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Antimicrobial Properties of Herbal Dyes of Indian Medicinal Plants

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Review
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ABSTRACT
Antimicrobial properties are gaining popularity and getting more attention in the textile industry. Also, the demand for antimicrobial products has increased significantly in the market because consumers are demanding fresh and clean clothes. Various chemical agents are used in industries to give an antimicrobial finish to textiles. These chemicals are long-lasting and highly effective against various bacteria, microbes and fungi, but those chemicals are harmful to the environment. Therefore, much of the research has been conducted on medicinal plant-based antimicrobial agents. Natural antimicrobial compounds have less harmful impacts on living beings and are also more environmentally friendly. Various medicinal plants that contain antimicrobial compounds are present and these plants are used as home medicines for various diseases. Such plants are neem (Azadirachta indica), basil (Ocimum basilicum), pomegranate (Punica granatum), Arjun tree (Terminalia arjuna), sage plant (Salvia officinalis) etc. This study is conducted systematically by considering only evergreen herbal medicinal plants of the Indian subcontinent. Medicinal plants were utilized to impart antimicrobial properties to textiles and to develop various products.

KEYWORDS
antimicrobial, medicinal plants, textile, environment, bacteria

INTRODUCTION

The role of textiles is most crucial in the daily life of people as they are in contact with humans round the clock. People use different kinds of textiles, including evening casual wear, interior furnishing, daywear, work wear, kitchenware, night dress, etc. Thus, textiles are utilized in some form or the other, either as clothing or some other form of textiles very close to the human body. Since the textile plays a vital role in connecting with the human body, it must have a few functional compliances focusing on health and comfort features, which are paramount as they are the most needed [1]. The textile industries are gradually focusing attention on environmental preservation and lowering carbon emissions. Researchers, as well, have discovered great charm and potential in the use of natural dyes. The dyeing process in which the textile products are readily dyed with both natural and synthetic dyes is considered one of the main environmental pollution processes, as it involves the excessive use of synthetic dyes [2]. Nowadays, some of aesthetic and functional values are also added in textiles with

dyeing, for instance antimicrobial finish, UV protection, waterproof finishes, antistatic finish, flame retardant finish, lustre, texture, durability and hand and surface appearance etc.

This review paper focuses on the developing area of antimicrobial textile finishes made from plant extracts. Antimicrobial finishes are applied to textiles by natural and synthetic agents.

LITERATURE REVIEW

The first antimicrobial fabric that Lister produced in modern history was developed in 1867, but the use of natural antimicrobial constituents on textiles dates to ancient times, when ancient Egyptians utilized herbs and spices to protect mummy wraps. Herbs were utilized to prevent the flourish of microbes on textiles. Interest in antimicrobial finishes on textile has increased over the past few years.

India is known as the centre of natural herbs. Textile products can be readily colonized by a large number of *bacteria* or even decomposed by them. The different kinds of microorganisms comprise various types of organisms, like unicellular animals and *plants*, viruses, certain algae and *fungi*, *bacteria,* which can lessen the strength of the textile and cause damage, discoloration, staining and also skin ailments. Natural textile products have cellulose and protein fibre, they promote *bacteria* and also provide the basic environment for the growth of *bacteria,* such as nutrients, temperature, oxygen, and moisture [3,4]. The taxonomy in the *bacterial* family is *Gram negative* and *Gram positive*, non-spore carrying or spore bearing class. Some kinds of *bacteria* are pathogenic in nature, which can cause infection in human beings. *Gram-positive bacteria* consist of teichoic and peptidoglycan acid; peptidoglycan acid is composed of amino acids and sugar and they make 90% of the peptidoglycan acid cell wall. *Staphylococcus aureus* is the leading cause of infection in hospitals. It also causes skin infections and abscess. *Gram-negative bacteria* are mostly similar to *Gram-positive bacteria*, except for an outer layer of membrane bound to peptidoglycan by lipoproteins that are used to carry substances of very low molecular weight. *Escherichia coli (E. coli)* is a type of *Gram-negative bacteria*. *E. coli* can be spread when eating or using raw foods. Symptoms of *E. coli* infection result in kidney destruction and rigorous diarrhoea (mostly in children) [5]. Nowadays, antimicrobial finishes of textiles are based on synthetic agents but current senior consumers are demanding an eco-friendly product. Synthetic antimicrobial finishes are applied to textiles and have a high impact on the development of *microorganisms* but these agents also have a very harmful effect on our earth and the health of human beings.

There is a lot of scientific research going on for the development of long-lasting antimicrobial agents. Synthetic agents are highly effective in providing protection against a vast range of microorganisms. Synthetic agents are long lasting and have no effect after multiple laundry treatments, such as washing

and bleaching. Yet, they can cause water pollution and also kill off desirable *microbes*. This has created a need for research into natural antimicrobial textile finishes made from essential oils, plant extracts, and many more [6]. Some natural *plants* have antimicrobial properties and treating the fabric with these natural agents gives good results. So many natural *plants* are used in Ayurveda as medicine for different diseases, like cold, cough and a runny nose. They are also used for some serious diseases, like various cancers and tuberculosis among many others. In the last few years, attention has been paid to the use of natural *plants* for dyeing and finishing of fabrics because excessive use of synthetic agents is very harmful to the environment and all living beings. In addition, consumers are also aware of sustainable products. Antimicrobial finishing plays an important role in medical textile; however, finishing is not limited to medical textiles. Nowadays, antimicrobial finish is used on many textile products. According to the environment some antimicrobial *plants* are available near the house. *Plants* from North India, for instance neem, tulsi, rishi, aloe vera, giloy, arjun tree and curry leaves, among many others, are easily available and people use them as home medicine.

