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A Review of Textile Fabrication Using Bioactive Compounds Derived from Natural Products

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Abstract: Antimicrobial-treated textiles should exhibit efficacy against a broad spectrum of bacterial and fungal species, all while maintaining user safety with a non-toxic profile. Natural antimicrobial compounds play a vital role in textile finishing processes. The proliferation of synthetic antimicrobial agents introduces environmental and consumer safety concerns. Given these potential hazards associated with synthetic agents, the utilization of natural antimicrobial agents is gaining traction, as they tend to have fewer adverse effects on users and are more environmentally sustainable. Numerous natural antimicrobial compounds, sourced from plants such as neem, basil, turmeric, aloe vera, and clove oil, have been developed, showcasing inherent antimicrobial properties. This review article highlights the importance of incorporating bioactive components in the creation of antibacterial textile fabrics.

Keywords: Antimicrobial-treated textile; Bioactive compounds; Natural products

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1. Introduction

Recent studies investigating antimicrobial compounds for textiles have been primarily driven by an increasing public concern regarding hygiene [1,2]. The growth of microorganisms on textile materials can have various adverse consequences for both the textiles themselves and the individuals using them [3]. Textiles not only serve as a platform for the proliferation of microbes but also actively facilitate their growth [4]. With a growing awareness among the general public about the risks associated with microbial infections, there is a rising demand for products equipped with antimicrobial properties to combat germ contamination [5]. The pursuit of a healthier lifestyle has led to a surge in scientific interest in antimicrobial finishing for textiles. As a result, numerous synthetic and natural antimicrobial treatments for textiles have emerged over time [6] malodors and stain formations caused by microorganisms, there is an increasing need for antibacterial materials in many application areas like medical devices, health care, hygienic application, water purification systems, hospital, dental surgery equipment, textiles, food packaging, and storage.(Shahidi et al, 2007. The global output of antimicrobial fabrics surpassed 100,000 tons in 2000 [7]. The production of antimicrobial textiles has experienced a remarkable surge in recent years, establishing itself as one of the fastest-growing segments within the textile industry [8]. According to recent industry research conducted by textile experts, the global market for antimicrobial agents, encompassing various consumer applications including textiles, is projected to witness an annual growth rate exceeding 12% [9]. Over the past two decades, antimicrobial fabrics have garnered considerable attention and widespread acceptance in both markets and everyday life. Textile manufacturers are continually exploring innovative production methods to enhance product quality and satisfy customer demands. The heightened competition in the industry has spurred the development of numerous synthetic antibacterial agents. However, despite their widespread adoption, these synthetic compounds pose potential risks to both human health and the environment. In response to these substantial concerns, several environmental organizations have implemented regulations restricting the use of synthetic chemicals. In contrast, natural antimicrobial compounds pose fewer risks to human health and exhibit greater environmental friendliness. Various natural substances, including turmeric (containing curcumin), neem (with active limonoids such as nimbinin and azadirachtin), basil (featuring eugenol as one of its active agents), pomegranate, onion, chitosan, aloe vera, sericin, and clove oil, are known for their antimicrobial properties [10].

2. The effect of microbes on textiles

The term "biodegradation" refers to "any undesirable alteration in the properties of a material resulting from the life processes of organisms." Microbes encompass a range of microorganisms, including algae, fungi, bacteria, and viruses. Ramachandran *et al.* characterized bacteria as unicellular organisms that thrive in warm, moist environments [11]. Textile fibers possess inherent features that create an environment conducive to the growth of microorganisms. Microbes can flourish due to factors such as substrate structure and chemical processes, with humidity and warmth further exacerbating this condition.

