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Advanced Textiles and Its Application in Food Preservation *

Juan Zhang [a], Yuexi Liang [a], Hai Liu [b], Zhaozhu Zheng [a,*]

[a] *College of Textile and Clothing Engineering, Soochow University, Suzhou 215123, China*

[b] *College of Innovation and Entrepreneurship, Soochow University, Suzhou 215123 China*

Abstract

In today's fast-paced life, ensuring food's freshness, safety, and optimal nutritional and economic value is paramount for both consumers and businesses. Textiles have played a significant role in the food preservation industry throughout history. With the continuous development of the textile and preservation industries, novel methods have been explored to enhance the effectiveness of preservation. This article provides a comprehensive overview of textiles' performance requirements and limitations in the food preservation process. Additionally, it introduces innovative techniques and recent advancements in textile materials designed explicitly for preservation purposes. Furthermore, the paper highlights the key challenges that must be addressed in future research. Consequently, this scientific review serves as a valuable reference for the application and advancement of textiles in the dynamic field of food preservation.

Keywords: Textiles; Food Preservation; Intelligent Textile; Antimicrobial Textile

1 Introduction

In recent years, the issue of food waste has reached critical levels, imposing substantial economic and environmental pressures on numerous countries. Food waste occurs at various stages, including production, harvesting, transportation, distribution, and storage [1]. Mitigating food waste, preventing spoilage, and optimising food utilisation have emerged as imperative challenges that demand utmost attention and diligent efforts. Various techniques have been used to prevent food from being corrupted and causing the loss of nutrients. Food preservation techniques include cool temperature Storage, drying, canning (water bath), canning (pressure canning), freezing, fermentation, preserving in salt and sugar, alcohol, vinegar pickling and Olive Oil Preserving.

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*Corresponding author.
Email address: zzzheng@suda.edu.cn (Zhaozhu Zheng).

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Due to their unique physical and chemical properties, textile materials have long been instrumental in food preservation and storage. With the continuous advancement of science and technology, researchers have persistently sought to refine existing preservation methods and pioneer novel processing techniques and approaches, all aimed at augmenting the efficacy of preservation.

This scientific paper presents a comprehensive overview of textiles' applications and advancements in food preservation. It encompasses exploring preservation principles, delineating various textile types used for preservation, and elucidating innovations in textile treatments. Furthermore, this study offers insights into future trends in preservation textiles. Additionally, a comprehensive analysis of the pros and cons associated with different improvements and innovations is provided, with the ultimate objective of fostering the widespread adoption of textiles in food preservation, thereby curbing food waste and minimising losses.

2 Methods

Search for relevant literature: Relevant literature was retrieved from the China National Knowledge Infrastructure (CNKI) and Web of Science databases using the Chinese search terms "food preservation," "textile," and "textile packaging," as well as the English search terms "food preservation," "textile," "textile packaging," "textile improvement," and "textile modification".

Evaluate sources: 178 articles were analysed based on their abstracts and content. Through inclusion and exclusion criteria, pertinent literature was identified, resulting in a final selection of 27 articles that met the criteria for comprehensive review.

Identify themes and gaps: This work will review advanced food preservation techniques. We emphasize functional textiles in food preservation because they allow both pathogen reduction and improvement of nutritional and physicochemical properties.

Write a review according to this structure: this work will first comprehensively overview the performance of traditional textiles, then introduce innovative techniques and recent advancements in textile materials specifically designed for preservation purposes.

3 Textiles Used for Preservation

Food deterioration and spoilage are attributed to various external physical, chemical, and biological factors encountered during transportation and storage. These factors contribute to moisture loss, microbial corrosion, and self-damage, ultimately leading to a decline in the nutritional and economic value of the food.

Effective food preservation entails addressing several crucial aspects, including reducing moisture loss, mitigating microbial corrosion, preventing mechanical damage, mitigating the adverse effects of temperature fluctuations, and preserving the food's desirable attributes. By diligently addressing these aspects, minimising food waste during storage and transportation becomes possible, ensuring the preservation of the food's optimal economic and nutritional value [2, 3].

