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Review Paper

Sustainable plant-based antimicrobial agents for textiles application: A Review

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Abstract

The textile industry is formidably striving to progress towards ecologically and sustainability. This has instigated the research to find an alternative solution for the extensive use of synthetic chemicals in textile wet processing and for cleaner production. Public awareness of infectious and viral diseases has created a requirement for sustainable antimicrobial material. Synthetic antimicrobial agents have intensive use for textile applications but this approach has various environmental concerns. The need for sustainable and ecological antimicrobial textiles has stimulated research in the medical textile field for a promising solution. The current review paper comprises various potent plant-based biomaterials for textile applications as antimicrobial agents and colorants. The antimicrobial activity of plant extracts on textiles is been reviewed in detail. As a future prospect, a few ethnomedicinal Indian plants have been critically reviewed to understand their mechanism and effectiveness in textile application.

Keywords: Antimicrobial textiles, Herbs, Plant-based, phytochemicals, Neem, Tulsi, Turmeric, Aloe vera, Glycyrrhiza glabra, Tinospora cordifolia, Andrographis paniculate, Psoralea corylifolia.

Introduction

The textile industries are one of the highest pollution-causing segments in the world. The use of hazardous chemicals, excessive water and energy usage, and the production of more liquid and solid waste are significant reasons[1]. Immoderate usage of hazardous chemical and dyes represent a major risk to the environment and sustainability. The maximum consumption of chemicals is in the wet processing of textiles i.e. pretreatment, dyeing, printing, and finishing processes[2]. A large number of chemical deployments in processes cause prolonged damage to theecology. Natural dyes and natural textile auxiliaries could bring a radical change in reducing the ecological footprint in the textile field[3]. The present world scenario has changed the expectation of textile materials other than aesthetic value. Textiles with anti-pathogenic (antimicrobial and antiviral) activity have prime importance in today's scenario.

In a near future, biomedical products will perhaps be the largest sector due to their preventive and curative products range such as antimicrobial masks, bandages, wound dressing, and similar medical textiles. Bacterial and virus-caused infectious health disease presents a major danger to people around the globe. Diseases and their congeners have changed the user's demand & necessity for clothing and it has caused a swift increase in the medical textile market.

All the leading textile industries throughout the world are concentrating on the production of technical textiles such as curative textiles, protective textiles, smart textiles, etc[4]. Antimicrobial textiles are being manufactured with enhanced environmental profiles due to the rising public awareness and growing sense of social responsibility concerning environmental issues. There are various approaches for functionalizing a textile material for antimicrobial properties. In the recent past, a multitude of organic compounds, including polymers/ biopolymers, have exhibited promising properties as antibacterial agents, effectively combating infections caused by detrimental bacteria and viruses[5].

The antiviral and antimicrobial finish has gained utter importance considering the current Covid -19 scenario[6] But there is another aspect of using such synthetic Antiviral and antimicrobial agents; Both the users and the environment face a potential threat from them. Hence there are various environmental regulations including health hazards, associated with the use of antiviral and antibacterial finishes for the fibers[7] The release of antimicrobial finish wash-off is hazardous to aquatic lives as well. The contaminated matters in the waste may be engulfed by living organism and can enter in food chain. This Contamination can be extended to water bodies and land[8].

In contrast, natural antibacterial agents that are eco-friendly and less harmful to people are getting a lot of attention.

Few advantages for this approach are reduced pollution, renewability, green chemistry, and sustainability which make natural antimicrobial agents suitable alternatives for functional finishes and coating on textiles[2]. Chitosan, sericin protein, and alginate are some of the most common natural antimicrobial agents[9] . Hence using natural antimicrobial agents for finishing is an eco-friendly alternative to address the above issues.

Various other natural agents such as chitosan, basil, turmeric, neem, clove oil, aloe vera, sericin, and pomegranate also have antimicrobial properties. Their eco-friendliness has garnered considerable attention[10]. Further research and screening of the vital phytochemicals shows very promising results against different type of diseases[11] have been main constituent for new drug development. A large number of plants contain phytochemicals causing antimicrobial action against a variety of human pathogenic viruses. The active compound present in the selected plant have to isolated and characterized for required properties[12].

Phytochemicals can be categorized as primary or secondary constituents based on their involvement in plant metabolism. Primary constituents encompass proteins, common sugars, purines, amino acids, pyrimidines of nucleic acids, chlorophylls, and more. On the other hand, secondary constituents encompass a diverse range of plant chemicals, including alkaloids, flavonoids, terpenes, plant steroids, lignans, curcumins, phenolics, saponins, flavonoids, and glucosides[11].

Requirements for Functionalized finishing

Functional Finished textiles are designed to serve specific purposes for example flame retardant textiles waterproof textiles, antimicrobial textiles, etc. The fundamental requirement for textile materials are the same but the individual requirement for textile materials may differ. Textiles are prone to easy damage and degradation. In an account of this, it is important to consider mechanical effects on the finished textiles. Apart from this physical requirement, chemical requirements and biological requirements also need to be contemplated. A few fundamental requirements are listed[13]. i. Resistance to dry-cleaning, washing, and hot pressing. ii. Targeted efficacy against undesirable microorganisms. iii. There should not be any negative impacts on the producer, consumer, or environment. iv. Compliance with regulatory requirements set by governing agencies. v. Compatibility with chemical processes. vi. Simple application method without compromising fabric quality. vii. Resistance to body fluids and disinfection/sterilization.

Action Mechanism of antibacterial agents: Action mode for the different antibiotics may vary depending on their molecular structure and affinity to the bacterial target site. Few are listed as under – i. Agents that block the creation of cell walls. ii. Agents that prevent cell membrane activity. iii. Protein synthesis inhibitors. iv. Blockers of the synthesis of nucleic acids. v. Agents that inhibit certain metabolic processes.

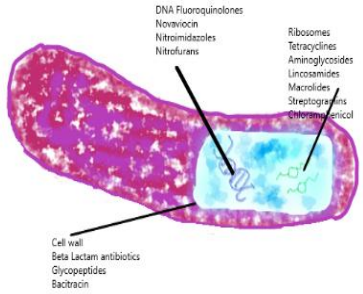

Figure-1: Major target of common antibacterial agents.

