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Fibers Derived from Plants with Antibacterial Properties

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Abstract

In recent years, there has been increasing focus on antibacterial substances due to the rising occurrence of bacterial infections. The emergence of bacteria resistant to antibiotics, caused by their misuse and overuse, highlights the need to explore alternative strategies in fighting bacterial infections. The use of plant-based antibacterial fibers has become popular because of their biodegradable nature, renewability, and environmental friendliness. Scientists have effectively harnessed the inherent qualities of plants to produce fibers capable of inhibiting microbial growth. This breakthrough offers promising prospects for healthcare and textile industries. This review provides a brief overview of plant fibers with antibacterial properties, explaining their mechanisms of action and potential applications in textiles. As a result, integrating plant fibers and leveraging their features in nanofibers has introduced a new dimension in antibacterial fabric technology. These fibers have significant potential in combating microbial growth and provide a sustainable, organic alternative to synthetic antimicrobial agents.

Keywords: Plant fibers, antibacterial, bacterial infection, antibiotic

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1. Introduction

Bacterial infections cause persistent illness and death, making them the main cause. Antibiotics have been the preferred treatment for bacterial infections because they are cost-effective and effective. However, research has shown that the widespread use of antibiotics has led to the development of bacterial strains resistant to multiple drugs [1].

Although some bacterial infections can be partially treated with antibiotics like penicillin and colistin, overusing these drugs can lead to antibiotic resistance. This creates a serious risk to human health [2].

Furthermore, the overuse and misuse of antibiotics cause widespread harm and promote the rise of antibiotic-resistant microorganisms. Due to these concerns, scientists and companies are increasingly exploring alternative, non-traditional, and non-antibiotic treatments derived from natural sources, such as plant extracts and essential oils [3].

The attachment and proliferation of bacteria on surfaces is a significant issue that poses risks to public health and safety in numerous scenarios. The presence of different bacteria on textiles, in particular, which we frequently come into contact with, can serve as a potential pathway for bacterial transmission and the dissemination of contagious illnesses. Due to the presence of uneven surfaces and pores within their structure, textiles offer a constantly changing setting for bacteria to attach, proliferate, and create biofilms. The researchers made antibacterial textiles with the ability to regulate the attachment and growth of bacteria [4]. Microbes tend to adhere well to natural fabrics due to the presence of organic compounds, which offer a solid foundation for bacterial attachment and the growth of biofilms. Furthermore, bodily fluids such as sweat, blood, sebum, and wound exudates are absorbed and preserved by textiles, serving as vital nourishment for the growth of microorganisms. As a result, fabric surfaces like clothing can function as fomites, aiding in the transmission of infections [5]. Biofilms refer to a group of bacterial cells that attach to a surface, with the cells being surrounded by EPS [6].

Textiles are recognized as a favorable environment for bacterial growth. Due to their natural hydrophilic and nutritious properties, cellulose fibers serve as an appropriate medium for bacteria to thrive. Generally, the bacteria's life cycle on fibers can be categorized into four phases: attachment, growth, dehydration, and cleansing. Initially, bacteria from perspiration are attracted to the fibers that tend to absorb water. Shortly after, bacteria firmly stick to the surface of the fiber and create a thin layer known as a biofilm. When the fibers become dry, surface bacteria permanently attach to the surface of the fibers due to capillary action, making it challenging to eliminate them through washing [7]. The rising need for textile products that offer a safeguard against infection caused by pathogenic microorganisms has gained significant importance and captured the interest of research and development institutions. There is a growing inclination to explore and develop new natural-based agents that are non-toxic and environmentally friendly for creating antimicrobial effects on textiles, considering the potential harmful impacts associated with various synthetic agents. Textiles are a breeding ground for microorganisms like fungi and bacteria, which can have adverse effects not only on the textiles themselves but also on the individuals who use them [8]. Consequently, the use of antibacterial substances is crucial in protecting human life against bacterial infections [9].

2. Advantages of natural fibers

Renewable resources like natural fibers present an advantageous option for sustainable supply due to their affordability, lightweight characteristics, minimal processing expenses, absence of health risks, and superior mechanical and physical properties [10]. At least, researchers attempt to maximize the utilization of synthetic fibers and natural fibers in the creation of sustainable products, to develop economically and environmentally friendly materials. This is due to the numerous benefits offered by natural fibers, including their low density, environmental compatibility, and biodegradability. They possess high specific strength and modulus, along with various other benefits such as being readily available at a low price, non-toxic, non-carcinogenic, and recyclable [11].

3. Antibacterial agents in natural plant fibers

Using plant components as a basis for creating new antimicrobial substances shows great potential. These natural compounds offer numerous advantages over synthetic alternatives, including their availability in local communities, affordability, and ease of use. The scientific community has taken note of the interest in antimicrobial compounds derived from plants among researchers [12].

