International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Review of Plant-Based Antimicrobial Agents - Their Extraction and Textile Application

Radhika Damuluri[1], Sudha Babel[2]

[1]Ph.D. Scholar, Dept. of Textiles and Apparel Designing, College of Community and Applied Sciences, MPUAT, Udaipur; India
radhikackrishna[at]gmail.com

[2]Professor, Dept. of Textiles and Apparel Designing, College of Community and Applied Sciences, MPUAT, Udaipur; India
sudha_babel[atyahoo.co.in

Abstract: ***There is a growing demand for pathogenic microbe-free surfaces and clothing, which has created a market for antimicrobial textile finishes. Most of these protective finishes given are chemical applications, which are toxic to the wearer as well as the environment. Hence, there is a need to develop eco-friendly, sustainable plant-based antimicrobial textile finishes. Over the past few decades, many types of research are being conducted to extract antimicrobial agents from medicinal plants for textile application. However, the durability of the finish over repeated washes is a major limitation. This review is an attempt to discuss the principles involved in imparting antimicrobial properties to textiles, types of antimicrobial agents generally used, various categories of bioactive components mostly extracted from plant sources, phytochemical screening, methods of application, and tests for assessing antimicrobial efficacy.***

Keywords: antimicrobial; biostatic; bioactive components; phytochemical analysis

1. Introduction

Textiles and clothing come in contact with the human body and provide a breeding ground for pathogenic bacteria. These microbes cling to the fibers, multiply rapidly and damage the fiber. Many types of skin allergies caused by microbes are found to be transmitted through textiles. Hence, textile finishes are applied to provide protection from pathogenic microbes. The practice of applying coatings of medicinal preparations to textiles dates back to ancient times in India when herbal extracts were applied on clothing in Ayurveda treatment. Egyptians used herbal coatings and spices on cloth for the wrapping of mummies to provide protection from microbial attacks on dead bodies [1]. During World War II, cotton fabrics used for tents, tarpaulins, and trucks were exposed to heavy rain, snow, and dust. To prevent deterioration due to microbial growth, and to arrest rotting, they were treated with antimicrobial agents such as mixtures of chlorinated waxes, antimony, and copper salts. But these treatments gave the textiles stiffness and odor. Though initially these ill effects were ignored, later, more attention was brought to the harmful effects of these chemicals on the environment and human health. Hence the concept of eco-friendly antimicrobial textile finishing came into existence [3].

The effect of microbes on textiles:
When coming in contact with textile fibers, the microbes cause damage by degradation and assimilation. Some textile fibers act as a source of nutrition for microbes. For example, the carbohydrates present in cellulosic fibers and proteins present in animal fibers provide nourishment to microbes. Cellulosics are more prone to deterioration by the action of fungi than bacteria. Wool is more prone to deterioration by bacteria than fungi.

Microbes may attack the whole textile material or act upon the dirt present in the material or they may feed on the textile finishing additives. Microbes release enzymes for the collection and assimilation of food, which will weaken the fiber and lead to ultimate damage. Certain microbes may cause a loss of strength and flexibility in textile material. Cellulolytic fungi release cellulase, which damages cellulosic fibers. Regenerated man-made fibers, which consist of cellulose are also damaged by bacteria, which release cellulase enzymes. Most fungi can produce pigments, which cause the discoloration of textiles. Though protein fibers have resistance to damage caused by fungi, under favorable conditions, fungi may multiply rapidly and release proteolytic enzymes, causing fiber damage. Synthetic fibers such as PET, nylon, and acrylic are highly resistant to microbial damage. However, textile finishes given to them may add a wide range of additives such as lubricants, anti-static agents, and thickeners. Sometimes dirt and soil get collected on the materials, which provide favorable conditions for microbial growth. Body fluids and body wastes from the wearer also promote the growth of microbes in textiles.

The initial stages of microbial growth on textiles can be identified by the occurrence of small spots and bubbles on the surface. In the later stages, the microbes migrate into the cavities or interstices of fibers, breaking the bonds, thus weakening the fiber and causing depletion of fiber mass. This will have a huge impact on the deterioration of physical properties such as tensile strength and breaking strength, chemical properties such as decreased resistance to strong chemicals, and deterioration of cellulose and proteins.

Thus, in order to provide protection for the textile material, as well as for the wearer, an efficient antimicrobial finish should meet the following requirements - [3,5]

1) It should provide efficient protection against a broad spectrum of pathogenic bacteria and fungi and should not be harmful to the wearers, and should not cause any irritation, itching, or skin allergies.