NATURAL ANTIMICROBIAL PLANTS

For many thousands of years, medicinal plants have played an important role in life. In many *plants*, natural chemical compounds are abundantly available, which is scientifically proven. Some compounds play significant roles in antimicrobial activities [7].

Using herbal *plants* can improve antimicrobial properties of textile products, and the fabric can be dyed. These *plants* are highly effective against many *bacteria* like Gram-positive and Gram-negative *bacteria*, *fungi*. Natural agents are never harmful to all living beings. Many types of research have also been done on the antimicrobial properties of different *plants* on different fabrics (cotton, silk, linen, rayon, nylon, wool) and found positive results.

Neem (*Azadirachta indica*)

The neem (*Azadirachta indica*) tree belongs to the Meliaceae family that grows naturally in regions of Asia, particularly in every part of Indian subcontinent in both subtropical and tropical regions. Homeopathic practices, such as Ayurveda and Unani, highly utilize neem *plants* as a medicine. Neem contains more than 140 bioactive compounds which are used for different applications since they provide different pesticidal properties [8]. Neem tree seeds are made up of 40% of oil with azadirachtin (the most active compound) as the common active ingredient. Neem seeds and oil are utilized as natural fertilizers in agriculture practices and the leaves are used to store grains due to their insect-repellent properties; these methods have been employed for centuries [9]. Moreover, the medicinal properties of neem plant have been known for a long time. Azadirachtin is the most important active ingredient in the neem plant and contains other compounds, such as sodium nimbinate, nimbin,

nimbolin, nimbidol, gedunin and solanine, whereas neem leaves contain compounds like nimbolide, 7-deacetyl-7-benzoylazadiradione, 17-hydroxyazadiradione, amino acids, nimbandol and nimbolide. Fresh neem leaves contain polyphenolic flavonoids, sitosterol and quercetin compounds, which have antibacterial and antifungal properties [10]. Ethanolic and aqueous extracts of neem (*Azadirachta indica*) show activity against microbes like *Staphylococcus aureus, Candida albicans, Aspergillus fumigatus* and *Microsporum canis,* by the disc diffusion technique. Much of the research has already been done on the antimicrobial properties of neem and it was shown that neem has a positive effect on antimicrobial properties of various fabrics [11]. Abd al-Ati et al. have done a research on antimicrobial properties of neem leaves on silk cloth. They conducted it on a white, 100%-silk cloth and dried neem leaves. The dye was extracted from the leaves by boiling. The silk fabric was dyed with different dye bath concentrations (40, 80, 120, 160, 200 and 240 g/l) using a liqueur ratio of 1:50 for 45 minutes at pH 5 and the temperature of 60 ^{0}C for each concentration. After that, the cloth was dyed in neem leaf solution. Then, the antimicrobial activity of the fabric was tested and the results showed that the silk fabric had strong antimicrobial activity against *Gram-positive bacteria (S. aureus, L. cereus and B. subtilis)*. According to the results, the dye inhibits the growth of *bacteria* when the concentration is increased [12].

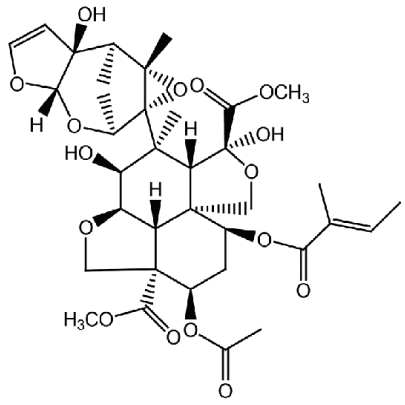

Figure 1. Chemical structure of azadirachtin [55]

Basil (*Ocimum basilicum*)

The scientific name of basil is *Ocimum basilicum*. Basil is cultivated for traditional medicinal and religious purposes. Basil is an annual and perennial *plant* grown in Asia, India (cultivated throughout) and Africa. *Ocimum tenuiflorum* contains some phytochemical agents like eugenol, rosmarinic acid and oleanolic acid [8]. *Ocimum basilicum* plant belongs to the Labiatae (Lamiaceae) family and Ocimum genus, and it is one of the oldest spices [13]. Indian traditional medicine has been using the Tulsi plant for various ailments (like feverish illnesses, abdominal cramps) for thousands of years [14]. *Ocimum basilicum* L. (basil), one of the very common and often utilized culinary herbs, contains phenolic acid

and aromatic compounds which play an important role in affecting the antimicrobial activities and are strong antioxidants. Basil leaves and stems contain a variety of components that may be biologically active, including tannins, saponins, triterpenoids, and flavonoids. In addition, the following phenolic actives were found to have anti-inflammatory and antioxidant properties: propanoic acid, rosmarinic acid, apigenin, cersimaritin, isothymucine and isothymonine. Orientin and visenin are both water-soluble flavonoids that have been shown to provide protection against radiation-induced chromosomal loss in human blood lymphocytes [15]. Moghaddam et al. conducted research into antimicrobial properties of basil oil against *Gram-positive (Staphylococcus aureus)* and *Gram-negative (Escherichia coli and P. aeruginosa) bacteria*. Basil oil extracted from the stem was used for this study. It was found that basil leaf oil has good antibacterial properties against *bacteria*. Rajendran et al. studied antimicrobial properties of cotton fabrics treated with basil leaves. The solution was prepared by dissolving dried leaves in water and boiling them for 6 hours at a temperature of 60 to 800 °C. For dyeing, they prepared 4 types of solutions: aqueous, ethanolic, methanolic and petroleum ether solution. The cotton was treated by the pad-dry-cure method. Test results of dyeing clothing with the solution were that methanol extract proved to have the most significant antimicrobial effect on clothing. Other extractions have also shown that they inhibit bacterial growth, but very little. In an investigation studying the AATCC 100 test of extract-coated cotton fabrics, *S. aureus* (98%) inhibition was lower compared to *E. coli* (81%). The minimum inhibitory concentrations of the crude methanol extracts were in the range of 30–80 g/ml [16].