Mechanism of antiviral agents

Mechanism of antiviral agents are quite different from the antibacterial agents. Antiviral agent first transforms to triphosphate and then inhibit the DNA synthesis. Sometime antiviral agent enhances the resistance of cell wall to a virus, It further suppresses the adsorption of virus in the It is possible to draw the conclusion that viral medications that are now being used can decrease the virus's adsorption and diffusion in the cell, a process known as deproteinization, and enhance the cell's resistance to viruses (interferons)[14].

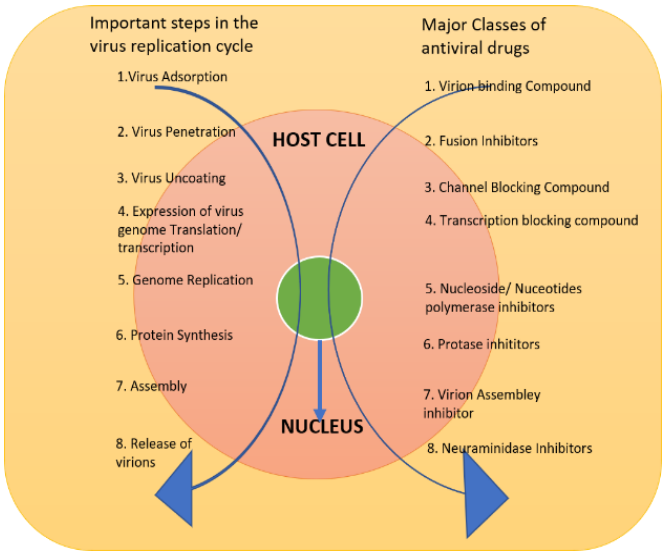

Figure-2: Significant viral replication cycle events that serve as antiviral targets[15].

In the case of textiles, focusing on the initial stages of viral entrance is a highly promising strategy. The said technique is extracellular and therefore relatively accessible[15].

Microorganisms and diseases caused by them

Major types of microorganism and their effect on human health are mentioned in Table-1.

Table-1: Disease caused by different microorganism[16].

Diseases caused by microorganism	Microbe Name	Type of microbe	Mode of Transmission
Diarrhea, Urinary tract infection	Escherichia coli	Gram-negative bacteria	Direct contact/close contact
Urinary tract infection	Proteus mirabilis	Gram-negative bacteria	Direct contact/close contact
Infection to burns and open wounds, nosocomial infections	Pseudomonas aeruginosa	Gram-negative bacteria	Direct contact/close contact
Skin Infection, Pyrogenic Infection	Staphylococcus aureus	Gram-positive bacteria	Direct contact/close contact
Skin and soft tissue infections, Odor from Body	Staphylococcus epidermis	Gram-positive bacteria	Direct contact/ Indirect contact
Acne vulgaris (or simply acne or pimples)	Propionibacterium acnes	Gram-positive bacteria	Direct contact to the infected person
Bacterial pneumonia	Streptococcus pneumonia	Gram-positive bacteria	Droplets of sneeze in the air
Tuberculosis	Mycobacterium tuberculosis	Gram-positive bacteria	Air
Skin diseases, Odor from body	Corynebacterium ditheroides	Gram-positive bacteria	Close contact
Cold, cough and flu	Rhinoviruses	Virus	Respiratory droplets in the air
Covid-19	Coronavirus	Virus	Respiratory droplets in the air and direct contact
Polio or Poliomyelitis	*Poliomyelitis visum*	Virus	Water, mouth or body waste
Oral and foot diseases	Picornavirus or Genus Aphthovirus	Virus	Animal and close contact with the infected agent
Ringworms	Puccinia Rust fungus	Fungi	Air and seeds
Rust of wheat	Micro Trichophyton and Epidermophyton fungi	Fungi	Contact with infected skin
Diaper Rashes	Candida albicans	Fungi	Contaminated hand and medical devices
Chronic infection of skin and nails	Trichophyton rubrum	Fungi	Infected towels, linens, clothing (contributing factors are high humidity, heat, perspiration, diabetes mellitus, obesity, friction from clothes).
Malaria	Plasmodium Malaria, Plasmodium Vivax and Plasmodium Falciparum	Protozoa	Anopheles mosquito (female)

Natural antimicrobial agents for textile applications

Nature is so prolific and profuse with a large number of different kinds of vegetation and plants. These various plants have distinct medicinal values. These plants are highly variable and their attributes and properties vary as the region changes. From ancient times, people are using various plants for medical purposes. The use of plant extracts and other natural compounds for the medicinal purpose were widely adopted during 1990. Natural herbal products with pharmaceutical properties include Neem, Tulsi, Pomegranate, Aloe Vera, Prickly Chaff Flower, Turmeric, Clove, etc. Research shows that some distinct kinds of herbs exhibit antimicrobial activity on textiles[17,18]. The antimicrobial activity is not limited only to the plant world but aquatic lives also have vast source such as prawns, fishes and Chitosan[19]. For millions of years, enormous Plant and animals have developed their unique preventive and curing mechanisms against a large group of microorganisms. Plants naturally evolve into biologically active substances, which produces a natural antibacterial agent[20].

Natural antimicrobial agents have various salient features. Compared to synthetic organic antibacterial agents, they are biocompatible and may spontaneously degrade. Additionally, they do not acquire any medication resistance. They are eco-friendly and contribute toward environmental sustainability. With the up surging necessity of antimicrobial textiles due to covid-19 and to fortify the lifestyle with prevention under the consideration of environmental aspects, natural antimicrobial agents are receiving global attention. Natural terpenes, alkaloids, anthraquinones, flavonoids, tannins, and coumarins make up the majority of the active components in plant-based antimicrobial treatments[21]. The antibacterial range of these compounds varies. While providing antimicrobial characteristics and enhancing the fabric's antioxidant, anti-UV, and other capabilities, several plant antimicrobial compounds can also be employed as natural dyestuffs[22]. Few plants are listed below.