Microbial infestation can lead to both pathogen transmission and the generation of unpleasant odors when textiles are worn close to the skin [11]. Furthermore, microbial attack can result in discoloration and a deterioration of performance attributes of textile materials. Natural fiber textiles are often more susceptible to biodegradation compared to synthetic (man-made) fibers. This susceptibility arises from the porous and hydrophilic nature of textile structures, which readily absorb water, oxygen, and nutrients, providing an ideal environment for bacterial growth [12]. According to a survey, 61% of women reported taking extra measures to purchase antibacterial or antimicrobial products [13]. People have significant concerns regarding issues such as stains, odors, degradation, and human health, including the risk of infectious diseases and allergies (**Table 1**).

3. Antimicrobial agents for textiles

Antimicrobial technology encompasses a wide range of approaches that offer varying levels of protection against microbes for various products. Antimicrobials exhibit significant diversity in terms of their chemical origins, mechanisms of action, impact on human health and the environment, handling characteristics during manufacturing, stability on different surfaces, cost considerations, and interactions with both beneficial and harmful microorganisms. These antimicrobial agents find applications in the management of microbial issues in textiles [14]. They serve to bolster resistance against microorganisms, enhance textile durability, and safeguard fabrics from colonization by odor-causing bacteria [15,16]. Additionally, antimicrobial treatments can reduce the frequency of laundering, resulting in substantial reductions in energy and water consumption, as well as a decreased demand for chemical additives in textile care [17]. An effective antimicrobial agent should possess

Table 1. Microorganisms and the disease caused by microorganisms

Microorganism	Diseases or conditions
Gram-positive bacteria	
Staphylococcus aureus	Pyrogenic infections
Staphylococcus epidermis	Body odor
Corynebacterium diphtheriae	Body odor
Brevibacterium ammoniagenes	Diaper rash
Streptococcus pneomoniae	Bacterial pneumonia
Mycobacterium tuberculosis	Tuberculosis
Gram-negative bacteria	
Escherichia coli	Infections of the urinogenital tract
Pseudomonas aeruginosa	Infections of wounds and burns
Proteus mirabilis	Urinary infections
Fungi	
Candida albicans	Diaper rash
Epidermophyton floccosum	Infections of skin and nails
Trichophyton interdigitale	Athletes foot
Trichophyton rubrum	Chronic infection of skin and nails
Aspergillus niger	Damage cotton
Viruses	
Poliomyelitis virus	Poliomyelitis
Vaccinia virus	Local disease induced by vaccination against smallpox
Protozoa	
Trichomonas vaginalis	Vaginal infections

broad-spectrum activity against a variety of bacterial and fungal species while posing minimal risks to humans and the environment, and being free from allergens and irritants.

The cytotoxicity, irritation, and sensitization test levels would be lowered for textiles treated with an antimicrobial agent, and they would also meet the following criteria, as outlined by [18]:

(1) Adherence to the regulatory standards established by governing bodies
(2) Resilience to repeated washing throughout the textile's lifespan
(3) Compatibility with chemical substances employed in textile finishing processes
(4) No requirement to eliminate non-pathogenic bacterial flora naturally occurring on the wearer's skin
(5) No adverse impact on the textile's appearance or properties, including its physical durability and handling
(6) Versatility and resistance to sterilization/disinfection processes
(7) Absence of negative consequences for the user, manufacturer, or environment [9]

There exist several methods for imparting antibacterial characteristics to fabrics [14]:

(1) Coagulants such as halogens and primary alcohols
(2) Oxidizing agents like aldehydes
(3) Compounds featuring quarternary ammonium
(4) Triclosan-based products (derivatives of bis-phenyl)
(5) Chitosan, derived from chitin, as well as natural alternatives from, herbs, shrubs, and plants
(6) Complex metallic compounds based on mercury, silver, and cadmium

4. Natural antimicrobial agents

The majority of diverse natural antibacterial substances are derived from plants. Globally, there are an estimated 5,000,000 different plant species, with less than 1% of these possessing any therapeutic properties [5,19]. Natural alternatives hold greater promise for research due to their eco-friendliness, low toxicity, suitability for use in next-to-skin innerwear, the extensive study aimed at combating antimicrobial-resistant bacteria, and safe handling [14]. In contrast, synthetic substances like quaternary ammonium compounds, triclosan, and nanosilver materials are available for the antimicrobial finishing of textiles. Notably, the production of nanoparticles is more cost-intensive compared to other synthetic options (**Table 2**) [10].

