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Ecofriendly antimicrobial finishing of textiles using bioactive agents based on natural products

M Joshi[a], S Wazed Ali & R Purwar
Department of Textile Technology, Indian Institute of Technology, New Delhi 110 016, India
and
S Rajendran
Centre for Materials Research and Innovation, The University of Bolton, Bolton BL3 5AB, UK

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In the present scenario of environmental consciousness, the new quality requirements not only emphasize on the intrinsic functionality and long service life of the product but also a production process that is environment-friendly. Therefore, research on environment-friendly antimicrobial agents based on natural products for textile application is gaining worldwide interest. This paper reports a comprehensive review on natural product based bioactive agents such as chitosan, natural dyes, neem extract and other herbal products for antimicrobial finishing of textile substrates. Different classes of active ingredients found in extracts of natural products and their mechanism of antimicrobial action have been presented. The major challenges and the future potential of application of natural products on textiles have also been critically reviewed.

Keywords: Chitosan, Ecofriendly antimicrobial agents, Herbal products, Natural dyes

1 Introduction

Increasing global competition in textiles has created many challenges for textile researchers and industrialists. The rapid growth in technical textiles and their end-uses has generated many opportunities for the application of innovative finishes. Novel finishes of high added value for apparel fabrics are also greatly appreciated by a more discerning and demanding consumer market. Antimicrobial textiles with improved functionality find a variety of applications such as health and hygiene products, specially the garments worn close to the skin and several medical applications, such as infection control and barrier material.

In the last few decades, with the increase in new antimicrobial fibre technologies and the growing awareness about cleaner surroundings and healthy lifestyle, a range of textile products based on synthetic antimicrobial agents such as triclosan, metal and their salts, organometallics, phenols and quaternary ammonium compounds, have been developed and quite a few are also available commercially[1]. Although the synthetic antimicrobial agents are very effective against a range of microbes and give a durable effect on textiles, they are a cause of concern due to the associated side effects, action on non-target microorganisms and water pollution. Hence, there is a great demand for antimicrobial textiles based on ecofriendly agents which not only help to reduce effectively the ill effects associated due to microbial growth on textile material but also comply with the statutory requirements imposed by regulating agencies.

The use of natural products such as chitosan[2] and natural dyes[3-5] for antimicrobial finishing of textile materials has been widely reported. Other natural herbal products, such as Aloe vera, tea tree oil, Eucalyptus oil and tulsi leaf (*Ocimum basilicum*) extracts, can also be used for this purpose. There is a vast source of medicinal plants with active antimicrobial ingredients. Although, there are many natural products rich in antimicrobial agents, the study on their use in textiles is very limited and not well documented. The relatively lower incidence of adverse reactions of herbal products as compared to modern synthetic pharmaceuticals, coupled with their reduced cost, can be exploited as an attractive ecofriendly alternative to synthetic antimicrobial agents for textile applications. Recent developments on plant based bioactive agents have opened up new avenues in this area of research. Most of the papers in this area concentrate on the technical details of

[a]To whom all the correspondence should be addressed.
E-mail: mangala@textile.iitd.ernet.in

applying individual natural agents, such as neem extracts, natural dyes, chitosan, and other herbal products (tulsi, Aloe vera, tea tree oil, etc.) on textile substrates and their testing. The other review papers in this area of antimicrobial textiles, on the other hand, cover a range of antimicrobial agents mostly synthetic and only a few natural products. There is no review exclusively on natural products and their application for imparting antimicrobial effect on textiles. Therefore, in this paper comprehensive critical review on the natural product based antimicrobial finishing agents for application on textiles has been reported. Besides, a comprehensive compilation of the different classes of active ingredients found in extracts of natural products and their mechanism of antimicrobial action has also been included along with the major challenges and potential for future research in this niche area.

2 Natural Antimicrobial Agents for Textile Applications

Among all the natural antimicrobial agents, the plant products comprise the major segment. Healing power of some of the plant materials has been used since ancient times. It is estimated that there are 250,000-500,000 species of plants on Earth[6]. A relatively small percentage (1-10%) of these is used as food by both humans and other animal species. Possibly, even more than this has medicinal properties[7]. Hippocrates (in the late fifth century B.C.) reported 300-400 medicinal plants[8]. Plants also have an almost limitless ability to synthesize aromatic substances, most of which are phenols or their oxygen-substituted derivatives[9]. Most of them are secondary metabolites, of which at least 12,000 have been isolated (less than 10% of the total)[8]. In many cases, these substances serve as plant defense mechanisms against predation by microorganisms, insects, and herbivores. Some compounds such as terpenoids give plants their odors; others (quinones and tannins) are responsible for plant pigment. Many compounds are responsible for plant flavor (e.g. the terpenoid capsaicin from chili peppers). Some of the herbs and spices used by humans in food yield useful medicinal compounds. Useful antimicrobial phyto-chemicals can be divided into several categories which are summarized in Table 1. A brief review based on the