Ocimum basilicum (Tulsi leaf): Tulsi "Queen of herbs" is described as a sacred and medicinal plant in Indian ancient literature. The main phytochemicals present in Ocimum basilicum are eugenol, ursolic acid, rosmarinic acid, oleanolic acid, carvacrol, linalool, and beta-caryophyllene[23]. It is suggested that the antimicrobial mechanism of Ocimumbasilicum involves disruption of the cell wall membrane and cytotoxic inhibition of energy generation due to eugenol[24]. The excellent antimicrobial activity of Ocimum basilicum leaves extracts against pathogenic gram-positive and gram-negative bacteria makes it suitable for textile application[25]. Ocimum tenuiflorum showed a significant reduction in bacterial growth against S. aureus and E coli bacterium on cotton, polyester, bamboo and its blends[26]. A synergistic antimicrobial effect of Curcuma aromaticasalisb and Ocimum tenuflorum had been studied and results showed effective bacterial reduction against s. aureus and E. coli bacterium[27]. In another report, a combination of Holy basil and Malabar nut was studied for an antibacterial activity for developing curative fabric[28]. Rajendran et al found the significant antibacterial activity of Ocimum sanctum encapsulated nanoparticles on cotton fabric[29]. A combination of neem and tulsi herbal extract as essential oil along with suitable softner treated fabric exhibited a significant improvement in antimicrobial properties and a improvement in physical properties such as tensile strength, roughness and water absorbency[30]. A comparative study revealed that Tulsi showed maximum antimicrobial activity against E. coli and S. Aureus among neem, tulsi, Mentha spicata (Spearmint), Centella asiatica (Indian pennywort)[31]. Although no specific study is available for anti-viral activity of ocimum tenflorum on fabric but the studies showed that ocimum tenflorum leaves extract have anti-viral activity against Hematopoietic Necrosis Virus (IHNV), polio virus type 3, herpes virus (HSV), hepatitis B virus, and New castle Disease Virus[32].

Curcuma longa L. (**Curcumin/ Turmeric):** The primary phytochemicals in Curcuma longa L. (Zingiberaceae family) rhizome are curcumin or diferuloylmethane, which has the chemical formula 1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptane-3,5-dione[33].

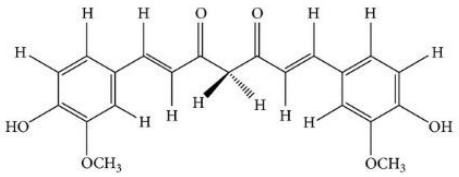

Figure-3: Chemical structure of curcumin[33].

Due to the presence of phenolic chemicals like curcuminoids, turmeric has antibacterial activity against B. subtilis, S. aureus, and E. coli. Turmeric's antibacterial properties are due to its essential oil, alkaloid, curcumins, turmerol, and valeric acid[34]. Action mechanism of Curcumin depends on the structural characteristics as it blocks bacterial growth and generate antioxidation products. Basic mechanisms of virus deactivation either direct interference in the viral replication or disturbing signalling pathways require for viral replication[35]. Being a photosensitizer, curcuma longa induce phototoxicity under blue light and inhibits bacterial growth. It is suggested that Curcuma longa is compatible with other antimicrobial agents in combination and produces synergistic effects[36]. A study of dyeing viscose fabric with curcumin longa rhizome in alkaline condition with mordant showed improved antimicrobial activityagainst E. coli[37]. Chaiman k et al. studied the antimicrobial activity of curcuma longa on cotton, silk, wool, polyester, and nylon. It is found that treated fabrics showed excellent antimicrobial activity against E coli and S. Aureus bacterium[38]. The microencapsulation application method of curcuma longa on cotton fabric showed improved antimicrobial activity than the direct application of extract[39].

Aloe vera: *Aloe vera is a succulent plant that looks like cactus and it is filled with a clear viscous gel. It belongs to the family called Liliaceae*. Although it has very less solid content about 0.5-1.0 % that exhibits potential antibacterial, antifungal, and antiviral properties. The rest of the composition contains mostly water ranging from 99 – 99.5%[40]. There are a total of 32 types of anthraquinone and its glycoside derivative present in aloe vera[41]. Aloin and emodin are the two most abundant comunds present in aloe vera that contribute to antimicrobial, antiviral, and analgesic activity in the plant[42]. The mechanism involved is the inhibition of protein synthesis and henceforth restriction of bacterial growth[43]. Extraction of aloe vera plant in Acetone medium exhibit maximum antimicrobial and antifungal activity as compared to water and ethanol extraction[44]. An investigation on the antimicrobial activity of crude aloe vera gel showed a significant bacteria reduction for Escherichia coli, Staphylococcus aureus, and Candida albicans bacterium[45].

100% cotton fabric is treated with aloe vera showed effective bacterial reduction against S aureus and Pneumonia bacterial even after four washing cycle[46].

A study of methanol-extracted aloe vera on bleached cotton fabric showed excellent antimicrobial activity against gram-negative bacteria (E. Coli and Pseudo) and good antimicrobial activity against gram-positive bacteria (B. Subtilis and B pumilus) without any adverse effect on the physical properties of fabric[47]. An experimental study on cotton fabric treated with methanol extracted aloe vera showed excellent bacterial reduction for S. Aureus bacteria. Using citric acid during the treatment provided wash durability for up to 50 washes[48]. A combination of aloe vera with neem reported to have significant antimicrobial and antifungal activity[49]. Selvi et al. also reported antimicrobial activity of aloe vera extract combined with the citric acid cross linking agent on cotton fabric[50]. Due to skincare properties of aloe vera, it has wide spread use in Cosmetotextiles[51]. A curative garment is developed with aloe vera extract found effective against Atopic Dermatitis[52].

***Azadirachta indica* (Neem):** Neem (*Azadirachta indica*) is a member of the Meliaceae family. Neem is the most useful medicinal plant from ancient times. Neem has various pharmacologically important compounds such as saponins, flavonoids, Catechins, gallic acid, limonoids, and tannins (epoxy azadiradione and nimbins). These components play a role in imparting antibacterial, antifungal, anti-inflammatory, antipyretic, and antitumor activities[53]. Neem is an ethnomedicine used to cure skin diseases, infectious diseases, and respiratory problems. Neem is a rich source of antioxidants responsible for free radical-scavenging and reductive potential[54]. A study is conducted to standardize the extraction of neem fabric for textile application. The results stated that the yield of the main bioactive components of neem can be obtained with acetone extract at alklineph and moderate temperature[55]. Joshi et al. investigated extracting properties from Neem tree (Azadirachta indica) seeds to give blend fabrics an antibacterial quality[56].