Textiles employed for preservation serve as a protective barrier through external packaging, safeguarding the food against external physical, chemical, and biological factors. This barrier

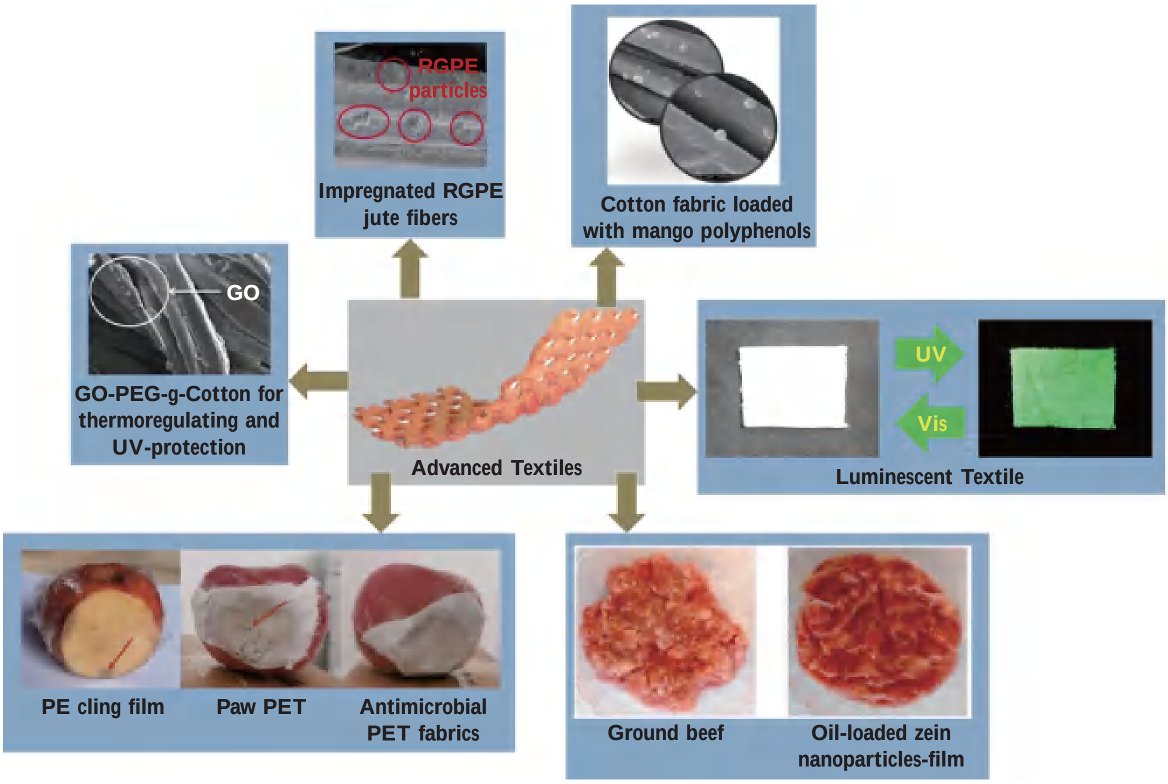

Fig. 1: Textiles used for preservation: jute fibre [5], cotton fibre [6], phase change thermoregulation textile [19], antimicrobial textile [7], surface-modified textile [8], intelligent textile [29]. Reproduced with permission. Copyright, respectively

function effectively reduces the risk of food spoilage and deterioration [4].

3.1 Original Preservation Textiles

The preservation technique of textile bags for food storage has a rich historical background. These preservation bags create a relatively enclosed environment conducive to food storage. By reducing the circulation of gases and water between the interior and exterior of the bag, preservation bags establish a favourable environment for food preservation and transportation, thereby reducing food waste. Moreover, certain textiles possess inherent antimicrobial properties, which effectively mitigate microbial corrosion of food during storage and transportation, thus safeguarding its nutritional and economic value. Examples of textiles employed in food preservation include jute fibre, cotton fibre, and silk fibre, each offering unique advantages.