Table 1— Major classes of antimicrobial compounds from plants

Class	Subclass	Example	Mechanism
Phenolics	Simple phenols	Catechol[10] Epicatechin[11]	Substrate deprivation Membrane disruption
	Phenolic acids	Cinnamic acid[12]	
	Quinones	Hypericin[13,14]	Bind to adhesins, complex with cell wall, inactivates enzymes
	Flavonoids Flavones	Chrysin[15, 16] Abyssinone	Bind to adhesins Complex with cell wall Inactivates enzymes[17, 18] Inhibit HIV reverse[19] transcriptase
		Totarol[20]	Not known
	Flavonols Tannins	Ellagitannin	Bind to proteins[21, 22] Bind to adhesins[23] Enzyme inhibition[24-26] Substrate deprivation Complex with cell wall Membrane disruption Metal ion complexation
	Coumarins	Warfarin[27-30]	Interaction with eucaryotic DNA (antiviral activity)
Terpenoids, essential oils	-	Capsaicin[31]	Membrane disruption
Alkaloids	-	Berberine[32-35] Piperine	Intercalate into cell wall and/or DNA
Lectines and polypeptides	-	Mannose-specificagglutinin Fabatin	Block viral fusion or adsorption[36, 37] Form disulfide bridges
Polyacetylenes	-	8S-Heptadeca-2(Z),9(Z)-diene-4,6-diyne-1,8-diol[38]	Not known

recent literature describing various natural products being explored for imparting antimicrobial properties to textile material is being presented in this section.

2.1 Chitosan

Chitosan [poly- (1-4) - 2- amino- 2- deoxy - β-D-glucan], a deacetylated derivative of chitin[39], is a natural, non-toxic, microbial resistant and biodegradable polymer (Fig. 1). Chitin is one of the most abundant polysaccharides found in nature, derived from marine shells and mollusks.

The process of deacetylation involves the removal of acetyl groups from the molecular chain of chitin, leaving behind a compound with a high degree of chemically reactive amino group. Chitin is made up of a linear chain of acetylglucosamine groups while chitosan is obtained by removing enough acetyl groups (CH_3-CO) leaving reactive $-NH_2$ group in the molecule. Owing to this, chitosan has two advantages over chitin. In order to dissolve chitin, toxic solvents such as lithium chloride and dimethylacetamide are used, whereas chitosan as such is readily dissolved in dilute acetic acid. The second advantage is that chitosan possesses free amine groups ($-NH_2$) which are the active sites for many chemical reactions[39, 40].

Antifungal or antimicrobial properties of chitosan are believed to originate from its polycationic nature, that can bind with negatively charged residues of macromolecules at the cell surface of bacteria[41] and subsequently inhibit the growth of bacteria. The

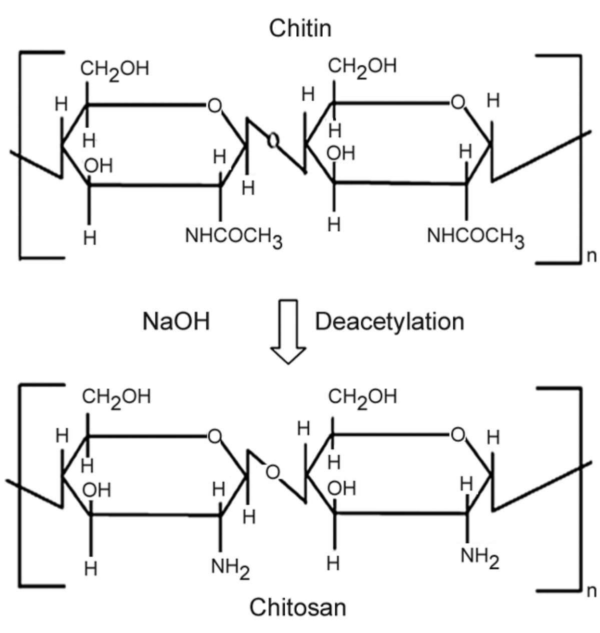

Fig. 1 — Chemical structure of chitin and chitosan

antimicrobial activity of chitosan is influenced by a number of factors that include the type of chitosan, the degree of deacetylation, molecular weight and other physicochemical properties. The antibacterial activity of chitosan is also sensitive to *p*H, with higher activity at lower values (pKa 6.5).