The results showed that the treated fabrics inhibited the growth of Gram-positive bacteria (*Bacillus subtilis*) effectively. An attempt had been done to dye silk fabric with neem-extracted natural dye without damaging the silk's physical properties. The results showed a good inhibitory impact against Gram-positive bacteria and moderate of activity against Gram-negative bacteria[57]. Research suggested that leaves of Azadirchta Indica exhibit excellent antimicrobial activity compare to bark and seed[58]. An experimental study on mulberry silk fabric revealed that neem with natural mordant has significant antimicrobial and mosquito repellent properties[59]. Efficiency of antimicrobial activity in case of neem extract enhanced on modifying the cotton fabric[30]. Neem barks also a good source of dyeability and antimicrobial activity. An experiment on hemp fabric with neem barks extract with mordant show good color strength and antimicrobial activity against S. Aureus bacterium[60]. Nanoparticle formation of neem herb alter the properties of fabric. An enhancement in antimicrobial activity and washing durability is observed with neem nanoparticles compare to plain neem extract[61].

Potential herbal plant as antimicrobial agents for textile application

Glycyrrhiza glabra: Glycyrrhiza glabra Linn. (Family: Fabaceae) is a popular medicinal plant used across the globe for its ethnopharmacological value to cure varieties of ailments[62]. Nitalikar et. al has reported antimicrobial activity by acetone extraction method against gram-positive (Bacillus subtle and Staphylococcus aureus) and gram-negative (Escherichia coli and Pseudomonas aeruginosa) bacteria[63]. Krishnaveni et al studied the antimicrobial activity on organic cotton fabric using yashtimadhu (glycyrrhiza glabra) for medical application and found that the 20% concentrated treated fabric was proved to possess the best antimicrobial property[64]. Glycyrrhiza glabra root extract has been used as a natural antibacterial agent in the finishing of textile and different color tones using different mordants[65]. The glycyrrhiza glabra root extract was evaluated for antimicrobial and comfort coolant finish and found 50 % concentration of glycyrrhiza glabra exhibited better thermal resistance and antimicrobial activity[66]. Wang et al. studied the antiviral activities of glycrrhiza glabra against Influenza. Glycrrhiza glabra for oral intake has shown antiviral potential against various other viruses such as SARS, herpes virus, NDV, RSV, etc [67].

Tinospora cordifolia: *Tinospora cordifolia, sometimes known as "Giloy," is well-known in traditional ayurvedic literature for its extensive use in the treatment of several ailments. The Menispermaceae family includes the species Tinospora cordifolia. It is a big, deciduous climbing shrub with a characteristic greenish yellow blossom that is genetically varied*[68]. When tested for antibacterial activity against certain Gramme negative and Gramme positive human pathogenic bacteria on fabric. Tinpospora cordifolia and Cassia fistula extracts in solvent and aqueous form shown good antimicrobial activity[69]. Antiviral activity of natural compounds from Tinospora cordifolia (Amritaballi) was evaluated for their efficacy against SARS-CoV-2 targets involved in virus attachment and replication. During Research it was found that Tinospora cordifolia showed high binding efficacy against SARS-CoV-2 targets involved in attachment and replication of the virus[70]. Tinnosporacordifloia also has antioxidant activity and can beevaluated its antioxidantactivity by DPPH (1-diphenyl-2-picrylhydrazyl) free radical scavenging method. Tinospora cordifolia has wound healing property[71].

Andrographis paniculate (green chiretta): Andrographis paniculate is well known as King of Bitters due to its bitter flavour. It can be produced throughout the year. The herb plant has a height of half to one meter. A. Paniculata is easily available in Asian countries. It is mostly found in Asian countries. It belongs to the Acanthaceae (Acanthus) family, has been used for centuries as a medicinal herb for treating various diseases[72]. It has a broad range of pharmacological effects[73]. A wide array of studies has been conducted, especially in Asia on medicinal properties of Andrographis paniculata herb.

It is a medicinal plant reported to have anti-oxidant, Anti-inflammatory/anti-allergic activities, insecticidal activities, anti-HIV, anti-pathogenic bacteria, and immunoregulatory activities[74]. Andrographolide has an antiviral effect on different viruses such as influenza A, Hepatitis B & C, and chikungunya[75]. Different part of this herb as leaf, aerial part, roots and whole plants are used for various medicinal applications. Andrographis paniculate contains various bioactive phytoconstituents that are useful in treating various diseases. Different parts of a plant have different phytochemicals. It has been studied that flavonoids are obtained from roots and leaves. The aerial part of the plant (area of plant above the land) is rich in alkanes, ketones, and aldehydes[76].

Researchers have found that the bitter nature of plants is due to the presence of lactone andrographolide in the leaves[77]. Using conventional phytochemical techniques, plant extracts were examined for the presence of significant secondary metabolite classes as alkaloids, flavonoids, saponin, terpenoids, tannin, glycosides, phytosterol, and proteins[78]. The presence of phytochemicals imparts different attributes to the plants. Phenol present in the plants offers resistance and anti-oxidant properties. Flavonoids are responsible for anti-allergic, anti-inflammatory, anti-microbial, and anti-cancer activities present in plants[72].

It was shown that the dried herb of A. paniculata's aqueous extract, and rographolides, and arabinogalactan proteins have antibacterial action against the bacteria Bacillus subtilis (B. subtilis), Escherichia coli (E. coli), and Pseudomonas aeruginosa[79].

Psoralea Corylifolia (Bakuchi): P. corylifolia has a significant role in Ayurveda and Chinese medicine therapies. The plant has cytotoxic, antibacterial, and cardioactive effects. The seeds are used in Ayurveda to treat a variety of ailments including alopecia, inflammation, leukoderma, leprosy, psoriasis, and eczema in the form of paste and ointment for both external and internal usage[80]. When used topically, a mixture of bakuchi and Haratalabhasma provide treatment from leukoderma[81].