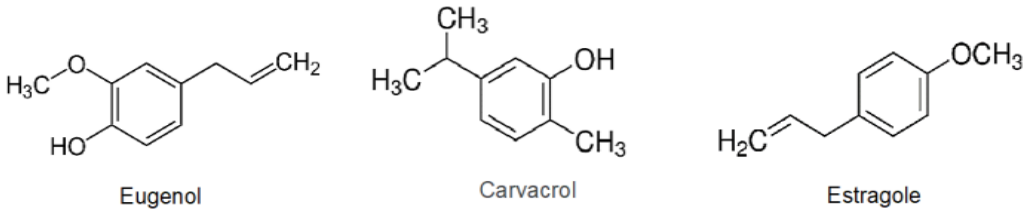

Figure 2. Active chemical compounds of basil [56]

Pomegranate (*Punica granatum*)

Punica granatum (pomegranate) belongs to the Punicaceae family. Pomegranate is the most commonly consumed fruit in many countries around the world [17]. In India, pomegranate is grown on a commercial scale in Maharashtra and is also seen in Karnataka, Haryana, Andhra Pradesh, Gujarat, Rajasthan, Punjab Uttar Pradesh, and Tamil Nadu. *Punica granatum* peel has many biological functions that inhibit numerous diseases and also has a good effect on antimicrobial activities on textiles. *Punica granatum* peel is reported as an antimicrobial agent containing a valuable amount of tannins, about 19%, and phenolic compounds with peltierin. So, fabric dyed with the peel of *Punica*

granatum has improved antibacterial and anti-allergic properties [18]. Pomegranates are rich sources of phenolic compounds including anthocyanins (pelargonidin glycosides, delphinidin and cyanidin), phenolic acids (p-coumaric acid, ferulic acid, phlorodizine, rutin, chlorogenic acid, syringic, o-coumaric acid, vanillic and caffeic), flavonoids Huh. (luteolin glycosides, kaempferol and quercetin), and ellagitannins (ellagitannin, gallotanin, punicalin, galagic acid, pedunculagin, punicaguin and ellagic acid) [19]. Antimicrobial properties of *Punica granatum* seeds are effective against the *common bacteria, Escherichia coli, Saccharomyces cerevisiae and Bacillus subtilis*. The leaves and bracts of that tree are good sources of ellagitannin and gallotanin, and the presence of flavonoids, tannins, and anthocyanins in the pomegranate peel is also notable [20]. Shahid et al. conducted an experiment on pomegranate rind to determine whether it confers enough antimicrobial activity to woollen fabric in order for it to be developed into antimicrobial textile. Pomegranate peel-dyed wool and mordanting with various metallic salts (potash alum, ferrous sulfate, stannous chloride) is effective against various *bacteria,* like *C. albicans, S. aureus* and *E. coli*. The comparative result of all mordants is that $SnCL_2$ is highly effective against *bacteria* but less effective against $FeSO_4$ *bacteria*. Dye protectionis also effective against *bacteria, with* 12% dye protection, 89.8- 93.1% reduction in *E. coli,* 87.7–96.7% reduction in *S. aureus*, and 91.8–98.2% reduction in *C. albicans*. Antimicrobial properties were reduced after 10 to 15 washes [21]. Lee et al. conducted a study on the improvement of antimicrobial properties of cotton dyed with pomegranate peel. The dye was extracted by two methods, consisting of aqueous and ethanolic solutions and mordanting the fabric with alum and copper sulphate. 10 gm of peel powder was used. After testing the fabric, the result was that the ethanolic solution was resistant to the *bacteria S. aureus* and *E. coli*, with good antimicrobial properties against *Klebsiella pneumoniae* and *Staphylococcus aureus*, germs that grow rapidly on cloth. Antimicrobial activities were reduced to zero after 10 washes [22].

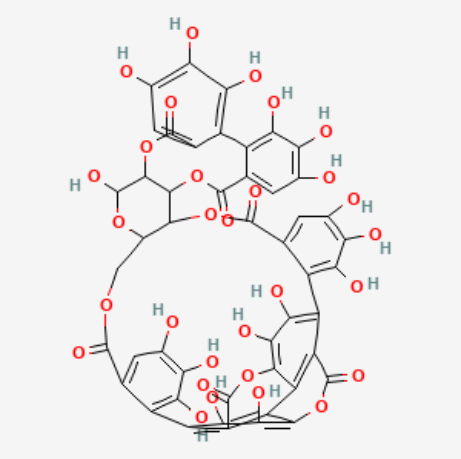

Figure 3. Punicalagin – the active compound of *Punica granatum* [57]

Turmeric (*Curcuma longa*)

The scientific name of turmeric is *Curcuma longa* and it belongs to the Zingiber Cease family. It is commonly known by the name of turmeric. *Curcuma longa* grows in various parts of India and is mostly grown in the western and southern part of India. Turmeric is the most prevalent dietary complement in the world. According to Ayurvedic medicine, *Curcuma longa* can be used as a cure for respiratory problems. It is also good for cough, sinusitis, liver disorders and many other ailments. Medicinal characteristics of turmeric include antimicrobial, insecticidal, antioxidant, antiviral, anti-malarial and antifungal properties [23,24]. Moreover, 326 biological activities of turmeric are identified. Three of the constituents that are widely researched in turmeric are gold-coloured alkaloids curcuminoids, bisdemethoxycurcumin, curcumin, and desmethoxycurcumin. Some other compounds are named as curlone, Phenolic, β-turmerone, α-turmerone, α-phellandrene, labda-8 (17)-diene-15, 16-dial, curcumadiol, terpinolene and three acidic polysaccharides [25].Turmeric is the most prevalent dietary complement in the world [26,27]. Yadav M. dyed 100% pure wool fabric with natural dyes containing raw turmeric root and madder dye powder. The wool fabric was treated with hydrogen peroxide. After oxidation the cloth was treated with chitosan mordant and after that the cloth was dyed with turmeric. The dye concentration had three levels, 3%, 6%, and 9%, and the fabric was dyed in different durations, temperatures and chitosan concentrations. They tested the antimicrobial properties of both fabrics by AATCC 100. High antimicrobial activity was achieved with chitosan mordant fabric. Fabrics treated with chitosan mordant 9% concentration, dyed with turmeric dye concentration 99.8% and madder dye 99.6%, tested wool fabrics found antimicrobial properties of wool fabrics against common bacteria. (*E. coli* and *S. aureus*) [28].