Chitosan and its derivatives have received a lot of attention as antimicrobial agents for use in textiles[2]. Chitosan can be attached chemically onto the cotton fabric by using cross-linking agents like glutaric dialdehyde[42] and polycarboxylic acids[43-45]. Chitosan is applied onto the fabric by padding the cotton fabric with a mixture of chitosan and citric acid followed by high temperature curing. Chitosan citrate has been used as a non- formaldehyde based durable press finish having antimicrobial properties[46]. The fixation of chitosan citrate solution onto cotton fabric was done by the padding of chitosan citrate on the cotton fabrics followed by dry-cure process[45]. Chito-oligosaccharides, on the other hand, have been applied onto the cotton fabric with or without a binding chemical such as a cross-linker to impart durable antimicrobial properties[47]. Sin *et al.*[48] used water soluble chitosan oligomers prepared by acid degradation for finishing polypropylene nonwoven fabrics to impart antimicrobial activity against *P. vulgaris, S. aureus* and *E. coli* at 0.01 - 0.05 % level. Chitosan coated cotton fabrics have been immobilized with tetracycline drug and the effect of drug concentration and treatment time on drug release characteristics and antimicrobial activity against both the Gram positive and Gram negative bacteria was studied by Shanmugasundaram *et al.*[49]

A chitosan derivative [N-(2 hydroxyl) propyl-3-trimethylammonium chitosan chloride] or HTCC has been used as an additive during polyacrylonitrle (PAN) spinning. A small amount of this additive imparts good antistatic and antimicrobial property to acrylic fibre[50]. Chitosan has been reported as a binder and thickener for pigment printing of polyester and polyester/cotton blends. The prints show a 96% reduction of *S. aureus* colonies within one hour[51]. Fibres made from chitosan are also available commercially[52].

Chitosan can be considered as a multifunctional textile finishing agent because its antimicrobial activity can be combined with other functions such a dyeing improvement[53], antistatic and deodorant activity. But the major limitation in its application on textiles is that chitosan is effective only at higher concentrations against microorganisms, and at this high concentration, it forms a film on the surface of the fabric which decreases the air permeability. Another disadvantage is that fabric becomes stiff after its application. Accordingly, an improved technique for chitosan application would be highly desirable for use in treating textile products wherein the users may value or benefit from excellent anti-microbial attributes of chitosan without loosing the textile properties.

2.2 Sericin

Silk sericin is a natural macromolecular protein derived from silkworm *Bombyx mori* and constitutes 25-30% of silk protein. It envelops the fibroin fibres with successive sticky layers that help in the formation of cocoon. Most of the sericin is removed during raw silk production at the time of reeling and other stages of silk processing and discharged in the effluent causing water pollution. However, sericin is a biomolecule of great value as it has antibacterial, UV resistant, oxidative resistant and moisturizing properties. Hence, recovery of silk sericin from degumming liquor or waste cocoons not only helps to reduce the environmental pollution but also is highly desirable as the recovered sericin has a lot of commercial value finding application in creams and shampoos as a moisturizing agent and also an important biomaterial for several applications including textiles[54].

Functional properties of some synthetic fibres can be improved by coating with silk sericin protein. Sericin modified polyester has been reported by Yamada & Matsunaga[55] and Wakabayashi and Sugioka[56]. The sericin modified polyester is five times more hydroscopic than untreated polyester. Although, sericin application on textiles for antibacterial property enhancement has not been reported as yet, it has been found that sericin (4% w/v) treated PET fabric shows 51% reduction of *P. vulgaris* and 38% reduction of *S. aureus*[57] and has a potential for such an application.

2.3 Neem Extract

Neem (*Azadirachta indica*), an evergreen tree of India, belongs to the plant family Meliaceae (mahogany). It has been recognized as one of the most promising sources of compounds with insect control, antimicrobial and medicinal properties[58]. Neem has been used as a traditional medicine against various human ailments from ancient times in India and about 700 herbal preparations based on neem are found in Ayurveda, Siddha, Unani, Amchi and other local health prescriptions. However, neem has also received a lot of attention worldwide for its potential use as a herbal pesticide and other healthcare formulations in countries such as China, USA, France, Germany, Italy, etc. The active ingredients of neem are found in all parts of the tree but in general, seed, bark, leaves and roots are used for extraction purpose. More than 300 different active compounds have been reported from different parts of neem tree but, the most important limonoids are azadirachtin, salannin and nimbin (Fig. 2)[59]. The neem extracts have been widely used in herbal pesticide formulation because of its pest repellent properties has a potential to inhibit growth of bacteria both Gram positive and Gram negative.