3.1. Bacteriostatic properties inherent in fibers

The natural antibacterial properties of plant fibers, such as brown cotton fibers rich in tannin pigments, can be observed without any alteration [13]. Rami fibers possess an exclusive intrinsic quality that exhibits a notable effectiveness in inhibiting bacterial growth [14]. Both flax and hemp possess natural antibacterial and antioxidant properties [15]. In contrast, when compared, ramie exhibited a bacteriostatic rate of over 90% against Staphylococcus aureus, while regenerated bamboo fiber had a rate of 75.8%. Jute and linen displayed rates of 48% and 8.7% respectively, in terms of bacteriostatic activity against Candida albicans [16].

The ramie yarn that was created demonstrated notable antibacterial effectiveness in terms of the zone of inhibition against Bacillus subtilis, Escherichia coli, and Staphylococcus aureus. Rami suture possesses natural antibacterial properties, setting it apart from other sutures made from natural fibers. These inherent properties make Rami suture effective in preventing difficult surgical site infections resulting from the use of suture materials. Additionally, Rami suture can inhibit the formation of biofilm on its surface and accelerate wound healing [17]. Ramie possesses excellent physical and mechanical qualities, making it one of the most robust natural cellulose fibers available [18]. Ramie fibers offer several environmental advantages in contrast to synthetic fibers as they possess biodegradability, renewability, and sustainability. By incorporating eco-friendly ramie fiber-based materials into practical applications, there is potential for mitigating the planet's escalating environmental challenges [19].

3.2. Extraction process

The antibacterial properties of plant fibers can be altered during the fiber extraction process, as it involves eliminating carbohydrates and inorganic salts, which facilitate bacterial growth, causing pH variations, and introducing secondary metabolites that boost antibacterial effectiveness [10].

The most frequently employed technique for assessing the antibacterial properties of plant materials is hemp extraction. This method involves separating the bioactive compounds from the inactive or inert components of the plant tissues. To extract the active ingredients, various solvents such as water, ethanol, methanol, chloroform, dichloromethane, ether, and acetone are commonly utilized. The choice of solvents employed in extraction techniques significantly impacts both the quantity of extractable active compounds and, consequently, the plant's antibacterial efficacy [20].

3.3. Antibacterial biological compounds

Plants encompass numerous biologically potent substances, many of which possess antibacterial characteristics. Scientists from various disciplines worldwide have examined the antibacterial benefits of plants. Antibacterial properties found within plants can be categorized into several groups, including phenols and polyphenols, terpenoids and essential oils, cannabinoids, alkaloids, lectins and polypeptides, and polyethylenes. Simple phenols and phenolic acids, quinones, flavones, flavonoids, flavonols, tannins, and coumarins are all examples of phenols and polyphenols [21]. At their site of action, these biomolecules can display potent antioxidant, anticancer, anti-inflammatory, and antimicrobial characteristics [22]. Plants possess numerous chemical compounds with antimicrobial properties, which can be utilized in the treatment of antimicrobial-resistant infections [23].

3.3.1. Phytochemicals

Phytochemicals are a diverse range of naturally occurring chemical compounds in plants that provide color, taste, smell, and texture. These compounds have evolved over numerous years to protect organisms from the harmful impacts of free radicals, viruses, bacteria, and fungi. Phytochemicals can be categorized into various primary groups according to their chemical composition, which include alkaloids, sulfur-containing compounds, terpenoids, and polyphenols [24].

3.3.2. Phenolic substances

Various phenolic compounds, including eugenol, tea polyphenols, chlorogenic acid, and thymol, exhibit potent antibacterial properties that effectively combat both gram-positive and gram-negative bacteria. Numerous research studies have substantiated the fact that these phenolic substances engage with the bacterial cell walls, leading to their eventual deterioration and inhibiting bacterial growth [25]. There have been reports of plant extracts containing hemp polyphenols inhibiting the formation of biofilms caused by Staphylococcus aureus, including Escherichia coli, methicillin-resistant Staphylococcus aureus, and Pseudomonas aeruginosa. Biofilm formation has been observed in Candida albicans, Staphylococcus aureus, and Pseudomonas aeruginosa [26].