The pigmentation during vitiligo is promoted due to furano coumarins which have psoralens. In aurveda treatment, the powder of this herb is used interally and externally for skin diseases. *Because P. corylifolia contains the phenolic component Bakuchiol, it has shown promise in anti-acne preparations. Because it caused no irritation and wasn't sensitising, it was found to be safe and non-irritating and could be worn for extended lengths of time during the day*[82].

Testing methodology for antibacterial and antiviral textiles

The two primary kinds of methods for assessing a textile's antimicrobial capabilities are qualitative and quantitative. In the Table-2, the techniques employed for the various standards, their nature, and their antibacterial effects are mostly listed.

Challenges in the development of natural medicinal textiles

There exists a vast reservoir of natural antimicrobial agents that can be harnessed to confer beneficial antimicrobial properties onto textile substrates. Although numerous studies have endeavoured to exploit these environmentally friendly bioactive natural products for textile applications, only a limited number have conducted comprehensive and systematic investigations.

The primary challenges associated with utilizing natural products in textiles stem from their complex composition, as they often consist of mixtures of multiple compounds that can vary among different species of the same plant. Furthermore, the activity and composition of these natural products can differ based on factors such as geographical location, age, and extraction method.

Acquiring these products in large quantities, as well as their extraction, isolation, and purification to achieve standardized forms, present additional challenges for their application. Concerns such as durability, shelf life, and antimicrobial efficacy relative to synthetic agents must also be addressed. Nevertheless, due to their eco-friendly and non-toxic nature, natural products remain promising candidates for niche applications, including medical and healthcare textiles. While plant-based natural products exhibit complex chemical structures, not all components possess antibacterial properties. Neem, tulsi, aloe vera, and chitosan have been extensively studied for their antimicrobial activity, whereas lesser-explored ethnomedicinal plant extracts should be investigated further for their antimicrobial and antiviral potential.

Additionally, selective isolation of bioactive ingredients represents a significant pathway toward reducing agent dosage. Identifying desirable synergistic combinations of major components with broad-spectrum inhibitory activity is another area of interest. The mechanisms underlying the bactericidal and virucidal actions of different natural antimicrobial agents remain largely unknown. Exploring the attachment of bioactive substances to diverse textile substrates to ensure long-lasting antimicrobial activity is a novel research avenue.

Although limited research has been conducted on the development of encapsulated natural agent products (such as microencapsulated neem oil), designing bioactive textiles with slow-release mechanisms for prolonged activity holds promise in the realm of biotextiles.

It is crucial to consider the potential adverse effects of certain natural products, such as strong odors that may contribute to mental discomfort for the wearer, before incorporating them into textile substrates. In addition, the bending rigidity and modulus of treated textiles, which affect the stiffness and drape of the fabric, should be altered as little as possible to maintain their desirable features.

Table-2: Testing standards and methods for antibacterial performance of textiles[83,84].

Method name	Standard number	Evaluation of effectiveness
Qualitative Methods		
Halo	AATCC 90	Width of inhibition ring
Agar Petri dish diffusion method (inhibition loop method)	GB/T 20944.1	Width of inhibition ring
Parallel delineation	AATCC 147	Width of antibacterial tape
Hoopla	AATCC 147	Width of inhibition ring
Absorption method	AATCC 147	Antibacterial value, Sterilization value
Hoopla	FZ/ T 73023	Width of inhibition ring
Transference (printing)	JIS L1902	Bacteria reduction value (inhibition value)
Absorption method	JIS L1902	Antimicrobial value
The law of transference	JIS L1902	Antimicrobial value
Quantitative methods		
Transference (printing)	ISO 20743	Antimicrobial value
Absorption method	AATCC 100	Rate of bacteriostatic and bactericidal
Absorption method	GB/T 20944.2	Inhibition value, inhibition rate
Oscillation	GB/T 20944.3	Bacteriostatic rate
Hoopla	FZ/ T 73023	Width of inhibition ring
Improved quinine law	FZ/ T 73023	Bacteriostatic rate
Absorption method	FZ/ T 73023	Bacteriostatic rate
Oscillation	FZ/ T 73023	Bacteriostatic rate

To preserve bioactivity on textile substrates, it is essential to avoid blocking active functional groups (which may be responsible for antimicrobial activity) during textile attachment. To address these challenges comprehensively, further research in the field of bioactive textiles derived from natural products is essential to establish them as viable alternatives to synthetic antimicrobial textiles. This research will also enable the utilization of natural products as effective odor control agents in sports and household textiles, as well as noble biocidal materials in medical textiles.

Conclusion

The increasing demand for comfort, hygiene, and well-being among customers has spurred a substantial and rapidly expanding market for antimicrobial textiles. The pervasive use of antimicrobial functional finishes in textiles for biomedical applications is on the rise. Major fiber and fabric producers have introduced antimicrobial products into their product lines, although variations persist in terms of effectiveness, speed of action, and durability. This field is dynamic, with ongoing efforts to further improve these products. This paper provides a concise overview of select natural agents, their modes of action, and some applications, as part of an ongoing extensive study. Future papers will delve into additional plant-based natural antimicrobial agents exhibiting promising antibacterial and antiviral activities. Technological aspects will also be examined, along with specific considerations regarding application methods and the durability of these functional finishing treatments for textiles.

References

1. Patel, B. H. (2011). Natural dyes. In *Handbook of textile and industrial dyeing* (pp. 395-424). Woodhead Publishing.

2. Akca, C. (2020). Antimicrobial Finishing. *Waste in textile and leather sectors*, 21.

3. Patel, B., & Kanade, P. (2019). Sustainable dyeing and printing with natural colours vis-à-vis preparation of hygienic viscose rayon fabric. *Sustainable Materials and Technologies*, 22, e00116.

4. Shanmugavasan, A., & Ramachandran, T. (2014). Investigation of extraction processes and phytochemical compositions of various plant extracts to develop curative medical bandages (Doctoral dissertation, Anna University).