Licensed Under Creative Commons Attribution CC BY

2) It should work against only harmful microbes and should not destroy non-pathogenic bacteria.
3) It should withstand laundering, dry cleaning, and hot-press processes, as most of the textiles are subjected to repeated laundering and other cleaning procedures at regular intervals.
4) The finishing process should be compatible with other textile finishes such as bleaching, scouring, dyeing, etc. should be cost-effective, and should not release harmful chemicals into the environment.

The antimicrobial agents are classified based on their mode of action as

1) Biocide: they kill the microbes.
2) Biostatic: they inhibit the growth of microbes.

For textile applications, mostly biostatics are preferred as they do not kill natural non-pathogenic microbes. A biocide is preferred for medical textiles and environmental applications. Many antimicrobial textile applications work by diffusion method. The rate of diffusion governs the efficacy of the finish. Some of the textile materials may be structured to provide an anti-adhesive surface (lotus effect) for microbial growth, thus providing passive antimicrobial conditions.

Antimicrobial mechanism:
Antimicrobial activity can be defined as a negative effect on microbes. The antimicrobial agents either completely destruct the microbes or inhibit their growth without much destruction. If the activity destructs only bacteria, then it is termed antibacterial and if destructs only fungi, then it is described as antifungal or antimycotic. Based on their mode of action, they are categorized as

Leaching antimicrobial agents: They are also known as controlled-release antimicrobial agents. They diffuse from the clothing and come in contact with the microbe. The antimicrobial agent leaves the garment and forms a sphere of activity. When a microbe gets in contact with the sphere, it is destroyed. But the disadvantage of leaching antimicrobial agents is, that in the course of time their strength will diminish causing inferior efficacy. They are not durable and may cause health issues. Examples of leaching antimicrobial agents are triclosan (halogenated phenols) and metal salts. [1,3,4,5]

Non-leaching antimicrobial agents: [1,3,5] they are bound to the textile and do not migrate from the clothing but they destroy any microbe coming in contact with the textile surface. They destroy the cell membrane of microbes. They do not lose their effectiveness and they will stay durable throughout the life cycle of the textile. But over a long period, the chemicals on the textile surface may be lost due to abrasion thus reducing the durability. Examples of non-leaching antimicrobial agents are QACs (Quaternary Ammonium Compounds), N-halamines, chitosan, and PHMB (polyhexamethylene Biguanide)

Methods of extraction of bioactive components from plants:

1) **Maceration:** [9-11] Maceration is used for a long time for making wine, and tonics for medicinal purposes and to extract essential oils from plant parts. This is a common, economical method followed for the extraction of bioactive components from plant sources. In the maceration, the plant part is ground into smaller particles so that the surface area is increased for soaking and mixing with a suitable solvent. Ethyl acetate, ethanol, methanol, hexane, and ethane are commonly used solvents. The solvent is termed menstruum. The powdered plant part is soaked or dissolved in the solvent and stored in a closed container, for a minimum of three days with frequent agitation or shaking at room temperature. The purpose of this process is to make the plant cell wall soft and break to release the phytochemicals, which are soluble in the solvents. The soft, solid plant material, known as the marc is pressed and the liquid obtained known as micelle is filtered or decanted. The efficiency of extraction depends on the polarity of the solvent selected and its suitability to the plant source. imitations of this method include less yield of extract, and usage of large quantities of solvents is hazardous to the environment.
2) **Infusion:** [11-12] An infusion is defined as a dilute extract of easily soluble plant constituents. This method of extraction involves powdering the plant material into a very fine powder, covering it with a suitable cold or hot solvent, and keeping it for a short period of time. The Material Liquor ratio commonly used is 1:4 or 1:16. If the plant parts consist of bioactive components that are readily soluble, then infusion is the most suitable process. Many medicinal plant extracts are prepared and sold as infusions. This method is most suitable if fresh plant extracts are required. Examples of medicinal infusions include teas of various types, basil infusion, guava leaf infusion, and passion flower infusion, etc.
3) **Digestion:** [11,13] Digestion is one extraction method, a form of maceration, where powdered plant material is covered with a suitable solvent and moderate heat (not more than 50°c) is applied by placing it in a water bath or an oven. The plant materials are placed in a container and a solvent preheated to the required temperature is poured over, the temperature is maintained for the required time period ranging from half an hour to twenty-four hours. The heat is applied to decrease the viscosity of the solvent and reduce the extraction of secondary metabolites. The temperature should not alter the bioactive components of the plant material. This method is most suitable for plant materials that are readily soluble.
4) **Decoction:** [11,14] This is an extraction method, wherein a dried, powdered plant part is placed in a clean container and then water is added and stirred. Continuous heat is applied for a short period of time for faster extraction. Generally, heating is done for short periods of 15-30 minutes with a Material to Liquor Ratio of 1:4 or 1:16. Due to heat application, the volume of the water will be brought down to one-fourth of the initial volume. At the end of the extraction, the concentrated extract obtained is filtered for further use. This method is most suitable for

Licensed Under Creative Commons Attribution CC BY

plant materials that are stable at high temperatures and water-soluble.