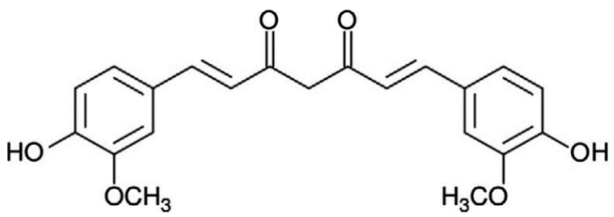

Figure 4. Chemical structure of curcumin [58]

Lemon plant (*Citrus limon*)

The scientific name of lemon is *Citrus limon* and it belongs to the Rutaceae family. Lemon *plants* are mostly found in Southeast Asia, Northeast India (Andhra Pradesh, Maharashtra, Gujarat, Tamil Nadu and Bihar) and Southern China. Since the ancient period, lemon was mostly used in homes as a medicine for various diseases. All parts of the lemon plant, such as the fruit, leaf, flower, branch and

roots have the ability to act against the microbial activity. Moreover, alkaloid compounds that play an important role in the treatment of cancer have been found in lemons. Methanolic compounds are extracted from the peel of the fruit and ethanolic compounds are extracted from the leaf of the plant, these components have good antimicrobial properties against *bacteria* and *fungi*. Research by Paw et al. discovered 43 compounds in lemon, identifying high concentrations of limonene and neral. Some of the other compounds are decanal, ethyl cinnamate, ethyl-methoxycinnamate, cis-α-bergamotene, geraniol, trans-carveol, nonanal, linalool, αterpineol, p-mentha-2,8-dien-1-ol, estragole, α-fenchene, perilol, β-curcumene, trans-limonene oxide, 1-naphthalenamine, camphor, 3-carene, β-sentalin, β-sesquiflandrene, α-pinene, terpinen-4-ol, 3-terpinolone, ziazine, germacrine-D, α-bisabolol, β-bisabolol, methyl N-hexadecanoate, citronellal, o-cymene and many more [29]. Vankar and Shukla researched the antimicrobial properties of lemon leaves from the biosynthesis of silver nanoparticles. In this project, they took pre-washed cotton and silk fabrics. After treating the fabric, the results showed that using lemon leaves increased the antifungal activity of silk and cotton fabrics [30]. Rosida et al. did research in which they dyed 100%-cotton fabrics with pomegranate and lemon peel powders. The peel powder was mixed with a 70% acetone-water solvent to form a dye solution. The fabric was dyed by the dip coating method to have an antibacterial finish. After that the dyed fabric was tested in accordance with AATCC 147 for antimicrobial activity against various bacteria. It was found that both plants are highly effective against S. pyogenes, L. fuformis and S. aureus. The concentration of the dye was 60 mg/l, which is highly effective against bacteria. Bacterial properties were inhibited after 6 washes of clothes.

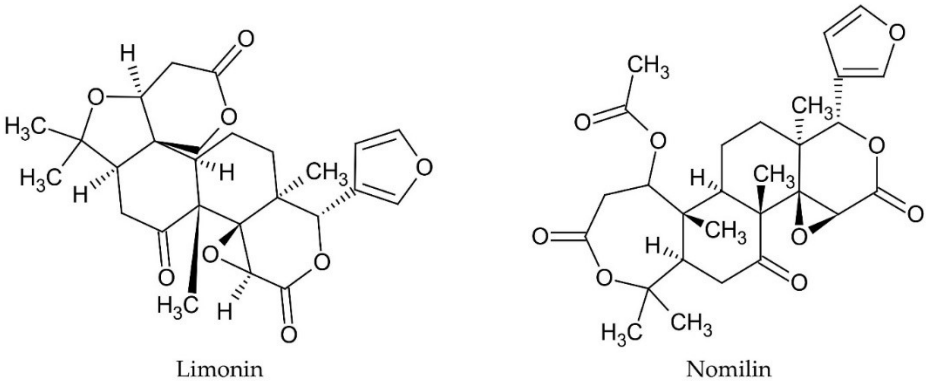

Figure 5. Chemical structure of lemon plant compounds (limonin and nomilin) [59]

Arjun tree (*Terminalia arjuna*)

The scientific name of the Arjuna or Arjun tree is *Terminalia arjuna* and it belongs to the *plants* of the family Combretaceae. The Arjuna tree is found across the Indian Subcontinent and also is found in high numbers in southern India (the Deccan regions) and the north-eastern part (Himalayas). The Arjuna tree has been described as a vital cardiotonic plant in earlier Indian medical sciences (Ayurveda)