Table 2. Active phytochemical agents from plants [10]

Class	Subclass	Example	Mechanism
Alkaloids		Berberine Piperine	Interactive into the cell wall and/or DNA
Terpenoids		Capsaicin	Membrance disruption
Phenolic	Simple phenols	Catechol	Substrate deprivation
	Flavonoids	Chrysin	Bind to adhesins complex with cell wall
	Flavones	Abyssinone	Interact with enzymes
	Flavonols tannins	Ellagitannin	Bind to proteins Bind to adhesion Substrate deprivation Membrane disruption
	Coumarins	Warfarin	Interaction with eukaryotic DNA
Lectins and polypeptides		Mannose	Block viral fusion or adsorption

5. Natural versus synthetic materials

The oil industry stands as the largest contributor to environmental pollution, closely followed by the textile sector. As the world increasingly emphasizes sustainability, it has become imperative for the textile industry to cease the use of hazardous materials and transition towards natural alternatives. Stringent regulations governing textile production have been enacted by numerous countries, compelling manufacturers to explore safer substitutes. Natural materials are consistently favored over synthetic ones due to their benevolence toward the users and the environment. Synthetic antimicrobial agents pose significant challenges owing to their harmful nature, which can result in adverse effects on human health and environmental contamination. While synthetic antimicrobial agents exhibit exceptional effectiveness, durability, and a broad spectrum of activity, their natural counterparts may not match this efficacy but are considered safe for both humans and the environment. To achieve a level of effectiveness similar to synthetic agents, there is a need to further field research on combinations of these natural antibacterial agents. Consequently, the future significance of natural antibacterial compounds derived from plant sources cannot be overstated. The preservation and protection of the natural ecosystem are essential steps towards restoring global sustainability [10].

6. The impact on normal microflora

The regular use of topical antimicrobial drugs on the skin poses primary concerns related to the development of allergies, irritating dermatitis, and alterations in the environmental stability of both the natural (resident) and host (transient) microflora. It is worth noting that there has been relatively less research dedicated to understanding the impact of antimicrobial agents on the microflora residing on human skin [21], despite the pivotal role of the skin microbiota in acting as a crucial barrier against potential pathogenic microorganisms and the proliferation of existing opportunistic microorganisms [20]. The majority of studies investigating the effects of antimicrobial agents on normal microflora have predominantly focused on the intestinal flora [20]. Further processing of free fatty acids, skin proteins, and sebum has also been proposed as beneficial roles [22]. Additionally, there has been limited exploration into the adverse effects of antimicrobial clothing, particularly form-fitting athletic and leisure lingerie, on the ecological balance of bacteria present on human skin.

To assess the potential negative impacts on the healthy skin microbiota, a placebo-controlled trial was conducted, comparing antimicrobial clothing with textiles having a similar structure but with lower antimicrobial properties. This study involved sixty participants, each provided with form-fitting T-shirts featuring two sides: a non-antibacterial control side and an antibacterial half exhibiting a 3–5 log-step reduction in bacterial activity due to the inclusion of silver-loaded or silver-finished fibers. Over the course of six weeks, the microflora on the scapular skin was assessed weekly for the presence of aggressive and pathogenic bacteria. The results indicated that the antibacterial halves did not disturb the quantity or composition of the microflora. However, a deodorant-containing silver did lead to a temporary disruption. Additionally, measurements of skin morphology and function (such as moisture, pH, and transepidermal water loss) did not reveal any significant changes. In summary, wearing antimicrobial clothing did not adversely affect the ecological balance of healthy skin microflora [23].

Disclosure statement

The authors declare no conflict of interest.

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