5) **Percolation:** [11, 15] percolation is an exhaustive extraction method, where all the soluble components of plant material are completely extracted. This process involves the use of apparatus called a percolator, a cone-shaped, narrow glass vessel with openings at both ends. The powdered plant material is initially wetted with solvent in a clean container and more solvent is added and kept at room temperature for four hours. Then the contents of the container are transferred to the percolator with a closed lower end and kept for twenty-four hours. After this time period, the suitable solvent for extraction is poured from the open end until the plant material is totally saturated. The percolator's lower end is opened and liquid will drip slowly. Some more solvent will be added, which passes through the plant material and extraction takes place through a percolator by gravitation. The solvent is added till the volume reaches 75% of the intended solvent quantity. The extracted liquid is filtered by decantation. The volume is then expressed and the remaining quantity of solvent is added to get the required volume. Different types of percolators are used for small-scale and large-scale extraction. The advantages of percolation extraction are this method is time-saving, and does not require continuous monitoring and manipulation. However, less than 3 mm-sized particles of plant materials should be used for percolation, as larger particles are not suitable for the equilibrium required for extraction. Very fine resins and powders, which swell to give viscous gel cannot be extracted by this method. Extraction by a continuous counter current is another advanced method, where the plant material and solvent flow in opposite directions, to provide contact between the plant material extract and fresh solvent. This method has the advantage of increasing the concentration of the plant extract.
6) **Soxhlet or continuous hot extraction:** [11, 16] Soxhlet method of extraction is a very popular method,commonly used in most solid analyses. This technique of extraction is used as a standard to compare the performance of modern techniques of extraction. The Soxhlet apparatus used for extraction consists of a round bottom flask, an extraction chamber, a siphon tube, and a condenser. A thimble is prepared with a porous clean cloth bag or filter paper and dried, powdered plant material is placed in the thimble and closed tightly. A suitable extraction solvent is added to the round bottom flask and then the thimble will be placed in the extraction chamber. Now the solvent in the round bottom flask is heated, so that it evaporates, reaches the condenser at the top, condenses, and flows back to the extraction chamber, comes in contact with plant material and extraction takes place. When the level of solvent and extract reaches the siphon, it flows back to the round bottom flask and again evaporation, and condensation takes place. Thus, continuous extraction takes place until no residue is left in the extraction chamber. This method of extraction is most suitable for plant materials having insoluble impurities and the plant material is not completely soluble in the solvent. This method does not allow for regular shaking or stirring. However, this method is not stable for materials that are not thermally stable. The advantages of Soxhlet extraction are, it is suitable for heat-stable plant materials, large quantities can be extracted with less quantity of solvent and no need for filtration. Over the time, many modifications have been made to the Soxhlet extractor to reduce the volume of extractant and the time taken for extraction.
7) **Microwave-assisted extraction:** [11, 17] Thismethod of extraction involves the use of dipole rotation and ionic transfer. The ions present in the plant material and solvent are displaced and transferred. This method is most suitable for plant materials having bio components such as flavonoids. In this extraction, electromagnetic radiation of 300Mhz – 300 GHz and microwaves at a frequency of 2450 Hz are applied. When the microwave hits the plant material, the electromagnetic energy generated will get converted to heat energy. This heat enables the entry of solvent into the plant material matrix. The microwave energy will partition the bioactive components of plant materials into the solvent. When a polar solvent is used for extraction, a dipole rotation and transfer of ions take place, increasing the mobility and penetration of the solvent, thus extraction occurs. The dipole rotation will break the hydrogen bonds and increases the migration of dissolved ions and promotes solvent penetration. This method is not effective when a non-polar solvent is used, as the heat generated is very less. The major benefit of microwave extraction is reduced extraction time and maximum yield of extraction. This extraction method is safe to use for plant materials consisting of flavonoids and phenolic compounds only. Tannins and anthocyanins may degrade due to high heat.
8) **Ultra-sound assisted extraction**: [11,18]In this method of extraction, very high-frequency sound waves are used to disrupt the plant cell to increase the surface area available for solvent penetration. Due to ultrasound waves, mechanical energy is produced, which creates a void or vacuum bubbles in the solution. This creates localized high temperatures (4500°C) and high pressure (50Pa), which causes sonolysis, and disruption of cell membranes and intracellular material will be effectively extracted into the solution. The dried finely powdered plant material is mixed with a suitable solvent and packed into the ultrasonic extractor. The high sound energy substitutes heat energy and make the extraction faster, gives maximum yield, and reduces solvent quantity requirement. This method of extraction can be used for smaller samples. However, replication is not possible.In this method, the sample is placed in the vessel, and extraction solvent is added. The sonotrode is placed in contact with the sample. The sonication of the sample takes place. Ultrasoundpropagation and implosion lead to localized high temperatures and pressures resulting in enhanced extraction. Now the sample is ready for the clean-up process. [18]