5. Patel, B. H., & Tandel, M. G. (2005). Antimicrobial finishing for textiles: An overview. *Asian Dyer*, 31-36.

6. Timmis, K., & Brüssow, H. (2020). The COVID-19 pandemic: some lessons learned about crisis preparedness and management, and the need for international benchmarking to reduce deficits. *Environmental microbiology*, 22(6), 1986-1996.

7. Rosenberg, M., Ilić, K., Juganson, K., Ivask, A., Ahonen, M., Vrček, I. V., & Kahru, A. (2019). Potential ecotoxicological effects of antimicrobial surface coatings: a literature survey backed up by analysis of market reports. *PeerJ*, *7*, e6315.

8. Uddin, F. (2014). Environmental concerns in antimicrobial finishing of textiles. *International Journal of Textile Science*, 3(1A), 15-20.

9. Shahid, M., & Mohammad, F. (2013). Green Chemistry Approaches to Develop Antimicrobial Textiles Based on Sustainable Biopolymers A Review. *Industrial & Engineering Chemistry Research*, 52(15), 5245-5260.

10. Tawiah, B., Badoe, W., & Fu, S. (2016). Advances in the development of antimicrobial agents for textiles: The quest for natural products. Review. *Fibres & Textiles in Eastern Europe*, 3(117), 136-149.

11. Alapati, P., & Sulthana, S. (2015). Phytochemical screening of 20 plant sources for textiles finishing. *International Journal of Advanced Research*, 3(10), 1391-1398.

12. Dhawan, B. N. (2012). Anti-viral activity of Indian plants. *Proceedings of the national academy of sciences, India Section B: Biological Sciences*, 82, 209-224.

13. Hipler, U. C., & Elsner, P. (Eds.). (2006). Biofunctional textiles and the skin (Vol. 33). Karger Medical and Scientific Publishers.

14. Vardanyan, R., & Hruby, V. (2006). Synthesis of essential drugs. Elsevier.

15. Galdiero, S., Falanga, A., Vitiello, M., Cantisani, M., Marra, V., & Galdiero, M. (2011). Silver nanoparticles as potential antiviral agents. *Molecules*, 16(10), 8894-8918.

16. Bisen, P. S., Debnath, M., & Prasad, G. B. K. S. (2012). Human and microbial world. *Microbes: concepts and applications*, 1st *edn. Wiley, Hoboken*, 1-64.

17. Patel, B. H., & Patel, P. B. (2006). Dyeing of polyurethane fibre with Ocimum sanctum.

18. Patel, B. H., Desai, K. U., & Jha, P. K. (2014). Azadirachta indica mediated bioactive lyocell yarn: Chemical and colour characterization. *Advances in Chemistry*, 2014(1), 259171.

19. Shalini, G., & Anitha, D. (2016). A review: antimicrobial property of textiles. *Int J Sci Res*, *5*(10), 766-768.

20. Patel, B., Mandot, A. A., & Jha, P. K. (2014). Extraction, characterization and application of Azadirachta indica leaves for development of hygienic lycra filament. *J. Int. Acad. Res. Multidiscip*, 1, 65-84.

21. Agarwal, B. J., & Patel, B. H. (2000). The reincarnation of natural colourants-A review. *Chemical Weekly-Bombay-*, *45*(38), 139-148.

22. Iyigundogdu, Z. U., Demir, O., Asutay, A. B., & Sahin, F. (2017). Developing novel antimicrobial and antiviral textile products. *Applied biochemistry and biotechnology*, 181, 1155-1166.

23. Bano, N., Ahmed, A., Tanveer, M., Khan, G. M., & Ansari, M. T. (2017). Pharmacological evaluation of Ocimum sanctum. *J Bioequiv Availab*, 9(3), 387-92.

24. Saharkhiz, M. J., Kamyab, A. A., Kazerani, N. K., Zomorodian, K., Pakshir, K., & Rahimi, M. J. (2014). Chemical compositions and antimicrobial activities of Ocimum sanctum L. essential oils at different harvest stages. *Jundishapur journal of microbiology*, *8*(1), e13720.

25. Pattanayak, P., Behera, P., Das, D., & Panda, S. K. (2010). Ocimum sanctum Linn. A reservoir plant for therapeutic applications: An overview. *Pharmacognosy reviews*, 4(7), 95.

26. Ijaz, M., Maqsood, M., & Naveed, M. (2020). Evaluation of antimicrobial activity of Ocimum tenuiflorum leaves on mechanical behavior of fabrics. *Pure and Applied Biology (PAB)*, *9*(1), 538-544.

27. Chandrasekaran, K., & Senthilkumar, M. (2019). Synergic antibacterial effect of Curcuma aromatica Salisb and Ocimumtenuiflorum Linn herbal extract combinations on treated cotton knitted fabrics against selective bacterial strains. *Indian Journal of Fibre & Textile Research (IJFTR)*, 44(3), 344-351.

28. Chandrasekaran, K., Ramachandran, T., & Vigneswaran, C. (2012). Effect of medicinal herb extracts treated garments on selected diseases.

29. Rajendran, R., Radhai, R., Kotresh, T. M., & Csiszar, E.

(2013). Development of antimicrobial cotton fabrics using herb loaded nanoparticles. *Carbohydrate polymers*, 91(2), 613-617.

30. Zaghloul, S., El-shafie, A., El-bisi, M., & Refaie, R. (2017). Herbal Textile Finishes–Natural Antibacterial Finishes for Cotton Fabric. *Egyptian Journal of Chemistry*, 60(2), 161-180.

31. Ashraf, R. H., Rahman, M., & Rahman, M. (2021). Comparative study on antimicrobial activity of four Bangladeshi medicinal plants used as antimicrobial finishes on cotton fabric. *Journal of Textile Science & Fashion Technology*, 8(3), 6.

32. Jayati, B. A., Kumar, A., Goel, A., Gupta, S., & Rahal, A. (2013). In vitro antiviral potential of Ocimum sanctum leaves extract against New Castle Disease Virus of poultry. *International Journal of Microbiology and Immunology Research*, 2(7), 51-55.

