustainable and holistic solutions, with the circular bioeconomy emerging as a potential solution to both (Kirchherr *et al.*, 2017).

The circular bioeconomy wherein biological resources are sustainably managed by transforming waste streams into high-value products which close material loops and environmental impacts is promoted (D'Amato *et al.*, 2020). Here, food waste is taking on a new role as a resource because it can be transformed into valuable material products due to its composition of carbohydrates, lignin, starch and other natural products, such as proteins and bioactive compounds (Cubas *et al.*, 2023). Biotechnological and material science innovations have recently allowed the conversion of residual streams from the food industry into bio-based fibers, biodegradable polymers and textiles, showcasing the value of valorization approaches (Pesante and Frison, 2023; Gong *et al.*, 2023).

But more importantly, the valorization of food waste in a textile production system helps transform the linear and unsustainable "take-make-dispose" economy into a circular and sustainable system (Geissdoerfer *et al.*, 2017). Technologies like nanocellulose extraction, biofermentation and biofabrication are increasingly being used to create sustainable textile products from agro-food byproducts (Joshi *et al.*, 2025). This technology not only eliminates fossil raw material dependency but also helps decrease carbon intensity and foster sustainable industrial practices (Ellen MacArthur Foundation, 2023).

As such, embracing a circular bioeconomy for converting food waste into sustainable textile products offers a way to accelerate the transition towards environmental sustainability and efficiency in resource use. This approach, connecting food waste and textile manufacturing, provides new ways of reducing waste, creating sustainable products, and promoting green economic development (D'Amato *et al.*, 2022; Pesante and Frison, 2023).

2. Circular Bioeconomy for Agro-Textile Systems

This model for food waste conversion into sustainable textiles with a circular bioeconomy is centred on the idea of circular resource management and mostly biological waste to value using sustainable and integrated processes (Tripathi *et al.*, 2024). It begins with the segregation and collection of food waste from home, food processing industry and farms. This is used as a renewable resource, and is a source of polysaccharides (cellulose, starch), proteins and pigments (Cubas *et al.*, 2023; Sagar *et al.*, 2025). (i) Proper separation and pre-treatment including drying, milling, and enzymatic hydrolysis are important in optimising the conversion process (Pesante and Frison, 2023).

The next step is bio-conversion and valorisation technologies where food waste is biologically or chemically converted into valuable products (such as microbial fermentation, chemical extraction and biorefinery). These technologies allow the extraction and valorisation of the valuable ingredients like nanocellulose, biodegradable polymers and natural dyes for textile applications (Joshi *et al.*, 2025). For instance, regenerated cellulose from fruit peels and other agricultural by-products, and fermentation techniques, can be used to create bio-based polymers such as bacterial cellulose and polylactic acid (PLA) that can be applied in textiles (Niinimäki *et al.*, 2020; Sagar *et al.*, 2025).

After extraction, biomaterials are turned into textile fibers and fabrics using spinning, weaving and nonwoven processes. Emerging processes like biofabrication and 3D textile processing are also increasingly being used to produce sustainable and biodegradable textiles using waste-derived materials (Geissdoerfer *et al.*, 2017). These methods ensure that the resulting textile products retain their desirable characteristics (such as strength, flexibility, and appearance) while maximizing sustainability.

The last part of the model highlights the use, recycling, and reintegration into the cycle to complete the circular cycle. Once their life cycle ends, textile products can either be bio-degraded or recycled into the production process, thus avoiding landfill and ensuring sustainability (Ellen MacArthur Foundation, 2023). The circular model eliminates waste and reduces the reliance on new materials, along with the energy, water and pollution needed to make textiles using traditional methods (FAO, 2023).

The circular bioeconomy model embeds waste, material, and production system innovations to promote a regenerative model. The transformation of food waste into textile materials presents an integrated solution to address twin global issues of food waste and textile sustainability while promoting economic development and environmental protection (Pesante and Frison, 2023).

3. Sources of Food Waste for Textile Applications

Food waste streams are a vital part of the circular bioeconomy for the development of textile products, as they convert low-value biomass into high-value textiles, while minimising waste generation. Food waste contains a variety of biopolymers like cellulose, hemicellulose, lignin, starch and protein that are required for fiber and material design (D'Amato *et al.*, 2020; Cubas *et al.*, 2023). Categorization of food waste into crop residues, food processing wastes, and agro-industrial by-products assists in determining best practices for the valorization of food waste for the textile industry (Blumenthal *et al.*, 2026).