Plant-based antimicrobial agents:

There are a vast number of plants with medicinal properties available globally. Due to their low cost, and non-harmful side effects, compared to synthetic antimicrobial agents, eco-friendly plant-based antimicrobial agents are considered the best alternative for pharmaceutical antimicrobials. Most plants synthesize aromatic compounds, which consist of

Licensed Under Creative Commons Attribution CC BY

phenols and their derivatives. They are mostly produced as part of the defense against predators (microbes, insects, and herbivores). Odors are given by terpenoids to plants [19].

Phytochemical screening of bioactive compounds [20-22]:

The tests conducted to detect the primary and secondary metabolites present in any plant extracts are termed phytochemical screening. These qualitative tests are conducted to detect the presence of alkaloids, tannins, flavonoids, saponins, terpenes, sterols, cardiac glycosides, proteins, carbohydrates, and fats. Any of these constituents may contribute to the antimicrobial efficacy of the plant source.

Tests for screening of Alkaloids:

1) Dragondorff's test: Take 1 ml of the plant extract in a test tube. Add 1 ml of potassium bismuth iodine solution or Dragondorff's solution. If an orange-red precipitate appears, it is an indication of the presence of alkaloids.
2) Wagner's test: Take 1 ml of the plant extract in a test tube, add 1 ml of potassium iodide solution or Wagner's reagent and shake well. If alkaloids are present in the extract a reddish-brownish precipitate appears.
3) Mayer's test: Take 1 ml of the plant extract in a test tube, add 1 ml of potassium mercuric iodide solution or Wagner's reagent, and shake well. If alkaloids are present in the extract a whitish or creamish precipitate appears.
4) Hager's test: Take 1 ml of the plant extract in a test tube, add 1 ml of saturated ferric solution or Hager's reagent and shake it. If a yellow color precipitate is formed, it means alkaloids are present in the extract.

Tests for screening of glycosides:

1) Modified Bontrager's test: weigh 1 gm of crude extract, take it in a test tube, and dissolve it in 5ml of dilute HCL. Then add 5 ml of 5% ferric chloride solution and shake the mixture. Now place the mixture in a water bath and boil for 10 minutes, let it cool, and filter. Now extract the mixture again with the benzene layer, and add an equal volume of ammonia solution to the benzene layer. If a pink color appears, it indicates the existence of anthraquinone glycosides in the extract.
2) Legals test: take 1 ml of extract, add 1 ml of sodium nitroprusside, followed by a small quantity of sodium hydroxide, and shake well. If a pink to red blood precipitate appears, it indicates the presence of cardiac glycoside.
3) Keller-Killian test: take 2 ml of the extract and dilute it with 2 ml of water. Then add 0.5 ml of lead acetate, shake and filter the mixture. Again, extract the mixture with an equal volume of chloroform, evaporate and dissolve the residue in glacial acetic acid. Now transfer the mixture into a test tube and add 2ml of sulfuric acid. If a reddish-brown layer appears, which turns bluish-green, then it indicates the presence of digitoxose.

Tests for screening of steroids and triterpenoids:

1) Liebermann Burchard's test: this method of screening is suitable for an alcoholic extract. Hence dry out the alcohol through evaporation, and then extract again with chloroform solvent and add a few drops of acetic anhydride and sulphuric acid. If a violet-to-blue-colored ring appears at the junction of two liquids, it means steroids exist in the extract.
2) Salkowski test: take 1 ml of extract in a test tube, add 2 ml of chloroform, shake it and filter it. Add a few drops of concentrated sulfuric acid, shake it and leave it to stand. If a golden yellow precipitate appears, it indicates the extract has triterpenes.