[31,32]. People have been using the seeds, leaves, bark, root and fruit of the arjuna tree as herbal medicine because it contains substances that fight many diseases, with inotropic, anti-ischemic and antioxidant blood pressure-lowering, hypolipidemic and antihypertrophic properties, among others. Apart from this, *Terminalia arjuna* is very effective against various diseases. Apart from this, the Arjuna tree is also effective against various types of cancer, such as head cancer, breast cancer, lung cancer. In addition, major chemicals contained in Arjuna tree include triterpenoids, ester glycosides, flavonoids, β-sitosterol minerals, tannins, triterpenoids, oxalic acid, glycosides, alkaloids, steroids, inorganic acid and cardenolide, which are highly effective against *bacteria*. *Terminalia arjuna* is very effective against various diseases [33]. Rather et al. conducted a study on the Arjuna tree. In this, they took 100% pure New Zealand semi-worsted wool yarn, powdered Arjuna tree leaves and chemical mordants (ferrous sulfate, stannous chloride, potash alum, magnesium sulfate). After dyeing the woollen threads, they were tested. The dye concentration was 5 mg/ml and 10 mg/ml and acidity was maintained at 3.5 pH. The yarns were dyed in different durations, for 50, 70 and 180 minutes. The result was that the antibacterial property of the fabric increased against *Gram positive* and *Gram-negative bacteria*. The percentage of activity against *bacteria* also increased according to the concentration of the dye. Antimicrobial activity of woollen yarns was decreased when chemical mordants were utilized in the dye. Wash cycles for yarns were 0, 5, 10, 15 and 20 times. After washing the unmordanted samples 20 times the reduction of *S. Aureus bacteria* was 67.76%, *Pseudomonas aeruginosa* 13.11%, *E.coli* 16.53%, and *Bacillus subtilis* 64% [34]. There still has not been much research on the antimicrobial properties of the Arjuna tree.

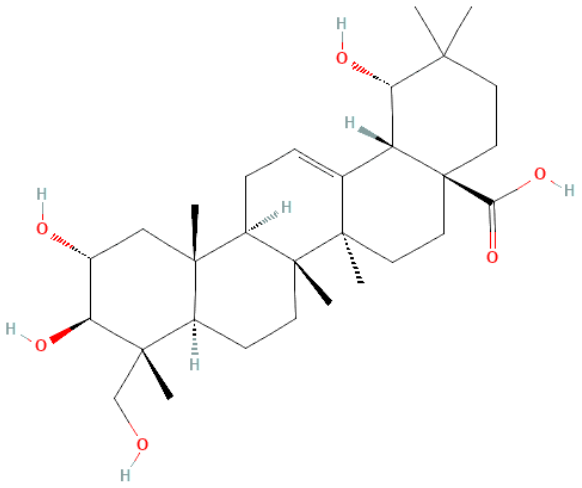

Figure 6. Chemical structure of Arjungenin [60]

Sage (*Salvia officinalis*)

The scientific name of the sage plant is *Salvia officinalis* and it belongs to the Lamiaceae family. Sage *plants* are mostly found in Europe, Central and Southeast Asia, South America or around the

Mediterranean Sea but, nowadays, these *plants* are found all over the world [35]. In India, the sage plant is mostly found in the western part of India. *Salvia officinalis* is used as a traditional medical treatment for various ailments, such as cough, dyspepsia, various neuralgias, dermatitis, age-related cognitive disorders, excessive sweating and is also used for insect bites. In addition, sage has uses in cosmetic products, such as hair care and skin care products [36,37]. A large number of bioactive compounds were detected by phytochemical investigations of sage, the most important of which are essential polyphenols and oil compounds. The major bioactive compounds of *Salvia officinalis* are thujone, (E)-β-caryophyllene, 1,8-cineole, α-humulene, β-pinene, β-thujone, camphor, aloe-aromadendrin, borneol, and α-pinene [38]. Also, *Salvia officinalis* (Sage) is a rich source of flavonoids, phenolic and triterpenoid acid compounds and is also known for its good antimicrobial properties [39,40]. Researchers researched the antimicrobial properties of sage, the plant, on 100%-cotton fabrics treated with chamomile, sage, and green tea. The dye was extracted from powder using the aqueous and methanol method. They took 10 grams of powder of these plants to dye the cloth. After dyeing the fabric, the fabric was tested according to standard forms. The result was that the sage plant contained *Gram-positive bacteria* such as *E. coli, S. aureus* and *unicellular fungi* and *Gram-negative bacteria* were less effective. Its antimicrobial properties were diminishing after each wash [41]. Khosroabadi et al. did research on antimicrobial activity of the sage plant. In this experiment, they took a polyester fabric, and treated it with a hydrogel mixture of silk. Simultaneously, the sage powder was mixed with ethanol, which was kept under ultrasonic vibration for 20 minutes. After treating the polyester fabric with sage solution, the samples were examined. The result was that after treatment with sage leaves, the polyester fabric showed good antimicrobial properties against both the common *bacteria E. coli* and *S. aureus* [42].

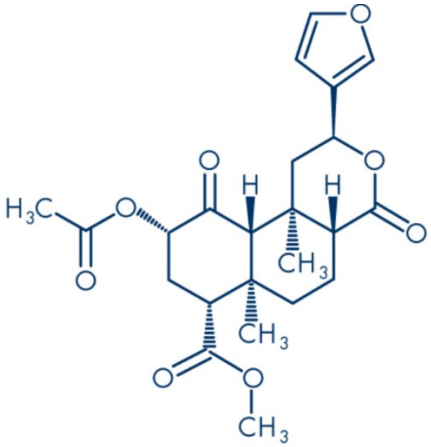

Figure 7. Chemical structure of salvinorin [61]

Henna (*Lawsonia inermis*)