Currently, little work has been reported on its textile application as an antimicrobial agent. Few patents based on the use of neem oil using microencapsulation technique have been recently reported[60]. A systematic study on integrating neem seed and bark extracts to cotton[61] and cotton/polyester blend[57] textiles has been reported in the last few years by our group. Figure 3 shows the photographs of bacteria colony forming unit of *Bacillus subtilis* before and after the finishing treatment of cotton/polyester blend fabric with neem seed extracts[62]. Bark extract of neem has also been used for wool dyeing under the optimum conditions[63].

2.4 Natural Dyes

Many natural dyes obtained from various plants are known to have antimicrobial properties. Pomegranate (*Punica granatum*) and many other common natural dyes are reported as potent

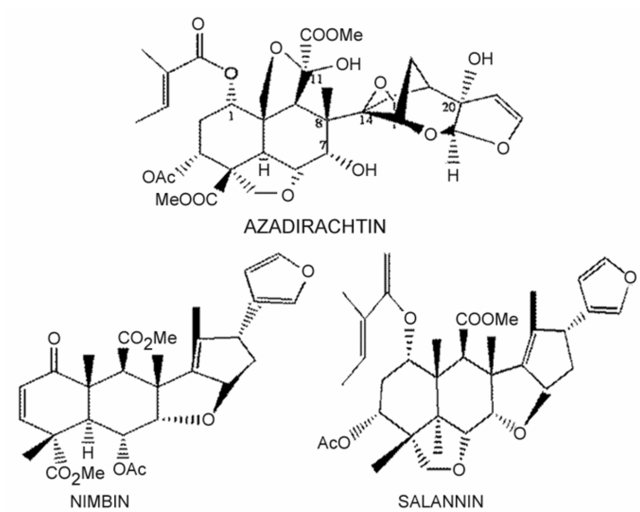

Fig. 2 — Active limonoids in neem extracts

antimicrobial agents owing to the presence of a large amount of tannins. Several other sources of plant dyes rich in naphthoquinones such as lawsone from henna, juglone from walnut and lapachol from alkannet are reported to exhibit antibacterial and antifungal activities. Curcumin (Fig. 4) a common non-toxic natural dye used in textiles and food has antimicrobial ability on wool[64]. Han and Yang[64] used a common dyeing process, either pad or batch, to provide wool with colour and antimicrobial properties using curcumin. The antimicrobial ability of the finished wool was semi-durable, more durable to home laundering than to light exposure. The inhibition rates against *S. aureus* and *E. coli* were 45% and 30% respectively after 30 cycles of home laundering.

Gupta *et al.*[3,4] have studied antimicrobial properties of eleven natural dyes against Gram positive and Gram negative bacteria. They found that the antimicrobial efficacy of a dye would vary when it is present in solution from that when it is held intimately by a textile substrate. Hence, the textile material impregnated with these natural dyes shows less antimicrobial activity as the uptake of these dyes on textile substrate is below minimum inhibitory concentration. The antimicrobial activity of these dyes is also dependent on their chemical structure specifically the functional groups present. The presence of tannins is responsible for antimicrobial activity of most of these natural dyes. Gupta *et al.*[3,4] also showed the increased antimicrobial activity (70–90%) of *Ouercus infectoria* extracts treated cotton fabric when the treatment is in combination with alum or copper mordants as compared to only 45–60% inhibition of bacterial growth without any mordanting. They also discussed the improved durability of activity of the mordanted sample which retains nearly 100% activity up to 5 launderings[65].

Tannins[66] (Fig. 5) are naturally occurring polyphenols, which are water soluble and found in many plant species as well as trees, accumulated in parts such as bark, wood, leaf, roots or fruits up to 10% by dry weight. Tannins possess antimicrobial activity against a wide range of bacteria and fungi[67].