Tests for screening of tannins:

1) Gold Beater's skin test: A gold Beater's skin is made from Ox skin. Soak this Gold Beater's skin in 2% hydrochloric acid and wash it with distilled water. Then place it in the extract for 5 minutes and wash it with distilled water. Now place it in a 1% ferrous sulfate solution. If the Gold Beater's skin changes to brown or black color, it indicates the extract has a tannin presence.
2) Gelatine's test: take 1 ml of extract in a test tube, add 1% gelatine solution, add sodium chloride and shake it. If a white precipitate appears, then it's an indication of tannin.

Tests for screening of flavonoids:

1) Shinoda's test: take 1 ml of extract in a test tube, add a few drops of concentrated hydrochloric acid and 0.5 mg of m-Rimandoium turnings and shake. If pink color appears, it indicates flavonoid presence.
2) Lead acetate test: take 1 ml of extract in a test tube, add a few drops of lead acetate and shake it. If a yellow precipitate appears, then it is an indication of flavonoids.
3) Alkaline reagent test: take 1 ml of extract in a test tube, add a few drops of sodium hydroxide solution and shake it. If an intense yellow color appears, and if you add dilute acid, if it disappears, it is an indication of flavonoids.

Tests for screening of phenols:

1) Ferric chloride test: take 1 ml of extract in a test tube, add 1% gelatine solution and sodium chloride and shake it. If a bluish-black color appears, it indicates the phenol's presence.
2) Lead acetate test: take 1 ml of extract in a test tube, add 1 ml of alcoholic solution, followed by dilution with 20% sulfuric acid. Then add sodium hydroxide solution. If a red-to-blue color appears, it indicates the presence of phenols.
3) Gelatine test: take 1 ml of extract in a test tube, add 2 ml of 1% gelatine solution and shake it. If a white precipitate appears, then it's an indication of phenol's presence.
4) Mayer's reagent test: take 1 ml of extract in a test tube, and add 1 ml of Mayer's reagent in an acidic solution. If a white precipitate appears, then it's an indication of phenol's presence.

Methods of application of antimicrobial agents on textiles:

1) **Spun additives:** antimicrobial properties are imparted to synthetic fibers by adding bioactive agents to the

Licensed Under Creative Commons Attribution CC BY

dope solution. This method of application gives permanent antimicrobial properties, as the antimicrobial agent is incorporated into the fiber polymer matrix. The additives selected for this purpose should be highly stable against strong chemicals and should have high thermal stability, solubility, and dispersibility. They should not interfere with the spinning process [3].

2) **Pad-dry-cure method:** this is the most common method of application. The fabric is usually padded with 70-80% of antimicrobial agent. Generally, some cross-linking resins or binders are used along with antimicrobial agents [2-3]. A drawback of this method is, that padding produces 70-100% wet pickup, which needs evaporation of water utilizing high-energy drying. During evaporation, the antimicrobial agent may migrate to the fabric surface leading to uneven finishing [6].
3) **Spraying:** this is the most suitable method for application on nonwovens. However, spraying antimicrobial compounds is not advised as the particulate matter may be inhaled by the workers involved. A proper containment facility should be available [3].
4) **Microencapsulation:** The liquid or solid particles of antimicrobial agents are covered in polymer capsules. This method is most suitable for cellulosic fibers, rendering a durable finish even after repeated launderings. The beneficial feature is the antimicrobial agent present in the core of the microcapsule will move to the outer layer, close to the surface of the fabric, when the fabric comes in contact with water during washing, enhancing the antimicrobial property of the fabric with each wash [7]. However, the capsule should be strong enough to withstand other textile processes and should be small enough to not alter the texture and other comfort properties of the treated fabric [3].
5) **Polymer modification:** The antimicrobial functionality can be imparted by the copolymerization of monomers with functional groups having bioactive elements. These bioactive elements will become an integral part of the fiber polymer system, which lasts for the life of the fiber. This is an expensive application method, as it requires special plants to carry out polymerization. An example is Quaternary Ammonium Salts [6].
6) **Plasma treatment:** this is a low-cost method of application, which does not involve the usage of chemicals. This method is used to change the surface properties of textile material, which is also renewable. It was found that the deposition of silver nanoparticles on plasma-treated fabric surfaces exhibited antimicrobial properties [1]. This method of antimicrobial finishing involves graft polymerization to deposit antimicrobial polymer, by spreading it as a thin film over a textile substrate. This process requires less water and energy [6].
7) **Sol-gel application:** In this method, the fabric is impregnated in a colloidal solution which gradually changes into a gel form, known as sol, and then passed through the padding, drying, and washing process. This is a cheap and low-temperature technique that is suitable for the application of an antimicrobial finish [8].
8) **Layer-by-layer deposition:** this method of application involves dipping the fabric in a cationic preparation in the first step and then in the second step the fabric is dipped in the cationic polymer solution. This will result in the deposition of polymer layers on the fabric. This process requires washing and drying intermittently. This process also requires water and energy. [1]