4. Organic and mineral factors

There are two main categories of antimicrobial agents commonly applied to plant fibers: organic and inorganic. Organic agents include biopolymers and naturally occurring biomolecules like chitosan, phenols, alginate, and bio-inspired formulations such as antimicrobial peptides, quorum sensing molecules, and bacteriolytic enzymes. On the other hand, inorganic agents consist of metal nanoparticles such as silver and copper nanoparticles, hydroxyapatite, polyammonium compounds, antibiotics, and synthetic polymers, which are widely used [27]. Organic nanoparticles obtained from plant and animal sources possess biocompatibility, exhibit non-toxicity at different levels of concentrations, and are frequently cost-effective. The majority of organic nanoparticles are manufactured utilizing natural polymers, including polysaccharides (e.g., chitosan, hyaluronic acid, and cellulose) and proteins (e.g., albumin, elastin, collagen, and silk) [28]. Alginate has gained significant interest in the field of tissue regeneration because of its lack of toxicity, compatibility with biological systems, ability to degrade naturally, and convenient formation of gel. Alginate nanofibers find applications in the regeneration of various tissues, including skin, tendons, heart, bones, and nerves. Sodium alginate (SA) is a naturally derived anionic polysaccharide from algae, possessing remarkable biocompatibility, minimal toxicity, absence of immune response, and affordability [29].

Alginate is derived from the cell wall of different brown alga species like Macrocystis pyrifera and Laminaria hyperborea. Isolation of Ascophyllum nodosum has been achieved [30].

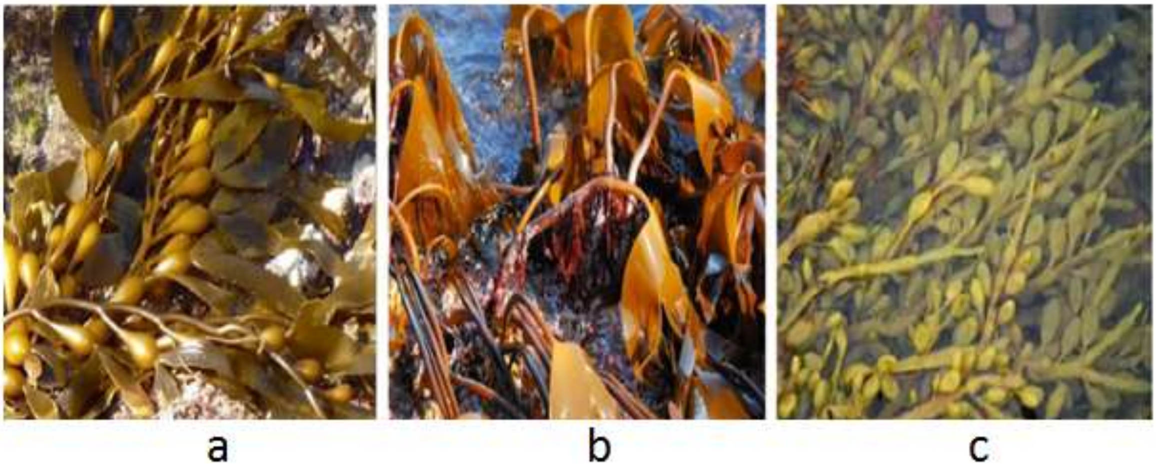

Figure 1. Origin of alginate: (a) Ascophyllum nodosum, (b) Laminaria hyperborea, (c) Macrocytisperifra

Alginate, a key constituent of the cellular wall in brown algae, is an essential element. This anionic polymer consists of β-d-mannuronate (M) and α-l-guluronate (G). Oligosaccharides can be derived from the breakdown of alginate. The polymer itself, as well as its byproducts, exhibit antioxidant, antimicrobial, and immunomodulatory properties [31].

5. Electrospun nanofibers containing plant extracts

Nanofibers could be derived from collagen, cellulose, silk fibroin, gelatin, keratin, chitosan, and other natural polymers [32]. Due to their inadequate mechanical properties, natural biomaterials possess certain limitations. Hence, it is necessary to enhance the properties of natural biomaterials by incorporating them with other materials or polymers [33]. Electrospinning is an uncomplicated technique that utilizes electrical forces for the production of polymer fibers with diameters in the nanometer range. This process leads to the formation of structures characterized by a high specific surface area and significant porosity, rendering them suitable for numerous applications [34].

Figure 2. Atropa belladonna plant

Atropa belladonna, a member of the Solanaceae family, is native to Europe, North Africa, and West Asia. It primarily grows in the northern regions of Iran, specifically in Shahbizak. The fruits, leaves, and roots of Atropa belladonna contain approximately 20 different alkaloids. The antimicrobial properties of this plant are attributed to these bioactive alkaloids. Various antibacterial experiments have shown that the complete extract from both the fruit and leaves possesses highly effective antibacterial properties against Pseudomonas aeruginosa. It is recommended to use the extract from the Atropa belladonna plant, especially in the form of nanofibers, for treating infections. Additionally, it is suggested that this extract be incorporated into wound dressings used in hospitals.