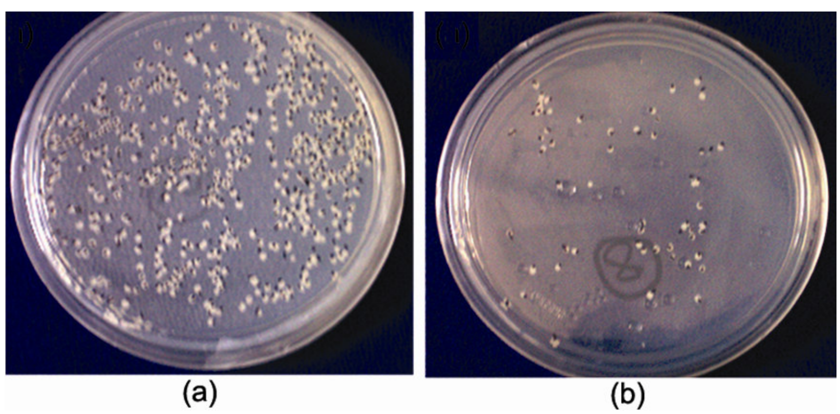

Fig. 3 — Photographs of (a) untreated and (b) neem seed extract (5%w/v) treated 52:48 cotton/PET blend (against *B. Subtilis* bacteria)

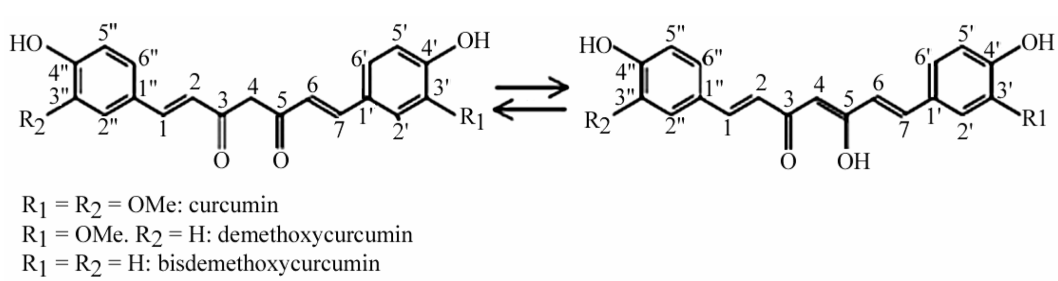

Fig. 4 — Chemical structure of curcumin

2.5 Aloe Vera

Aloe vera (*Aloe barbadensis*, Miller) belonging to family Liliaceae is known as 'Lily of the desert'. Aloe vera has been used as a skin care product for more than 2000 years. In modern times, scientific research has shown that the Aloe leaf contains over 75 nutrients and 200 active compounds, including 20 minerals, 18 amino acids and 12 vitamins. These rich constituents give the Aloe vera gel special properties as a skin care product which has been used in the USA since the 1970s and is found today in virtually all cosmetic products. Aloe vera has been used in traditional medicinal practices of many cultures for a host of curative purpose such as healing of wounds and burns and finds uses for medical and cosmetic purpose as well as for general health[68]. Aloe vera also possesses antifungal and antibacterial properties, which can be exploited for medical textile applications, such as wound dressing, suture, bioactive textiles, etc.

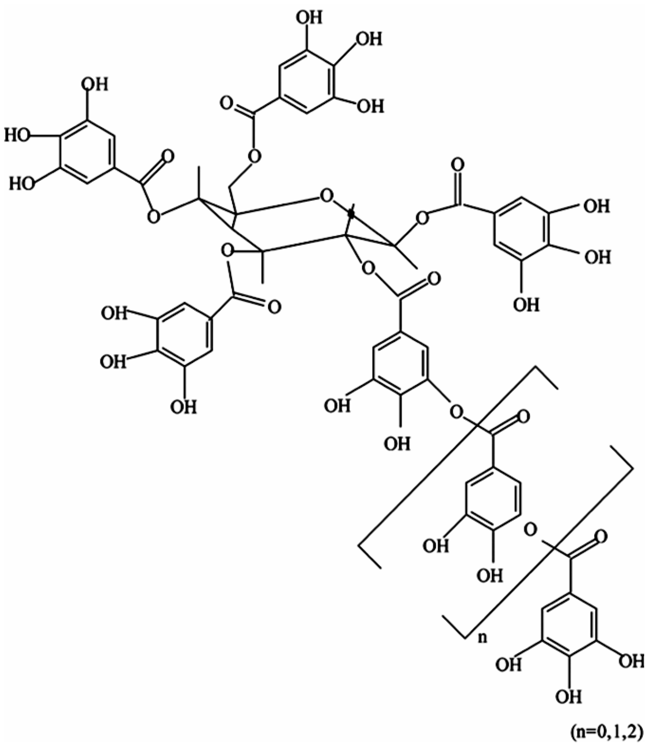

Fig. 5 — Chemical structure of tannin

There are different polysaccharides in Aloe vera, such as glucomannan with different molecular weight, acetylated glucomannan, galactogalacturan, glucogalactomannan with different composition as well as acelylated mannan or acemannan (Fig. 6)[69]. Acemannan a long chain polymer consisting of randomly acetylated linear D-mannopyranosyl units has immunomodulation, antibacterial, antifungal and antitumor properties.