Jute fibre serves as an illustrative example. It is a widely available and cost-effective natural biodegradable fibre, often called the "golden fibre" [9]. The single-cell diameter of jute fibre is similar to that of cotton fibres, but the cell length is much shorter than that of cotton fibres. It is evident that jute fibres are strong and durable compared to various other fibres. Furthermore, the lumen structure of jute fibres imparts moisture absorption and moisture transmission properties to them, ensuring a dry surrounding environment [10]. Jute fibre exhibits exceptional antimicrobial properties, effectively inhibiting microbial growth and reducing food spoilage from microbial activity. Its remarkable waterproofing ability aids in maintaining a dry environment for food, thereby facilitating favourable preservation conditions while deterring insect survival

[11]. Furthermore, ramie fibres comprise cellulose, hemicellulose, lignin, and other constituents. As a biodegradable fibre, the ultimate degradation products do not pollute the environment, aligning with sustainable development. This offers a partial solution to the global environmental pollution caused by plastic packaging bags. Furthermore, as a biodegradable fibre, jute fibre ultimately decomposes into environmentally friendly byproducts, aligning with the principles of sustainable development and mitigating global environmental pollution associated with plastic packaging bags. Consequently, jute fibre boasts a diverse range of applications in the past and holds promising prospects for future development [12, 13]. However, relying solely on jute fibre for weaving textiles used in food packaging has shown limitations in terms of preservation effectiveness, as it solely depends on the inherent characteristics of the fibre and the weaving methods employed.

Another example is cotton fibres, which are used for weaving cloth bags in food packaging. These cotton fibre-based packaging materials exhibit high breathability due to the larger pores formed during weaving. Additionally, they possess high heat resistance, making them suitable for products that require subsequent heating. Moreover, these bags offer convenience in terms of portability, exhibit low production costs, ensure hygiene and safety, cause no environmental pollution, offer an extended shelf life and are capable of multiple recyclable uses [14]. However, the functional effectiveness of textiles woven solely from cotton fibres is directly influenced by the properties of the fibres and the fabric formation methods employed, leading to limited preservation effectiveness, a common limitation shared by most original textiles.

Table 1: Overview of ramie and cotton textiles for food preservation

	Advantages	Disadvantages	Limitations	Future Research Direction	Ref.
Jute Fibre	Natural and Biodegradable, Breathability, Low Cost, Renewable Resources, Customizability	Moisture Sensitivity, Limited Barrier Properties, Durability	Compatibility with Food Types, Regulatory Compliance	Enhance the barrier properties of jute textiles through coatings, treatments, or laminations; Integration with other materials with superior barrier properties; Appeal to environmentally conscious consumers seeking sustainable packaging options; Contribute to local economic development	[11]
Cotton Fibre	Natural and Biodegradable, Breathability, Absorbency, Softness and Flexibility, Customizability	Moisture Sensitivity, Limited Barrier Properties, Durability	Compatibility with Food Types, Regulatory Compliance	Enhance the barrier properties of cotton textiles through coatings, treatments, or laminations; Integration with other materials with superior barrier properties; Appeal to environmentally conscious consumers seeking sustainable packaging options; Contribute to local economic development in cotton-producing regions	[14]

3.2 Improvement and Treatment of Preservation Textiles

Through research on primitive preservation textiles, it becomes evident that utilising textile bags made from a single material and employing common weaving methods can moderately slow down food spoilage and extend the shelf life to some extent. However, the preservation effect achieved is not significant. Therefore, it is essential to improve the raw materials and optimise the performance of original preservation textiles to enhance their preservation effectiveness, thereby preserving the nutritional value of food and generating greater economic value. The quest for improved textile preservation effectiveness can be traced back to ancient practices incorporating spices into fabrics to enhance preservation [15]. Over time, a diverse range of preservation methods has been discovered. Although these methods are not flawless, they have demonstrated promising results in enhancing the preservation effectiveness of raw materials to a certain extent, thus holding potential for further development.

3.2.1 Filling with Phase Change Materials

By incorporating phase change materials (PCMs) into textiles, the distinct characteristics of PCMs can be leveraged to achieve self-temperature regulation within a specific temperature range. This is accomplished by storing or releasing thermal energy through phase change. Such an effect prevents excessive heat or cold and enhances the temperature adaptability of textiles [16, 17]. This not only extends the service life of the textile itself but also establishes a relatively stable environment for the food within the textile bag, as the textile responds to external temperature changes. Consequently, this approach proves beneficial in prolonging the shelf life of food.