33. Zorofchian Moghadamtousi, S., Abdul Kadir, H., Hassandarvish, P., Tajik, H., Abubakar, S., & Zandi, K. (2014). A review on antibacterial, antiviral, and antifungal activity of curcumin. *BioMed research international*, 2014(1), 186864.

34. Nisar, T., Iqbal, M., Raza, A., Safdar, M., Iftikhar, F., & Waheed, M. (2015). Turmeric: A promising spice for phytochemical and antimicrobial activities. *Am.-Eurasian J. Agric. Environ. Sci*, 15, 1278-1288.

35. Mathew, D., & Hsu, W. L. (2018). Antiviral potential of curcumin. *Journal of functional foods*, 40, 692-699.

36. Zheng, D., Huang, C., Huang, H., Zhao, Y., Khan, M. R. U., Zhao, H., & Huang, L. (2020). Antibacterial mechanism of curcumin: a review. *Chemistry & Biodiversity*, 17(8), e2000171.

37. Mirjalili, M., & Abbasipour, M. (2013). Comparison between antibacterial activity of some natural dyes and silver nanoparticles. *Journal of Nanostructure in Chemistry*, 3, 1-3.

38. Chairman, K., Jayamala, M., Christy, V., & Singh, R. A. J. A. (2015). Phytochemical screening and antimicrobial activity of Curcuma longa natural dye. *General Medicine*, 3(2), 304-312.

39. Sudha, S., & Yamuna, V. (2013). Development of anti-microbial textiles using microencapsulated honey and turmeric. *International Journal of Pharmacy & Life Sciences*, *4*(8).

40. Radha, M. H., & Laxmipriya, N. P. (2015). Evaluation of biological properties and clinical effectiveness of Aloeávera: áAásystematic review. *Journal of traditional and complementary medicine*, 5(1), 21-26.

41. Kahramanoğlu, İ., Chen, C., Chen, J., & Wan, C. (2019). Chemical constituents, antimicrobial activity, and food preservative characteristics of Aloe vera gel. *Agronomy*, *9*(12), 831.

42. Surjushe, A., Vasani, R., & Saple, D. (2008). Aloe vera: a short review. *Indian journal of dermatology*, *53*(4), 163-166.

43. Kamble, K. M., Chimkod, V. B., & Patil, C. S. (2013). Antimicrobial Activity of Aloe Vera Leaf Extract.

44. Arunkumar, S., & Muthuselvam, M. (2009). Analysis of phytochemical constituents and antimicrobial activities of Aloe vera L. against clinical pathogens. *World journal of agricultural sciences*, 5(5), 572-576.

45. Stanley, M. C., Ifeanyi, O. E., & Eziokwu, O. G. (2014). Antimicrobial effects of Aloe vera on some human pathogens. *International Journal of Current Microbiology and Applied Sciences*, 3(3), 1022-1028.

46. Khan, A. F. (2012). Extraction, stabilization and application of antimicrobial agents from Aloe Vera. *Pakistan Textile Journal*, 61(4).

47. Hein, N. T., Hnin, S. S., & Htay, D. H. (2013). A study on the effect of antimicrobial agent from aloe vera gel on bleached cotton fabric. *International Journal of Emerging Technology and Advanced Engineering*, 4(2), 7-11.

48. Jothi, D. (2009). Experimental study on antimicrobial activity of cotton fabric treated with aloe gel extract from Aloe vera plant for controlling the Staphylococcus aureus (bacterium). *African Journal of Microbiology Research*, 3(5), 228-232.

49. Khurshid, M. F., Ayyoob, M., Asad, M., & Shah, S. N. H. (2015). Assessment of eco-friendly natural antimicrobial textile finish extracted from aloe vera and neem plants. *Fibres & Textiles in Eastern Europe*, (6 (114), 120-123.

50. Selvi, B. T., Rajendren, R., Nithyalakshmi, B., & Gayathirignaneswari, S. (2011). Antimicrobial activity of cotton fabric treated with Aloevera extract. *Int. J. Appl. Environ. Sci*, *6*, 127-131.

51. Cheng, S. Y., Yuen, C. W. M., Kan, C. W., Cheuk, K. K. L., & Tang, J. C. O. (2010). Systematic characterization of cosmetic textiles. *Textile Research Journal*, 80(6), 524-536.

52. Krishnaveni, V., & Aparna, B. (2014). Microencapsulation of copper enriched Aloe gel curative garment for atopic dermatitis.

53. Islas, J. F., Acosta, E., Zuca, G., Delgado-Gallegos, J. L., Moreno-Treviño, M. G., Escalante, B., & Moreno-Cuevas, J. E. (2020). An overview of Neem (Azadirachta indica) and its potential impact on health. *Journal of functional foods*, 74, 104171.

54. Hossain, M. A., Al-Toubi, W. A., Weli, A. M., Al-Riyami, Q. A., & Al-Sabahi, J. N. (2013). Identification and characterization of chemical compounds in different crude extracts from leaves of Omani neem. *Journal of Taibah*

University for Science, 7(4), 181-188.

55. Bukhari, H., Heba, M., & Khadijah, Q. (2014). Eco-friendly dyeing textiles with neem herb for multifunctional fabrics. Part 1: extraction standardization. *Int. J. Tech. Res. App*, 2, 51-55.

56. Joshi, M., Ali, S. W., & Rajendran, S. (2007). Antibacterial finishing of polyester/cotton blend fabrics using neem (Azadirachta indica): a natural bioactive agent. *Journal of Applied Polymer Science*, 106(2), 793-800.

57. Abd El Aty, A. A., El-Bassyouni, G. T., Abdel-Zaher, N. A., & Guirguis, O. W. (2018). Experimental study on antimicrobial activity of silk fabric treated with natural dye extract from neem (Azadirachta indica) leaves. *Fibers and Polymers*, 19, 1880-1886.

58. Raja Ratna Reddy, Y., Krishna Kumari, C., Lokanatha, O., Mamatha, S., & Damodar Reddy, C. (2020). Antimicrobial activity of Azadirachta Indica (neem) leaf, bark and seed extracts.