Recently, attempt has been made by Wasif *et al.*[70] to impart antimicrobial finishing on cotton woven fabric using Aloe vera extract at various concentrations (5, 10, 15, 20 and 25gpl) in presence of ecofriendly cross-linking agent glyoxal (100gpl) by pad-dry-cure technique. Aloe vera gel on cotton fabric as an antibacterial finishing agent has been reported in another study[71]. Both the qualitative (AATCC-147-1998) and quantitative (AATCC-100-1998) evaluation was done to assess the degree of antibacterial activity of the Aloe vera treated cotton fabric. Figure 7 shows the number of colony reduction in Aloe vera treated cotton fabric as compared to that in untreated one[71]. Absorbance of the sample is directly proportional to the concentration of the cells in the sample. The absorbance values at 600 nm for the untreated and treated samples were compared (Table 2)[71].

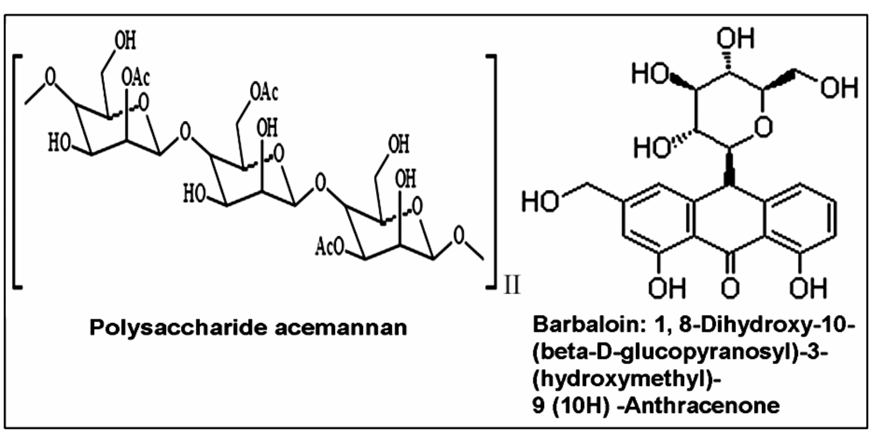

Fig. 6 — Components in Aloe vera gel responsible for antimicrobial activity

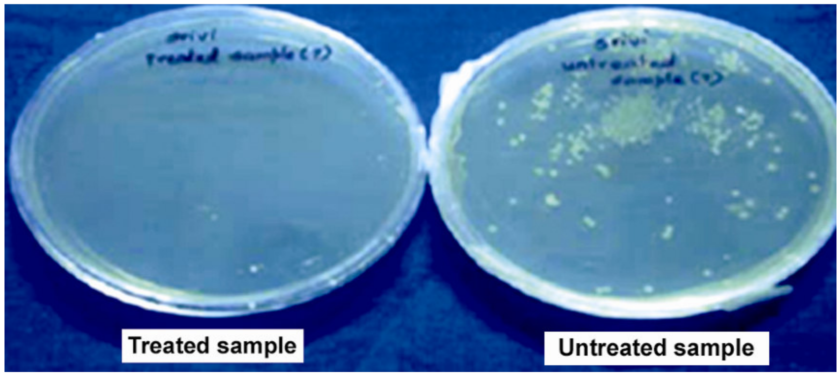

Fig. 7 — Antibacterial activity of 75% Aloe vera gel on cotton fabric

Table 2 — Absorbance tests at 600 nm

Sample	Absorbance value
Untreated	1.02
75% gel treated	0.93
100% gel treated	0.89
75% Leaf treated	0.94
Commercial gel treated	0.97