The scientific name of Henna is *Lawsonia inermis* and it belongs to the *plants* of Lithraceae family [43]. Henna *plants* are found throughout Asia, north-east Africa, northern Australia and the Arabian Peninsula. In India, *Lawsonia inermis* plant is mainly found in Gujarat, Madhya Pradesh, Rajasthan, Haryana and Punjab. *Lawsonia inermis* is a natural source for dyes and is commonly used by people all over the world to dye skin or hair [44]. In addition, it is also used in the medical field to treat burns, wounds, skin infections and ulcers due to its anti-inflammatory and antibacterial properties [45]. Henna (*Lawsonia inermis*) contains flavonoids, saponins, carbohydrates, proteins, alkaloids, phenolics, terpenoids, coumarins, xanthones, quinones, tannins, fat and tannins. *Lawsonia inermis* also contains lawsone (4-naphthoquinone), and 2-hydroxy-1. In addition, the leaves yield compounds 1,2-dihydroxy-4-glucosylnaphthalene, 1,3-dihydroxy naphthalene, 4-naphthaquinone, and 2,4-trihydroxynaphthalene-2-O-beta-D-glucopyranoside. A variety of phenolics, flavonoids, naphthoquinone derivatives and alkaloids are extracted from different parts of henna, which play a significant role in inhibiting the growth of *bacteria*. These antimicrobial compounds are isolated from various parts of the henna plant, such as seeds, fruits, leaves, roots, stem, bark and flowers [46,47]. Bhuyan et al. conducted research on the antimicrobial properties of the henna dye. For this, they took the powder of henna leaves, chitosan and 100%-jute cloth. The fabric was first treated with chitosan and then dyed with the henna dye. The result was that the fabric treated with chitosan exhibited antimicrobial activity against both *bacteria*; on the other hand, jute fabric that was not treated with chitosan was also highly effective against *S. aureus bacteria* [48]. Maqbool et al. conducted research on 100%-cotton fabric to investigate the antimicrobial properties of various *plants.* For this, they took rosemary leaves, turmeric rhizome, kikar bark, Tasmanian blue gum, pomegranate peel, onion peel and marigold flowers to make a powder for dyeing clothes. The dye extraction method was 0.3 M NaOH. The result was that all *plants* had antimicrobial activity against both *gram-negative* and *gram-positive bacteria*. Also, henna equally inhibits the growth of both *bacteria* [49]. Henna was mostly used to dye different fabrics, while little work has been done on its ultimate antimicrobial properties.

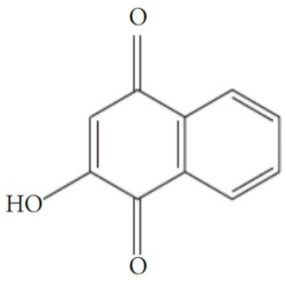

Figure 8. Chemical structure of *Lawsonia inermis* [62]

Babul tree (*Vachellia nilotica*)

The scientific name of the acacia (babul) tree is *Vachellia nilotica* and it is a member of the Fabaceae family. It is also known as Arabic gum tree. The *Vachellia nilotica* tree is found in various subtropical and tropical countries. Babul tree is easily found in Africa and throughout India sub-continent, Pakistan and Australia. The acacia tree can be used for a variety of purposes. The pods of the acacia (babul) tree are used by African regions for leather tanning and are also a source of dye. The acacia tree also has medicinal properties. It is a laxative, astringent and beneficial for many diseases, like neuralgia. The leaves of the tree are used to treat wound ulcers, eye and sore throat diseases [50]. *Vachellia nilotica* has anti-malarial, anti-fungal and anti-bacterial properties. Condensed tannins, flavonoids and hydrolysable tannins contain anti-bacterial compounds. Acacia species contain compounds such as cyanogenic glycosides, alkaloids and amines, seed oils, fatty acids and cyclitol, amino acids, fluoroacetates, nonproteins, gums, terpenes, condensed tannins, flavonoids and hydrolysable tannins, diester, pentacosan dioic acid, dihexaic acid, esters, ellagic acid and leucocyanidins. Gulzar and others did research on dyeing cotton cloth with the bark of the babul tree. They dyed cotton fabric with different pH balance, temperature and dye concentrations. They got brown colour from the bark [51]. So much of the research has been done on the acacia tree in various fields, like the food, pharmacy, and textile sector. Many of these researchers have found good antimicrobial properties against various *bacteria* (*gram positive and gram negative*) and *fungi*.

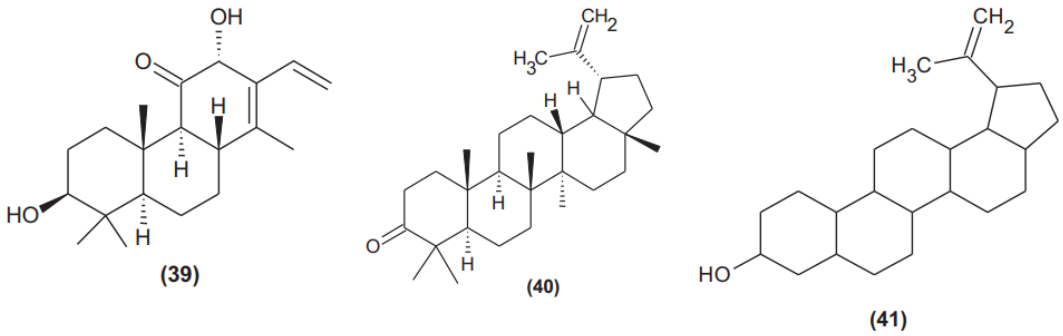

Figure 9. Chemical structure of (39) terpenes, (40) niloticance, (41) lupenone [63]

Giloy (*Tinospora cordifolia*)