Other methods of application:
1) Direct application
2) Foaming
3) Natural dyeing with antimicrobial plant extracts
4) Application of nano-particles [2]

Tests for antimicrobial efficacy: [1,5, 23]

The minimum inhibitory concentration (MIC) value is defined as the lowest concentration able to inhibit the growth of the tested bacterial strains. The minimum bactericidal concentration (MBC) is determined by sub-culturing the cells exposed to different concentrations of the antimicrobial compound, used to evaluate MIC, in a fresh growth medium and defined when no growth is observed

1) **Agar diffusion test:** These tests are qualitative, and suitable for diffusive finishes and fabrics only. These tests include AATCC 147-2004 (AMERICAN ASSOCIATION OF TEXTILE CHEMISTS AND COLORISTS), JISL 147-2004 (JAPANESE INDUSTRIAL STANDARDS), and SN 195920-1992 (SWISS NORM). these tests are beneficial when a large number of samples need to be tested.In these tests, bacterial cells are inoculated on nutrient agar plates on which the samples are placed closely for intimate contact. These plates are incubated at 37°C for a time period of 18-24 hours. The plates are examined for the growth of bacteria underneath the sample surface and around the edges, which is known as the zone of inhibition. If there is no bacterial growth identified underneath the sample, it indicates the presence of antimicrobial activity. When the antimicrobial agent diffuses into the agar, a zone of inhibition becomes evident, its size is an indication of the efficacy of the antimicrobial activity and the release rate of the antimicrobial agent [5].
2) **AATTC Test Method 147-2004 is known as the parallel Streak Method:** The average width of the zone of inhibition along the streak on either side of the sample is calculated by the equation
   W= (T - D)/2
   where: W =width of clear zone of inhibition in mm
   T = total diameter test specimen and clear zone in mm
   D = diameter of the test specimen in mm [23]
3) **AACT Test method100-2004**: The test microbes are grown in a liquid medium culture. Standardization of the concentration of test microbes will be done. The culture is diluted in a sterile nutritive solution. The control sample and test samples are inoculated with microorganisms. The samples are kept on the microbial suspension to closely touch the solution and they are inoculated. Elution in a large volume of neutralizing broth is done, to find out bacterial levels on both control and test samples at time zero. Then dilution and plating are done. A control test is conducted to test the accuracy of elution. Additional test and control samples, which

Licensed Under Creative Commons Attribution CC BY

are inoculated are incubated by storing them in sealed jars for a period of 24 hours and then the concentration of microbes is determined. A comparison of initial concentrations of control and treatment samples and reduced concentrations is done by calculations. The formula used for calculations of the percent reduction in bacteria is

R= 100 (B – A)/B

Where R= % reduction in bacteria

A= the number of bacteria recovered from the inoculated treated and test samples incubated over desired contact time

B= the number of bacteria recovered from the inoculated treated and test samples immediately after inoculation

at "0" contact time [23].

4) **AATCC Test Method 90-2011 Antibacterial Activity Assessment of Textile Materials (agar plate method):** both control and treatment fabric samples will be placed in close contact with agar treated with test bacterium inoculum. After incubation, the area of bacterial growth is assessed. A standard bacterium strain, specific to the test material is used to test antimicrobial activity. The zone of inhibition area width on either side of the sample is calculated by