2.6 Tea Tree

Tea tree (*Melaleuca alternifolia*) is native to the north coast of New South Wales. This is world famous natural Australian product, used for thousands of years by the Aborigines to help alleviate cuts, bites, burns and other skin ailments. The oil of tea tree brings together over 100 different compounds and is globally recognized as a natural medicinal product. It has antiseptic (five times stronger than the usual household disinfectants), dermatological (prevents dry skin), and anti-fungal benefits and can also be used to fight infections/ infestations (effective against head lice, ticks, etc.)[72]. Its oil is considered to have some of the best natural antiseptic / antifungal properties in the world. The oil is active against a wide range of bacteria, such as *Escherichia coli, Propioibacterium acnes, Proteus vulgaris, Pseudomonas aeruginosa, Staphylococcus aureus, Proteus mirabilis, Salmonella typhimurium, Streptococcus pyogenes, Helicobacter pylori,* etc. Its oil also has gained widespread therapeutic use for fungal and microbial infections but is not yet registered for use by the medical profession and its novel medicinal activity is yet to be explored on textile substrates.

2.7 Eucalyptus Oil

Eucalyptus (*Eucalyptus radiate*) has terrific cleansing properties. Eucalyptus oil has been shown to fight against infection causing bacteria, fungi, and virus very effectively. It is powerful in helping our psoriasis and also it is natural and complements the skin. The sol–gel immobilization and controlled release of eucalyptol from modified silica coatings were investigated in order to evaluate the suitability of functionalized textiles for the following application in skin-friendly textiles with antimicrobial and antiallergic effects[73]. Although it is added into much commercial soap today, its application on textile substrates is also yet to be explored.

2.8 Azuki Beans

The water extracts of green, black and red colored Azuki beans (*Vigna angularis*) show antibacterial effects against *Staphylococcus aureus*, *Aeromonas hydrophila* and *Vibrio parahaemolyticus*[74]. In contrast, the extract of white Azuki beans shows no inhibition towards any of the microorganisms examined. The extracts of colored Azuki beans contain large amounts of polyphenols including proanthocyanidins than the extracts of white azuki beans. Hori *et al.*[74] showed that the counts of *S. aureus* cells, inoculated in the medium containing the extracts of colored Azuki beans were significantly reduced in comparison with those of control and white Azuki beans after 24 h. These results suggest that polyphenols including proanthocyanidins in colored Azuki beans may be responsible for their antibacterial activity. This antimicrobial activity of Azuki beans can also be explored on textile materials as well.

2.9 Prickly Chaff Flower

Prickly chaff flower (*Achysanthus aspera*) is one of the Ayurvedic herbs found all over India. Thilagavathi *et al.*[75] showed the antimicrobial activity of prickly chaff flower against both the Gram positive and Gram negative bacteria, but its level of activity was found to be lower than that of neem oil. The antibacterial activity of prickly chaff flower treated cotton fabric was tested by parallel streak method for Gram negative bacteria (*E. coli*). The treated fabric showed mild antibacterial activity[75].

2.10 Tulsi Leaves

Tulsi (*Osmium basilicum*) belonging to Labiatae family consists of the leaves of *Ocimum sanctum* Linn. The main constituents of tulsi are eugenol (70%), methyl eugenol (20%), carvacrol (3%), caryophylin, etc. From the very ancient age, tulsi leaves are used as antimicrobial, insecticidal, antiprotozoal, diaphoretic and expectorant and also as aromatic carminative. Thilagavathi *et al.*[75] observed that tulsi leaves having antimicrobial activity are suitable for textile application. Methanolic extracts of tulsi leaves were applied on cotton fabric by dipping method. In their preliminary study, although tulsi did not show any activity, it exhibited a bacterial reduction of 73% in challenge test. The bacteria-resist properties of tulsi oil have also been studied by Sarkar *et al*.[76] The oil was added to the size paste as size preservative for application on cotton yarn in lea form but it did not produce any encouraging results after storage of the sized leaves from the strength retention point of view.

2.11 Clove Oil

Clove oil (eugenol) is a main product of *Syzygium aromaticum*. Bioactivity of clove oil was explored in size paste as size preservative as well as finishing agent for cotton textiles to make it antibacterial. The wash fastness of the finished fabric was improved by using dimethylol dihydroxyethylene urea based in-built catalyst (KVSI)[76]. In a study, Sarkar *et al*.[76] showed that clove oil with 0.5% conc. shows 17 mm of zone of inhibition using *Staphylococcus aureus* and *Klebsiella pneumonia,* whereas cotton fabric treated with 1% clove oil (along with KVSI) shows 47 mm (Table 3) zone of inhibition against *Staphylococcus aureus* (Gram positive) bacteria.