In the work conducted by Abdus Shahid et al., the surface of jute fabric was coated with hydrophobic adhesive microcapsule phase change materials (MPCM), and subsequent tests were performed on the modified jute fabric samples. The findings revealed that the treated jute fabric exhibited commendable thermal stability. As the temperature increased, the jute fibres absorbed heat and underwent a weight reduction. However, the weight change observed in jute fibres treated with CPCM was less pronounced than in untreated fibres. The enhanced thermal stability of the jute fabric extends its service life. It ensures a stable internal environment for food, as it exhibits heat absorption and release in response to temperature changes. Moreover, introducing the additional material reduces the fabric's porosity, minimising gas exchange between the internal and external environments, thereby favouring food preservation [18]. Nevertheless, further advancements are necessary in selecting and exploring phase change materials, aiming to identify more cost-effective and significantly efficient options. Continued optimising jute fabric performance and expanding its application scope will enhance economic benefits.

A notable contribution by A. Kumar et al. involved the development of carboxylic acid-terminated polyethene glycol (PEG) grafted cotton using a chemical grafting method. PEG-grafted cotton enables intelligent temperature control based on phase change materials. This grafting treatment enhances the fabric's thermal stability and augments its thermal conductivity. Additionally, the deposition of graphene oxide on PEG-grafted cotton further improves the fabric's thermal conductivity and effectively blocks harmful ultraviolet radiation. This non-toxic, environmentally friendly, and cost-effective approach effectively enhances the fabric's tensile strength and abrasion resistance, offering exceptional prospects for development and a wide range of applications [19]. The utilisation of PEG-grafted cotton enhances the temperature stability of the internal fabric environment in textile packaging, effectively preventing food from being exposed to harmful ultraviolet radiation, thus significantly extending the shelf life of the food. However, further advancements are still required to address specific preservation requirements.

3.2.2 Antimicrobial Treatment

Antimicrobial textiles have emerged as a valuable solution for inhibiting microbial growth or eliminating microorganisms, thereby extending the service life of textiles. In the context of the food preservation industry, these textiles offer the ability to create an environment that effectively suppresses microbial proliferation, consequently prolonging the shelf life of food and mitigating losses during transportation and storage. Antimicrobial textiles can be categorised into antibacterial, antifungal, and antiviral textiles, targeting specific microorganisms. Mechanistically, antimicrobial textiles can be classified into two primary groups: those employing antimicrobial agents to kill microorganisms and those utilising physical actions, such as electrostatic forces, to impede microbial growth. To achieve optimal preservation effects for different types of food, selecting appropriate antimicrobial textiles becomes crucial [20].

While certain fabrics inherently possess antimicrobial properties, such as natural jute, which features a lumen structure containing a substantial amount of oxygen, effectively impeding the growth of anaerobic bacteria [21], most fabrics exhibit inherent antimicrobial activity limited to specific groups of microorganisms. Therefore, fabric treatments have been explored to broaden the spectrum of antimicrobial activity, enhance effectiveness, and expand application possibilities.

In the case of natural fibres, enhancing the antimicrobial properties of fabrics can be achieved by incorporating natural substances with inherent antimicrobial effects or synthesised antimicrobial substances, employing methods such as impregnation or coating. This approach proves to be straightforward, cost-effective and holds significant potential for development [22]. However, it is important to note that this method exhibits certain limitations and is typically more suitable for porous fibre materials or those possessing abundant side-chain groups [23]. An example of this approach is demonstrated by Y. Berkli et al., who introduced a method of dyeing wool fabric using hibiscus extract as an assistant dye. Remarkably, the hibiscus extract adhered to the wool fabric without additional chemicals. Using a natural material ensures fabric safety and aligns with the current concept of environmental friendliness. The dyed wool fabric exhibited enhanced antimicrobial effects [24]. Beyond the functional benefits, fabric dyeing contributes to improved aesthetics and increased value. Nevertheless, further advancements are required to enhance the dyeing rate and extent of antimicrobial enhancement. Nonetheless, this method holds significant importance in fabric antimicrobial properties.