W= (T - D)/2

W= clear zone of inhibition on either side of sample width in mm

T= test specimen and clear zone of inhibition total diameter in mm

D= test specimen diameter in mm

5) **AATTC Test Method 30-2004 - test for antifungal activity:**

Mildew and Rot Resistance of Textiles

a) Test-I: Soil Burial Test: This test is suitable only for textile materials such as tarpaulins, sandbags, and tents, which directly come in contact with soil.
b) Test -II Agar Plate Test: This test is specific for the fungus *Chaetomium globosum.* This test is most suitable for cellulosic materials, which do not come in contact with soil. This test is used for assessing rot resistance and also uniformity of the fungicide finish given for cellulosic.
c) Test -III (specific to *Aspergillus niger*): This test is most suitable to assess the growth of fungi, *Aspergillus niger*, which causes undesirable effects on textile materials. In this method, the agar provides an environment conducive to the growth of fungus (anti-microbial free zone), so that fungus overgrows on the textile sample.
d) Test-IV Humidity Jar, Mixed Spore Suspension method: In this method, control and treatment samples of size 1x3 inches strips, saturated with nutrients are sprayed with a mildew-causing suspension of mixed spores and incubated in a closed jar, where sterile water is placed at the bottom of the jar to provide the humid condition for microbial growth. The percent growth of the fungus is assessed after the incubation period. In this method, the fungus will germinate from the spores and grows on the fabric. This method is less aggressive than test method III.

Applications of antimicrobial textiles

Healthcare personnel are susceptible to infections caused by prolonged exposure to pathogenic microbes, affecting their performance, and may even cause hospitalization. Textiles used in a hospital environment are potential sources of infection. Though coats worn by healthcare professionals provide protection by acting as a barrier between the wearer and the environment, they are one of the significant contributors to the transmittance of microbes, particularly if the coat is not laundered frequently and hand cleaning practice is not followed diligently [24]. The transmission might occur indirectly by coming in contact with the surface touched by patients, or by aerosols being deposited on the textile surface [25]. The textile characteristics along with external factors such as heat and humidity influence the extent of microbial growth [26].

The following categories of medical textiles are currently being treated with antimicrobial agents

1) Medical upholstery: curtains used for privacy in doctor's offices, and partition curtains used in hospitals and in-patient rooms pose a potential threat of microbial transmission. Hence many companies such as "Microban" are developing antimicrobial curtains for medical use [27].
2) Coats and scrubs: most health care professionals including doctors wear scrubs or coats while visiting in-patients for regular check-ups, which may lead to cross-transmission. Hence scrubs and coats made with antimicrobial functionality are gaining acceptance [27].
3) Disposable surgical gowns and patient gowns: If plant-based antimicrobial agents are used for providing an antimicrobial finish, the non-woven (biodegradable) disposable gowns are made for health care professionals as well as patients, and can be made totally biodegradable [28].
4) Medical textiles: the medical textiles used for healing, such as bandages, absorbent pads made of viscose or cotton used for wound healing, gauze, and cotton can be given antimicrobial treatment to provide better protection and faster healing [28].
5) Other medical textiles used for surgical care: various categories of textiles used in operation theatres such as drapes, bedding sheets, surgical masks, absorbent padding, and uniforms of health care professionals, which are potential sources of transmission must be treated with antimicrobial agents [28].
6) "Antimicrobial face masks": the majority of the population globally is using face masks for protection. If non-toxic, durable antimicrobial treatment can be given to the face masks, the functionality can be improved multifold [29].
7) PPE kits: PPE kits are essential means of protection from direct contact with microbe transmission and play a crucial role in providing protection to people working in areas having a high risk of contagious diseases. All the components of PPE kits must be treated with antimicrobial agents to provide maximum protection [30].

Licensed Under Creative Commons Attribution CC BY

2. Conclusion

A lot of research is being carried out during the past two decades to impart antimicrobial properties to textiles. Over a period of time, a vast number of natural and synthetic antimicrobial applications have been developed and tested by researchers. Many plant materials have been reported as sources for textile finishing to impart antimicrobial functionality by scholars. The antimicrobial agents developed must be non-toxic, biodegradable, durable, and effective over a wide spectrum of microbes. The development of sustainable extraction and application methods with maximum durability is crucial for the success of the textile application of plant materials to meet future needs.