Giloy (*Tinospora cordifolia*) is a member of the Menispermaceae family. *Tinospora cordifolia* is also known as guduchi, giloy, heart leaved moonseed, gurch and amrita. In India, this plant is known as giloy. Giloy is a plant native to India (throughout tropical regions of India), although it is also found in tropical regions of China, Australia and Africa. Giloy has been used as a medicine since ancient times. *Tinospora cordifolia*'s leaves, roots, fruits, and stem are used to manufacture anticancer, anti-leprotic,

anti-hyperglycaemia, anti-allergic, and anti-diabetic medications, and it also enhances the immune system. Giloy is now used in the manufacture of a variety of food and cosmetic items, such as face packs and juices. *Tinospora cordifolia* has antibacterial properties that are effective against a variety of microorganisms [52]. The highly active compounds against the *bacteria* of Giloy are alkaloids, terpenoids, lignans and steroids. Various compounds that are available in giloy are tembetarine, magnoflorine, tetrahydropalmatine, isocolumbin, palmatine, cordioside, cordifolioside A, cordifolioside B, furanolactone, diepoxy-cleroda-13 (16), 14-dieno-17, jateorine, columbin, octacosanol, heptacosanol, tinosporidine, cordifol, cordifelone, giloin, giloinin, tinosporic acid etc [53]. According to Selvam et al., the giloy leaf extract has low antimicrobial properties against *E. coli* and *S. coli* compared to the AgNPs, but a lot of research has been done by many researchers on the antimicrobial properties of *Tinospora cordifolia,* and they have found good antimicrobial agents against the *pathogenic* and *non-pathogenic* organisms [54].

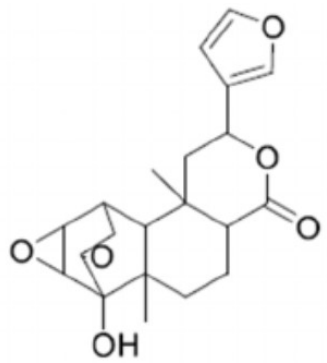

Figure 10. Giloy - chemical structure of tinosporide [64]

SIDE EFFECTS OF NATURAL DYES

Natural colours are not harmful but some plants are harmful for us, like logwood. Logwood contains ingredients called hematin and hematoxylin, which can cause harmful effects if inhaled, swallowed, or absorbed through the skin. We need moderating on natural colours. Different chemical agents used for mordanting are harmful for us and the environment. Some mordants that are mostly used for cooking more natural dyes are aluminium, copper, iron and chrome. Plants, fruits, barks, stems, minerals and herbs are also used to make clothing with anti-bacterial, anti-inflammatory and anti-allergic fabrics. However, it is difficult to obtain good colour fastness properties and obtain all desired shades [65].

Table 1. Uses and antibacterial activities of natural plants

Natural Plants	Home Remedy For Ailments	Properties Of Plants	Antibacterial Compounds	Results
Neem (*Azadirachta indica*)	Leprosy, Eye Disorders, Bloody Nose, Intestinal Worms, Stomach Upset, Loss Of Appetite.	Antiulcer, Antimalarial, Immunomodulatory, Anti-Inflammatory, Antioxidant, Antimutagenic, Antibacterial Properties.	Polyphenolic Flavonoids, -Sitosterol And Quercetin Compounds.	The strong antimicrobial activity against *Gram-positive bacteria (S. aureus, L. cereus and B. subtilis).*
Basil (*Ocimum basilicum*)	Stomach Spasms, Loss Of Appetite, Intestinal Gas, Kidney Conditions, Fluid Retention, Head Colds.	Anti-Inflammatory, Antibacterial, Antioxidants, Antibacterial Properties.	Phenolic Acid, Aromatic Compounds, Tannins, Saponins, Triterpenoids, Flavonoids.	The antimicrobial properties against *Gram positive (Streptococcus, Corynebacteria) and negative bacteria (Pseudomonas, Klebsiella, Proteus, Salmonella, Providencia, Escherichia).*
Pomegranate (*Punica granatum*)	Coughs, Urinary Infections, Digestive Disorders, Skin Disorders, Arthritis, Cancer, Osteoarthritis.	Antiatherogenic, Antihypertensive, Antioxidant, Anti-Inflammatory, Antibacterial Properties.	Tannins, phenolic, coumaric acid, ferulic acid, flavonoids.	High antimicrobial activities against the *C. albicans, S. aureus and E. coli., Klebsiella pneumoniae.*
Turmeric (*Curcuma longa*)	Inflammation, Gastritis, Fever, Depression, High Cholesterol, Heart Disease, Diabetes And Hepatic Disorders.	Anti-Inflammatory And Antioxidant, Alzheimer's Disease, Antiviral, Anti-Malarial, Antifungal, Antibacterial Properties.	Alkaloids, β-turmerone, α-turmerone, α-phellandrene, labda-8 (17)-diene-15.	The antimicrobial properties against *Gram positive (Streptococcus, Corynebacteria) and negative bacteria (Providencia, Escherichia, Morganella, Aeromonas, and Citrobacter).*
Lemon plant (*Citrus limon*)	High Blood Pressure, The Common Cold, Irregular Menstruation, Coughs.	Antiatherogenic, Antihypertensive, Antioxidant, Anti-Inflammatory, Antibacterial Properties.	Alkaloid, Methanolic, Ethanolic, Ethyl-methoxycinnamate, Cis-α-bergamotene, geraniol, Trans-carveol, Nonanal, Linalool.	Highly effective against the *S. pyogenes, L. fuformis and S. Aureus bacteria.*