Biologically active green tea extract was incorporated into chitosan/PEO nanofibers through electrospinning. The resulting nanofibers display antibacterial properties against

Gram-positive and Gram-negative bacteria, specifically Staphylococcus aureus and Escherichia coli.[36].

Figure 3. Green tea plant

The antibacterial and antioxidant properties of Artemisia essential oil were examined. The essential oil derived from this medicinal plant demonstrated antibacterial activity against various bacteria, such as Staphylococcus aureus, Escherichia coli, Bacillus cereus, and Listeria monocytogenes. The lowest concentration required to inhibit the growth of Bacillus cereus and Listeria monocytogenes was 4.2 mg/ml. However, the essential oil did not show any effectiveness against Pertheus mirabilis. [37].

Figure 4. Medicinal plant

6. Natural fabrics, antimicrobial dyes and pigments

The worldwide usage of textiles is approximately 30 million tons and will increase by 3% each year. Consequently, a significant quantity of paint, around 700,000 tons, is needed to dye these textiles, resulting in the escalating discharge of hazardous chemicals into the environment as a consequence of artificial coloring [38]. Because of their non-toxic, non-allergenic, and biodegradable characteristics, natural dyes are considered to be safe [39]. Different locations may have a coating of biocolors, such as the roots of plants like rhizomes (such as Rhubarb and Turmeric), insects like Laciferlacca and Kermes, as well as the secretions of sea snails [40]. In the past, fabric was dyed using natural dyes and pigments, which served two purposes: providing color and serving as an antimicrobial agent [41]. When natural dyes are used on textiles, they can exhibit antibacterial properties, making them suitable for this application. Research in the field indicates that a wide range of natural sources have been utilized as eco-friendly antibacterial agents in the process of dyeing textiles [42]. Over the past few decades, the increasing worldwide response has led consumers to display greater curiosity in natural green dyes, primarily due to their benefits over hazardous artificial pigments. Furthermore, they exhibit enhanced biodegradability and environmental friendliness, along with reduced incidence of allergic responses and toxicity [43]. To investigate the antimicrobial characteristics of four commercially accessible dyes, namely Acacia catechu, Kerrialacca (reddish), Quercus infectoria (Majoj or tin oak), and Rubiacordifolia, the study used various common microorganisms.

a b c

Figure 5. (a) Rubiacordifolia, (b) Majoz or tin oak, (c) Sengaliacatecho

Various natural dyes were evaluated to determine their efficacy in inhibiting the growth of specific microorganisms (Escherichia coli, Bacillus subtilis, Klebsiella pneumoniae, Proteus vulgaris, and Pseudomonas aeruginosa). Initial screening demonstrated that oak exhibited antimicrobial properties against all tested microorganisms. However, all other dyes except for oak proved effective against Pseudomonas aeruginosa [44].

7. Conclusion

Pathogenic microorganisms can develop resistance to antibiotics through genetic mutations, leading to the emergence of new, untreatable strains. Fibers and textiles are often the first and most prolonged points of contact with these microorganisms. They coexist with the human body and create an ideal environment for bacterial growth, highlighting the need for alternative, health-friendly approaches. Plant fibers are still widely studied due to their eco-friendly characteristics and versatile applications. By utilizing careful extraction methods, we can harness the natural properties of plants to produce fibers that inhibit microbial growth. Moreover, nanomaterials made from plant fibers, enriched with essential oils, phenolic compounds, and other bioactive substances, offer significant advantages in combating microbial pathogens. These additional substances not only maintain the composition and original characteristics of plant fibers but also augment them with valuable attributes, including antibacterial, antifungal, and antiviral properties. It serves as an environmentally-friendly and long-lasting substitute for conventional antimicrobial substances, minimizing the use of artificial chemicals and mitigating detrimental impacts on the environment. Furthermore, the inherent characteristics of plant fibers make them a suitable option for antibacterial uses. The integration of plant extracts into nanofibers has the potential to enhance the properties of wound dressings and offer a safer and more efficient resolution in the fight against microbial infections. Using plant pigments as antibacterial agents in textiles has various benefits compared to synthetic alternatives. Initially, these pigments are obtained from natural sources, making them biodegradable and environmentally friendly. Secondly, in comparison to synthetic chemicals, they have a lower probability of inducing allergic reactions or sensitivities. Thirdly, the availability of various plant sources allows for a diverse array of color options. Additionally, plant pigments exhibit antibacterial properties when applied to textiles.

Additional research is required to enhance extraction methods and uncover the complete capabilities of these plant fibers. Additionally, thorough investigations on the prolonged impact of these fibers on microorganisms and their viable uses are imperative for their effective incorporation into textile fibers.

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