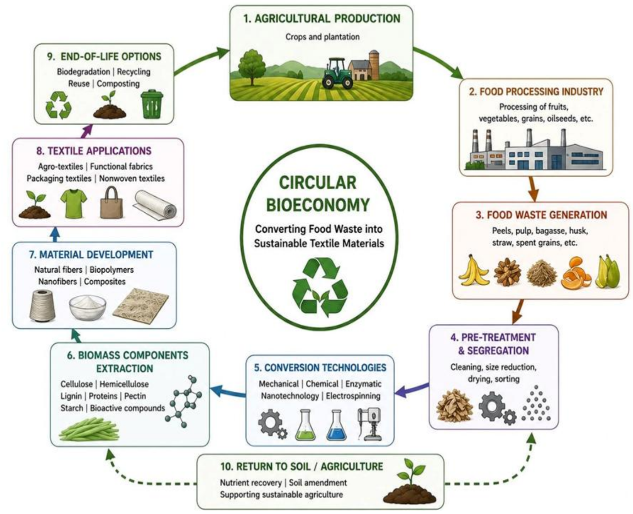

Fig. 1. Circular bioeconomy model for conversion of food waste into sustainable textile materials

3.1 Crop Residues

Crop residues are one of the largest sources of lignocellulosic materials, resulting from crop harvesting and processing. Examples include banana pseudostem, pineapple leaves, rice straw, wheat straw and corn husk (Joshi *et al.*, 2025), which have high cellulose and fiber content (Dantas *et al.*, 2025). These residues are especially valuable because of their renewable, biodegradable and strong nature, and can be used as competitors to traditional textile fibres (Niinimäki *et al.*, 2020).

The banana pseudostem fiber, known for its strength, absorbency and resilience, has been used for blended textiles and nonwoven products (Blumenthal *et al.*, 2026).Pineapple leaf fiber (PALF) is another crop residue that has excellent properties in terms of fineness and strength, and is used in high-end textiles products (Dantas *et al.*, 2025). Likewise, wheat and rice straws can be used for chemical pulping and enzymatic hydrolysis processes to obtain cellulose for regenerated cellulose fibers and composite products (Joshi *et al.*, 2025). The abundance and low value of these residues also make them excellent candidates for sustainable textiles (D'Amato *et al.*, 2020).

3.2 Food Processing Waste

Food processing waste refers to byproducts from industrial treatments of fruit, vegetables, and cereals such as peels, pomace, seeds and pulp. These wastes are a good source for polysaccharides such as cellulose, pectin and starch, which can be used to produce sustainable textile materials and textile additives (Gong *et al.*, 2023; Cubas *et al.*, 2023). Valorisation of such wastes can reduce the environmental footprint and contribute towards the production of bio-textiles (Geissdoerfer *et al.*, 2017).

For instance, orange peel waste is rich in pectin and cellulose, which can be used to produce biofibers or textile finishes with improved functional properties, such as antioxidant and antimicrobial properties (Gong *et al.*, 2023). Mango residues (peels and kernels) contain starch and polyphenols, which can be used as biopolymers or natural textile dyes (Blumenthal *et al.*, 2026; Cubas *et al.*, 2023). Fermentation processes can also be used to turn fruit and vegetable waste into bacterial cellulose, a pure form of cellulose that is used in advanced textiles and biomedical systems. Such approaches showcase the multiple benefits and excellent potential of food processing waste in eco-friendly textiles (Cho *et al.*, 2023).

3.3 Agro-Industrial By-products

Agro-industrial by-products are another important source of food waste that can be used for textiles. Agro-industrial by-products are waste products that are obtained from the processing of large-scale agricultural products. This group of by-products includes sugarcane bagasse, coffee husk, coconut coir and oilseed by-products, which are rich in cellulose and hemicellulose (Baloyi *et al.*, 2023; Kumar *et al.*, 2023). These can be made into fibers, yarns or composites for textile use (Niinimäki *et al.*, 2020).

Bagasse is the waste product of sugarcane processing, has been extensively studied with regard to the extraction of cellulose and the production of regenerated viscose-like fibers (Baloyi *et al.*, 2023). Coffee husk is another type of agricultural waste than can be processed to separate fibrous and active parts that can be used in textiles with improved properties such as odour removal and antioxidant properties (Kumar *et al.*, 2023). Coconut coir is known for its durability, strength and anticorrosiveness, and are used as technical textiles and insulation (Niinimäki *et al.*, 2020).

Additionally, these agro-industrial wastes can be integrated into biorefinery operations where multiple products (such as fibres, biofuels and chemicals) are co-produced, efficiently and cost-effectively (D'Amato *et al.*, 2022; Geissdoerfer *et al.*, 2017). Their valorisation reduces waste in industry, and allows for the circular economy and sustainable innovation of new materials (Cubas *et al.*, 2023).

Table 1. Food Waste Sources and Their Textile Applications

Food Waste Source	Major Component	Extraction Method	Textile Application
Banana pseudostem	Cellulose	Mechanical + chemical retting	Natural fibers, yarn
Pineapple leaves	Cellulose	Mechanical extraction	Fabric, blended textiles
Citrus peels	Pectin, cellulose	Chemical extraction	Biopolymers, coatings
Sugarcane bagasse	Cellulose, lignin	Alkali treatment	Composite textiles
Coffee husk	Lignocellulose	Mechanical processing	Fillers, composites
Soy protein waste	Protein	Wet spinning	Biofibers
Rice straw	Cellulose	Enzymatic treatment	Nonwoven textiles

4. Extraction and Processing Technologies

Converting food wastes into textiles involve the use of mechanical, chemical, biological and modern technologies. Fibre extraction techniques such as decortication and retting, are some of the physiochemical processes used to obtain fibre such as banana pseudostem fiber and pineapple leaves which offer a pockets-friendly and simple process (Nqoro *et al.*, 2023).