Natural Plants	Home Remedy For Ailments	Properties Of Plants	Antibacterial Compounds	Results
Sage (*Salvia officinalis*)	Seizure, Ulcers, Gout, Rheumatism, Inflammation, Dizziness, Tremor, Paralysis, Diarrhoea, Hyperglycaemia.	Anticancer, Anti-Inflammatory, Antimutagenic, Antidementia, Hypolipidemic, Antibacterial Properties.	Thujone, (E)-β-caryophyllene, 1,8-cineole, α-humulene, β-pinene, β-thujone, Camphor, Aloe-aromadendrin, Borneol, α-pinene.	The strong antibacterial properties against the *B. cereus, Staph aureus and unicellular fungi, Gram-negative (Morganella, Aeromonas, and Citrobacter) bacteria*.
Henna (*Lawsonia inermis*)	Astringent, Anti-haemorrhagic, Intestinal Antineoplastic, Cardio-Inhibitory, Hypotensive, Sedative, Amoebiasis, Headache, Jaundice.	Antioxidant, Antimicrobial, Anticancer, Anti-Inflammatory, Antidermatophytic Properties.	Flavonoids, Saponins, Carbohydrates, Proteins, Alkaloids, Phenolics, Terpenoids, Coumarins.	The antimicrobial properties against *Gram positive (Streptococcus, Corynebacteria) and negative bacteria (Providencia, Escherichia, Morganella, Aeromonas, and Citrobacter).*
Babul tree (*Vachellia Nilotica*)	Cough, Cold, Diarrhoea, Lose motion, Oral problems, Arthritis.	Inotropic, Anti-Ischemic, Hypolipidemic, Antiatherogenic, Blood Pressure Lowering, Antiplatelet, Antibacterial Properties.	Terpenes, Condensed Tannins, Flavonoids, Hydrolysable Tannins, Diester, Pentacosan Dioic Acid	The antimicrobial properties against *Gram positive (Streptococcus, Corynebacteria) and negative bacteria (Providencia, Escherichia, Morganella, Aeromonas, and Citrobacter).*
Giloy (*Tinospora cordifolia*)	Diabetes, High Cholesterol, Allergic Rhinitis (Hay Fever), Upset Stomach, Gout, Lymphoma.	*Bacteria,* Antiatherogenic, Blood Pressure Lowering, Antiplatelet, Antibacterial Properties.	Jateorine, Columbin, Octacosanol, Heptacosanol, Tinosporidine, Cordifol, Cordifelone, Giloin.	The antimicrobial properties against *Gram positive (Streptococcus, Corynebacteria) and negative bacteria (Providencia, Escherichia, Morganella, Aeromonas, and Citrobacter).*

In this article, various *plants* used for natural antimicrobial finishing are discussed. These *plants* are very easily found all over India and these *plants* are always green. Several researchers have investigated the antimicrobial properties of these *plants* with various fabrics such as wool, cotton, polyester, nylon, silk, and more. Microorganisms attack some fibres very quickly, such as silk, cotton and wool, whereas man-made fibres are not easily attacked by microorganisms. Therefore, antimicrobial properties of each fabric are different. Antimicrobial properties of the fabric can be improved when the fabric is treated with antimicrobial agents. Antimicrobial properties can be easily achieved by using natural and chemical agents. As of recently, the textile industry has started avoiding chemical agents because chemical agents leave a negative impact on our environment, which is harmful for us. Natural antimicrobial agents are derived from many *plants,* like neem, giloy, lemon, garlic, acacia and many other *plants* on earth. Several researchers have enhanced the antimicrobial properties of the fabric by treating it with different parts of various *plants*. A variety of fabrics have been used by the researchers but very limited antimicrobial finishing has been done by researchers on silk and cupro lyocell fabrics.

CONCLUSION

The textile industry is one of the largest polluting industries in the world. As the world is now moving towards sustainability, it has become necessary to stop the use of harmful chemical agents in the textile industry because these chemical agents are very harmful to our earth as they are not easily biodegradable, and at the same time, they pollute our earth and release harmful gases. Every green material is always preferred over synthetic ones as they are more user-friendly and eco-friendlier. For this reason, the demand for natural agents has increased nowadays.

There are many types of *plants* found on earth, among which there are many such *plants* available in nature that have good antimicrobial properties. Antimicrobial properties are quite essential in textile items nowadays. Several studies have been conducted to produce environmentally friendly antimicrobial agents for textile finishing.

Antimicrobial finishing is beginning to be provided not only on medical textiles but also on various products used on a regular basis. Antimicrobial finishing is used to protect textiles from various *bacteria* and fungi. Various chemical agents, which play a significant role against *bacteria* and *fungi*, are utilized in the textile industries. These chemical agents are very effective and long-lasting but these agents leave harmful effects on human health as well as on the environment, whereas antimicrobial refinement can be achieved by using natural antimicrobial agents. India has a rich heritage of herbal *plant* usage. Many herbal *plants* were used in Ayurveda for various ailments, like cold, cough, runny nose, fever, viral diseases as well as serious illnesses like cancer. Medicinal herbal *plants* contain many

antimicrobial agents that play an important role against *bacteria*. Herbal *plants* are not only used for antimicrobial finishing, but they can also be used to dye clothing.

Some of herbal *plants,* like neem (*Azadirachta indica*), basil (*Ocimum basilicum*), *Punica granatum* (pomegranate), turmeric (*Curcuma longa*), lemon plant (*Citrus limon*), arjun tree (*Terminalia arjuna*) and sage (*Salvia officinalis*) *plants* are easily available and remain green throughout the year. This study focused on the antimicrobial properties of herbal *plants* that are commonly used as home remedies. All parts of these herbal *plants,* such as stem, seeds, flowers, leaves, bark, stem and root, have antimicrobial properties against various *bacteria*. Plant extract antimicrobial finishes have less durability than synthetic finishes. This area should be focused on while doing research.

Author Contributions

Conceptualization – Singh S, Rani J; methodology – Singh S; formal analysis – Singh S, Rani J; investigation – Rani J; resources – Singh S, Rani J; writing-original draft preparation – Singh S, Rani J; writing-review and editing – Singh S, Rani J; visualization – Singh S; supervision – Singh S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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