2.12 Onion Skin and Pulp Extracts

Onions (*Allium cepa*), member of the Lilliaceae family, are found in a bewildering array of recipes and preparations. Chen and Chang[77] studied the antimicrobial property of onion-treated cotton fabric. In their study, the oxygen plasma treated cotton fabrics were grafted for different durations at 70°C with onion pulp extracts. The zone of inhibition against *Staphylococcus aureus* bacteria was 1.1–0.8 cm by 10 min grafting time of onion skin extraction and 0.7–0.5 cm by 30 min grafting time of onion pulp extraction.

2.13 Other Herbal Products

Turmeric or cumin, a yellow florescent pigment extracted from rhizomes of several species, has been used as a colorant for dyeing of wool, silk and unmordanted cotton. The turmeric also imparts antimicrobial property because of its bactericidal activity. A recent study has been reported[78] on the application of hiba oil (cypress oil) as an antimicrobial agent for textiles. The authors have developed an analytical method for investigating the hiba oil content of the commercially available textiles using thujopsene (the main component of hiba oil) as an index with the help of gas chromatography / mass spectroscopy (GC/MS). The antimicrobial activity of other plant extracts, such as pepper (allyl thiocyanate AITC), evening primrose and perilla oil, has also been explored for textile applications[73,74]. Some of the other important natural products, such as karanga oil[79], cashew shell oil[80], henna or mehndi[81], and *Moringa oleifera* (drumstick tree)[82], can also be explored on textile substrates for antibacterial property which will have tremendous applications in apparels and medical textiles.

3 Present Perspective and Major Challenges

Although a lot of research work has been started in the exploration of antimicrobial activity of natural products on textiles substrates, several issues are there which need to be discussed. The plant natural products are complexed in their chemical structure and all the components do not possess the antibacterial activity. Thus, the selective isolation of the bioactive ingredients is a major path of reducing dose of the agents. The desirable synergistic antibiotic combination of the major components possessing a

Table 3 — Antimicrobial activity of finished fabric treated with clove oil against *S. aureus*

Fabric	Conc. of KVSI gpl/clove oil, %	Zone of inhibition, mm
Control	-	Profuse growth of bacteria in and around the fabric
KVSI treated	100 gpl	Nil
Clove oil treated	0.25%	Nil
Clove oil treated	0.5%	17
Clove oil + KVSI treated	0.5%	Very small zone
Clove oil + KVSI treated	1.0%	47

broad spectrum inhibitory activity is also to be looked in. The mechanism of bactericidal action of the different natural antimicrobial agents is still unknown. The dissolution of the agents for textile application is also a major challenge because most of the products are not soluble in water. The attachment of the bioactive substances to the different types of complex textile substrates for longer durability of the antimicrobial activity is also a new avenue of research. Although a little research has been done for the development of natural agents encapsulated products (such as microencapsulated neem oil), the design of bioactive textiles with slow release mechanism for longer activity will be a good area of innovations in the world of biotextiles. Some natural products have very stringent and bitter smell which may cause mental illness of the wearer is also to be considered before putting those substances onto textile substrates. The physical and other performance properties of the treated textiles also need to be unaltered too much during making it antibacterial. For example, air permeability of the fabric which ultimately affects the comfort of the wearers is reduced after coating the textile surface with chitosan and so on. The antimicrobial finishing should not alter the other important functional and physical properties, such as bending rigidity and bending modulus which directly affect the fabric stiffness and drape characteristics. The blocking of the active functional groups (which may be responsible for their antimicrobial activity) during their textile attachment may also loose their bioactivity on textile substrates.

To address all these issues, more and more research should be done in the field of bioactive textiles made from natural products to make it viable alternative to synthetic product based antimicrobial textiles and to utilize natural products as an effective antiodor for use in sports and household textiles and also as a noble biocidal material in the field of medical textiles.

4 Conclusions

There is a vast resource of natural antimicrobial agents, which can be used for imparting useful antimicrobial property to textile substrates. Although, there are many cited literature, wherein efforts have been made to exploit these ecofriendly bioactive natural products for textile application, but there are very few studies which have carried out systematic in-depth investigation. The major challenges in application of natural products for textile application are that most of these biomaterials are complex mixtures of several compounds and also the composition varies in different species of the same plant. The activity and composition also vary, depending on their geographical location, age and method of extraction. The availability of these products in bulk quantities, their extraction, isolation and purification to get standardized products are other challenges in their application. The durability, shelf life and antimicrobial efficiency vis a vis synthetic agents are other issues, which need to be looked into. However, because of their ecofriendly nature and non-toxic properties, they are still promising candidates for niche applications such as medical and health care textiles.

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