3.2.3 Absorption of Plant Hormones

Fruits and vegetables play a vital role in our food system. Plant hormones regulate and control many physiological processes during their growth and ripening stages. Even after harvesting, the influence of plant hormones persists, impacting the ripening process and subsequent spoilage and decay of fruits and vegetables. Manipulating the levels of plant hormones in the storage and transportation environment can effectively slow down the decay rate, extend the shelf life, and reduce food waste. Notably, climacteric fruits and vegetables, such as apples, bananas, and mangoes, are highly susceptible to ethylene. This plant hormone accelerates their ageing and decay after harvest, challenging their storage and transportation and contributing significantly to food waste [25, 26]. Textile surface modification can be achieved through methods such as coating or chemical grafting. The introduced chemical substances can form chemical bonds with plant hormone molecules or encapsulate them with their unique molecular structure. This enables the regulation of plant hormones, thereby influencing the decay rate of fruits and vegetables.

In their research, Fan Xin et al. focused on applying ultrasound-treated corn zein protein solution to create a membrane with improved ethylene adsorption capacity and desirable mechanical and oxygen barrier properties. This packaging material's enhanced ethylene adsorption capability demonstrated its potential to extend the shelf life of climacteric fruits and vegetables, consequently reducing food waste [27]. Meanwhile, Y. K. Yuan et al. conducted a comprehensive review on corn zein protein nanoparticle coatings, emphasising their superiority over corn zein protein nanoparticle colloids in terms of performance and stability, making them highly suitable for various applications in the food industry. The review summarised different coating methods, including solvent precipitation, co-precipitation, layer-by-layer, solvent evaporation, and pH-driven methods, each with advantages and limitations. These coating methods hold significant promise for imparting ethylene adsorption properties to textiles, facilitating food preservation [28]. However, it should be noted that the surface coating method utilising corn zein protein nanoparticles is still at an early stage of development, with limited application on textiles. Further research is needed to enhance the stability of corn zein protein nanoparticles and optimise their effectiveness on textiles.

3.2.4 Intelligent Textile Packaging Materials

With the increasing prominence of smart textiles in recent years, their exceptional performance and unique advantages have garnered widespread recognition, leading to their extensive application across various industries and the exploration of new application scenarios. Industries such as transportation, agriculture, medicine, and firefighting have embraced smart textiles, and they also hold promising potential in food preservation packaging. These textiles not only enhance the aesthetics and economic value of food packaging but also address concerns related to gas exchange control, temperature regulation, and microbial corrosion, thereby reducing food spoilage and extending the shelf life of food. Consequently, they bring about greater economic benefits while mitigating environmental pollution caused by food waste.

In textile packaging, flax has always been a significant material. In their research, Salhah D. Al-Qahtani et al. employed a simple spray coating method to apply a nano-composite material layer onto the flax fibres' surface. This coating combined various desirable properties, including flame retardancy, antimicrobial activity, hydrophobicity, pollution resistance, and luminescent performance. Through a series of instrument tests and a comparison of data obtained before and after the spray coating, the researchers observed the development of a carbon layer on the treated flax surface, resulting in excellent flame retardancy. Moreover, the treated flax exhibited remarkable antimicrobial properties and emitted green light under ultraviolet irradiation. The coating treatment effectively enhanced the inherent properties of flax, such as flammability, moisture absorption, and microbial susceptibility, which typically hinder practical applications while preserving the inherent elasticity and breathability of flax. The simplicity and cost-effectiveness of this process enable mass production and its application in large-scale processing of flax textiles without the need for complex procedures, thus presenting promising prospects for implementation [29]. However, further investigation is warranted to ascertain the impact of the coating on the flax surface on food safety and potential substance migration.

Cotton, renowned for its softness and excellent moisture absorption, has also found utility in food preservation. However, its high flammability limits its extensive use. To address this constraint, Nisha Lama et al. developed an economical and safe method to significantly enhance cotton fibres' flame retardancy and antimicrobial properties. This method fulfils consumer demands and solves the flammability issue associated with cotton fibres [30]. Nevertheless, further developments are necessary to optimise materials and process requirements.