59. Jahan, N., & Arju, S. N. (2022). A sustainable approach to study on antimicrobial and mosquito repellency properties of silk fabric dyed with neem (Azadirachta indica) leaves extractions. *Sustainability*, 14(22), 15071.

60. Inprasit, T., Motina, K., Pisitsak, P., & Chitichotpanya, P. (2018). Dyeability and antibacterial finishing of hemp fabric using natural bioactive neem extract.3 *Fibers and polymers*, 19, 2121-2126.

61. Ahmed, H. A., Rajendran, R., & Balakumar, C. (2012). 3Nanoherbal coating of cotton fabric to enhance antimicrobial durability. *Elixir Appl Chem*, 45, 7840-7843.

62. Lim, T. K., & Lim, T. K. (2016). Glycyrrhiza glabra. *Edible Medicinal and Non-Medicinal Plants: Volume 10, Modified Stems, Roots, Bulbs*, 354-457.

63. Nitalikar, M. M., Munde, K. C., Dhore, B. V., & Shikalgar, S. N. (2010). Studies of antibacterial activities of Glycyrrhiza glabra root extract. *Int J Pharm Tech Res*, *2*(1), 899-901.

64. Krishnaveni, K. (2017). Effect of imparting antimicrobial coating on organic cotton fabric using yashtimadhu for medical application. *J Textile Eng Fashion Technol*, 3(3), 650-2.

65. YILMAZ, F. (2020). Application of Glycyrrhiza glabra L. root as a natural antibacterial agent in finishing of textile. *Industrial Crops and Products*, 157, 112899.

66. Krishnaveni, V. (2013). Combined antimicrobial and coolant finishing treatment for cotton using yashtimadhu (Glycyrrhiza glabra L.) roots extract.

67. Fiore, C., Eisenhut, M., Krausse, R., Ragazzi, E., Pellati, D., Armanini, D., & Bielenberg, J. (2008). Antiviral effects of Glycyrrhiza species. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, 22(2), 141-148.

68. Saha, S., & Ghosh, S. (2012). Tinospora cordifolia: One plant, many roles. *Ancient science of life*, 31(4), 151-159.

69. Upadhyay, R. K., Tripathi, R., & Ahmad, S. (2011). Antimicrobial activity of two Indian medicinal plants Tinospora cordifolia (Family: Menispermaceae) and Cassia fistula (Family: Caesalpinaceae) against human pathogenic bacteria. *J. of Pharma. Res*, 4(1), 167-170.

70. Sagar, V., & Kumar, A. H. (2020). Efficacy of natural compounds from Tinospora cordifolia against SARS-CoV-2 protease, surface glycoprotein and RNA polymerase.

71. Mittal, J., Sharma, M. M., & Batra, A. (2014). Tinospora cordifolia: a multipurpose medicinal plant-A. *Journal of Medicinal Plants*, *2*(2), 33.

72. Okhuarobo, A., Falodun, J. E., Erharuyi, O., Imieje, V., Falodun, A., & Langer, P. (2014). Harnessing the medicinal properties of Andrographis paniculata for diseases and beyond: a review of its phytochemistry and pharmacology. *Asian Pacific journal of tropical disease*, 4(3), 213-222.

73. Roy, S., Rao, K., Bhuvaneswari, C. H., Giri, A., & Mangamoori, L. N. (2010). Phytochemical analysis of Andrographis paniculata extract and its antimicrobial activity. *World Journal of Microbiology and Biotechnology*, *26*, 85-91.

74. Pongtuluran, O. B., & Rofaani, E. (2015). Antiviral and immunostimulant activities of Andrographis paniculata. *HAYATI Journal of Biosciences*, 22(2), 67-72.

75. Gupta, S., Mishra, K. P., & Ganju, L. (2017). Broad-spectrum antiviral properties of andrographolide. *Archives of virology*, 162(3), 611-623.

76. Singha, P. K., Roy, S., & Dey, S. (2003). Antimicrobial activity of Andrographis paniculata. *Fitoterapia*, 74(7-8), 692-694.

77. Das, P., & Srivastav, A. K. (2014). Phytochemical extraction and characterization of the leaves of Andrographis paniculata for its anti-bacterial, anti-oxidant, anti-pyretic and anti-diabetic activity. *Int. J. innov. res. sci. eng. technol*, *3*, 15176-15184.

78. Pandey, J., Saini, V. K., & Raja, W. (2019). Evaluation of phytochemical analysis of Andrographis paniculata leaf and stem extract. *World Journal of Pharmaceutical and Life Sciences*, 5(2), 188-190.

79. Wen, L., Xia, N., Chen, X., Li, Y., Hong, Y., Liu, Y., & Wang, Z. (2014). Activity of antibacterial, antiviral, anti-inflammatory in compounds andrographolide salt. *European Journal of Pharmacology*, 740, 421-427.

80. Alam, F., Khan, G. N., & Asad, M. H. H. B. (2018). Psoralea corylifolia L: Ethnobotanical, biological, and

chemical aspects: A review. *Phytotherapy Research*, 32(4), 597-615.

81. Khushboo, P. S., Jadhav, V. M., Kadam, V. J., & Sathe, N. S. (2010). Psoralea corylifolia Linn.—"Kushtanashini". *Pharmacognosy reviews*, *4*(7), 69.

82. Uikey, S. K., Yadav, A. S., Sharma, A. K., Rai, A. K., Raghuwanshi, D. K., & Badkhane, Y. (2010). The botany, chemistry, pharmacological and therapeutic application of psoralea corylifolia L.–A review. *Int J Phytomed*, 2(2), 100-107.

83. Jayapriya, S., & Bagyalakshmi, G. (2013). Textile antimicrobial testing and standards. *International Journal of Textile and Fashion Technology*, 4(1), 2250-2378.

84. Song, X., Padrão, J., Ribeiro, A. I. F., & Zille, A. (2021). Testing, characterisation and regulations of antimicrobial textiles.

85. Zorofchian Moghadamtousi, S., Abdul Kadir, H., Hassandarvish, P., Tajik, H., Abubakar, S., & Zandi, K. (2014). A review on antibacterial, antiviral, and antifungal activity of curcumin. *BioMed research international*, *2014*(1), 186864.