Chemical processes such as alkali treatment result in the extraction of lignin and hemicellulose that strengthen and improve the materials. Post-extraction processes such as bleaching and hydrolysis are also used to provide high purity and high yield cellulose and regenerated product, but we need to restrict the use of chemicals for environmental sustainability (Kumar *et al.*, 2023).

Biotechnology techniques such as enzymatic extraction and fermentation are emerging for sustainability. These processes enable removal of non-cellulosic components and production of high purity and high strength materials like bacterial cellulose (Suen *et al.*, 2023).

High technologies also enhance material properties. Nanocellulose derived from food waste has high strength and functionality and electrospinning can be used to produce ultra-fine fibres to create high-performance and functional textiles (Suen *et al.*, 2023).

Table 2. Key Technologies for Food Waste Valorization in Textile Production

Technology	Principle	Advantages	Limitations
Mechanical extraction	Physical separation	Low cost	Lower purity
Chemical treatment	Alkali/acid processing	High efficiency	Environment al concerns
Enzymatic processing	Biological degradation	Eco-friendly	Costly enzymes
Electrospinning	Nano-fiber formation	High performanc e textiles	Expensive setup

5. Development of Sustainable Textile Materials

Food waste-based natural fibers are biodegradable and sustainable alternatives to synthetic fibers (Tang, 2023). Biopolymers like cellulose, starch and proteins are being used to create sustainable textile materials since they are renewable and non-toxic (Gong *et al.*, 2023).

Hybrid materials based on natural fibers and polymers have better mechanical properties and strength, making them fit for purpose in industrial applications (Baloyi *et al.*, 2023).

Table 3. Comparison of Conventional Versus Food Waste-Derived Textile Materials

Parameter	Conventional Textiles	Food Waste-Derived Textiles
Raw material	Synthetic (petroleum-based)	Renewable agro-waste
Biodegradability	Low	High
Environmental impact	High pollution	Eco-friendly
Cost	High (long-term)	Potentially low (waste-based)
Carbon footprint	High	Reduced
Sustainability	Limited	High
Waste generation	Significant	Minimal (circular use)

6. Uses in Agritech and Food

Agritech uses food waste-used textiles for the manufacture of biodegradable mulch mats, crop covers and shade nets. They reduce plastic consumption and enhance soil properties (Nqoro *et al.*, 2023). For foods, textiles in packaging, filtration and storage. Biodegradable textile packaging helps to address plastic waste and increase sustainability (Tang, 2023). Antimicrobial textiles that use natural compounds are also utilised in food processing to enhance hygiene (Pulikkalparambil *et al.*, 2023).

7. Environmental and Economic Implications

Circular bioeconomy strategies are an efficient way of reducing pollution through waste and carbon footprints (Dantas *et al.*, 2025). Use of food waste as a resource helps to decrease reliance on synthetic materials and fossil fuels (Tang, 2023). In economic terms, it provides farmers with extra sources of revenue and facilitates rural industrial development. Decentralised industries associated with agro-waste processing can improve jobs and growth (Baloyi *et al.*, 2023).

8. Challenges and Limitations

While promising, the mass adoption of textiles made from food wastes is limited by several factors, such as variability in waste physical properties, processing cost and lack of standardisation of technologies (Suen *et al.*, 2023). There are also regulatory and market entry barriers (Tang, 2023).

Fig. 1. Challenges and Limitations

9. Future Perspectives

- Creation of new biomaterials from food waste for performance
- Design of smart and functional textiles with additional functionality like antim
- icrobial, and self-cleaning effect
- Use of artificial intelligence for biomass processing and enhanced production
- Development of efficient and affordable technologies for large-scale manufacturing
- Adoption of integrated biorefining processes for efficient resource use
- Introduction of consistent processing techniques and quality standards
- Refining policies and partnerships between industry and academia for commercialization
- Promoting awareness and consumer acceptance for sustainable textiles

- Establishment of effective supply chains for food waste collection and processing Life cycle assessment to assess environmental impact

10. Conclusion

The bio-based circular economy provides sustainable solutions for upgrading of food waste into valuable textiles. Harnessing different types of food waste, and advanced and smart extraction technologies and processing, can result in sustainable, biodegradable and functional textiles. This approach effectively addresses critical global challenges of food and textile waste, and enables the sustainable and efficient use of feedstocks.

Furthermore, embracing textiles from food waste will bring significant economic benefits through new sources of revenue to farmers, growth of agriculture-based industries and enabling rural development. Their applications in the areas of agritech and food systems also highlights the versatility of these textiles. However, variability in feedstock characteristics and manufacturing cost, technology standardisation and regulatory acceptance needs to be addressed for uptake at an industrial scale.

Finally, future research on biomaterials, smart textiles and integrated processing technologies, along with strong policymaking and industry support will advance the new textiles. In conclusion, tapping into food waste valorisation in textile manufacturing in the broader bioeconomy promises to be a sustainable development, sustainable environmental and textile industry innovation opportunity.

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