Table 2: Summary of functionalized antimicrobial textiles textiles for food preservation

	Advantages	Disadvantages	Limitations	Future Research Direction	Ref
Phase Change Thermoregulation Textile	Temperature Regulation, Extended Shelf Life, Customizability, Reusable and Durable, Flexibility	Limited Heat Storage Capacity, Cost, and Integration Challenges	Limited Temperature Range, Insulation Properties	Integration with smart packaging; Innovation in material development; Phase change materials derived from renewable sources or with recyclable properties	[16-19]
Antimicrobial Textile	Microbial Control, Extended Shelf Life, Enhanced Food Safety, Reduced Dependency on Chemical Preservatives, Flexibility	Resistance Development, Safety Concerns, Limited Spectrum of Activity	Durability, Integration Challenges	Innovation in treatment technologies, Smart packaging integration, Antimicrobial treatments derived from natural sources or with biodegradable properties	[24]
Surface-Modified Textile	Customizability, Enhanced Food Safety, Improved Shelf Life, Reduced Food Waste, Sustainability	Cost, Complexity, Durability	Compatibility with Food Types, Regulatory Compliance	Innovation in surface modification techniques; Integration with smart packaging technologies; Appeal to consumers seeking enhanced safety, freshness, and sustainability in packaged foods	[27, 28]
Intelligent Textile	Real-time Monitoring, Data-driven Decision Making, Quality Assurance, Traceability and Transparency, Adaptive Packaging	Cost, Complexity, Reliability and Maintenance	Compatibility with Food Types, Regulatory Compliance	Innovation in sensor technology; Integration with blockchain technology; Enable consumer engagement and education	[29, 30]

4 Summary

The application of textiles in food preservation and storage boasts a rich historical background and is currently gaining renewed momentum, particularly in environmental protection. It holds immense potential for diverse applications. To achieve enhanced preservation outcomes, researchers continually strive to improve the effectiveness of existing preservation textiles based on fundamental preservation principles. The primary goals encompass maximising the preservation of food's nutritional value, enhancing its economic value, reducing food waste and economic losses, and selecting specific preservation textiles tailored to the unique characteristics of various food items. Numerous researchers are currently exploring avenues for improving textile preservation through surface modification or incorporating substances with special properties (e.g., antimicrobial agents, phase change materials) to augment preservation effectiveness. However, certain limitations persist within the field of textile improvement. For instance, the significance of preservation effectiveness after fibre modification and its potential impact on other relevant preservation-related properties remain uncertain. Most preservation textiles excel in specific aspects, and developing textiles that combine multiple preservation advantages into a single entity remains an ongoing pursuit. The prevalent methods for textile improvement predominantly involve coating, necessitating considerations regarding the durability of modified effects after multiple washing cycles. Cost-effectiveness and the duration of the improvement process also warrant critical evaluation. Moreover, implementing nanomaterials and edible silk protein coatings as novel solutions for food preservation packaging has demonstrated remarkable potential in addressing the challenges of food spoilage and waste [31]. Future researchers in this field could explore simpler operational methods that still yield effective results. Alternatively, significant advancements could be achieved by delving into the research of enhanced textile materials, building upon a comprehensive understanding of food spoilage and deterioration processes. Additionally, the research outcomes related to nanomaterials and various substances possessing unique functionalities are expected to significantly contribute to the progress of preservation textiles. Collaborative efforts from professionals across diverse fields are imperative to drive the research and development of preservation textiles. Such concerted endeavours are necessary to formulate exceptional preservation textiles that integrate desirable features, such as swift processing, low cost, minimal environmental impact, antimicrobial properties, reduced moisture loss, and limited food self-consumption. This collective commitment will effectively reduce losses during food preservation and transportation processes, tackling the pervasive issue of food waste.

5 Conclusions

Food-packaging textile is an old but new material; it has direct or indirect effects on the food. Proper food preservation should balance freshness and food security. Nanotechnology, especially nanoparticles, plays a crucial role in food preservation and anti-bacteria. However, its toxicity, safety to consumers and genetic factors is still under debate and discussion. Eating materials have attracted widespread attention in food preservation. They can not only effectively extend the shelf life of food but also relieve the environmental impact of human activity. Further work needs to be done on visual sensors and artificial intelligence, the internet of food and people's habits. This would help change the sustainable food industry through digitalisation.

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