References

[1] R. Gulati, S. Sharma. and R. Kumar, "Antimicrobial textile: recent developments and functional perspective", polymer. Bull., vol. 79, pp. 5747-5771, August 2022.
[2] D. Radhika,"Review Study on Antimicrobial Finishes on Textiles – Plant Extracts and Their Application", IRJET, Vol. 6 (11), pp. 3581-3588, November 2019.
[3] Vishnu. A. Dorugade,and K. Bhagyashri,"Antimicrobial finishing of textiles", Man-made Textiles in India,vol.3, pp. 89-98, 2010.
[4] https://www.intechopen.com/chapters/77673
[5] https://textilernd.com/antimicrobial-finishing-on-textiles/
[6] M. Naebe, Md. Abu Naser, A. Haque, and A. Haji," Plasma-assisted Antimicrobial Finishing of Textiles: A review", in Engineering, Elsevier, 2020.
[7] K. Pushpalatha, D. Anitha, and Sarada Devi, "Antimicrobial micro Encapsulated Cellulosic textiles", International Journal of Science and Research, vol. 4, pp.882-884, March, 2013.
[8] http s://textilernd.com/antimicrobial-finishing-on-textiles/
[9] N. Srivastava, A. Singh, P. Kumari, N. Jay Hind, V. Singh, and K. N. Ravindra, et al., "Advances in extraction technologies: isolation and purification of bioactive compounds from biological materials", Chapter 21. Natural Bioactive Compounds – Technological Advancements, AP Publications. Pp. 409-433, 2021.
[10] R. Sumaira, M.R. Lone, N. Bisma, N. Hina, A.A. Bhat, and G. A. Bashir,"Phytomedicines: Diversity, extraction and conservation strategies", Chapter 1. Phytomedicine – A Treasure of Pharmacologically Active Products from Plants, AP Publications, Pp. 1-33, 2021.
[11] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7398001/
[12] https://www.medicinalplants-pharmacognosy.com/pharmacognosy-s-topics/extraction-methods/infusion/
[13] https://www.medicinalplants-pharmacognosy.com/pharmacognosy-s-topics/extraction-methods/digestion/
[14] M. Natalia, J. Sarakatsiano,and V. Samanidou, "Extraction Techniques of Phenolic Compounds and Other Bioactive Compounds from Medicinal and Aromatic Plants", Chapter 10, Engineering Tools in the Beverage Industry – The Science of Beverages, Woodhead Publishing, vol. 3, pp.283-314, 2019.
[15] P. K. Mukherjee, "Extraction and Other Downstream Procedures for Evaluation of Herbal Drugs", Chapter 6, Quality Control and Evaluation of Herbal Drugs – Evaluating Natural Products and Traditional Medicine, Elsevier Publication, Pp. 195-236, 2019.
[16] A. Ziegler, M.Slominska. and J. Namiesnik, "Soxhlet Extraction and New Developments Such as Soxtec", Chapter 2.04, Reference Module in Chemistry, Molecular Sciences and Chemical Engineering, Comprehensive Sampling and Sample Preparation – Analytical Techniques for Scientists, Elsevier,vol. 22, pp. 65-82,2012.
[17] A. Dekebo, Introductory Chapter: Plant Extracts, Intech open, 2019.
[18] A. Wiggler, B. Gruber, P. Teehan, R. Jaramillo, and F. L. Dorman, Chapter5 – "Inlets and Sampling", Separation Science and Technology, Elsevier,vol. 12, pp. 141-203, 2020.
[19] M. W. Joshi, S. Ali, and R. Purwar, " Ecofriendly antimicrobial finishing of textiles using bioactive agents based on natural products", Indian Journal of Fibre and Textile Research,vol. 34 (9), pp. 295-304, 2009.
[20] A. R. Abdullahi,and Mainulhaque, "Preparation of medicinal Plants: Basic Extraction and Fractionation Procedures for Experimental Purposes" J Pharm Bio allied Sci., Vol. 12(1), pp. 1-10, 2020.
[21] S.Sasidharan, Y. Chen, D. Sarvanana, and L. Yoga Latha," Extraction, Isolation, and Characterization of Bioactive Compounds from Plant's Extracts", African Journal of Traditional, Complementary and Alternative Medicine, 2011.
[22] A. Padma and S. Khateeja, "Phytochemical Screening of 20 Plant Sources for Textiles Finishing", IJAR,vol. 10 (3), 1391-1398, 2015.
[23] S. Jayapriya and G. Bagyalakshmi, "Textile Antimicrobial Testing andStandards", International Journal of Textile and Fashion Technology (IJTFT), vol. 4 (1), pp. 1-10, 2013.
[24] G. Schneider, F.L. Bim, A.F.L. Sousa, E. Watanabe, D. Andrade,and I. Fronteira, "The use of antimicrobial-impregnated Fabrics in health services: an integrative review", Rev lat Am Enfermagem, vol.29, 2021.
[25] G. Borkow, "Antimicrobial Medical Textiles Used in Clinical Settings May Play an Important Role in Reducing Healthcare-Acquired Infections", Journal of Infectious Diseases & Travel Medicine, 3 (2), 2019.
[26] U. Rozman, D.Z. Pavlinić, E. Pal, V. Gonc, and S.S. Turk," Efficiency of Medical Workers' Uniforms with Antimicrobial Activity",Textiles for Advanced Applications, London, United Kingdom, Intech Open, 2017 [online].
[27] https://www.microban.com/odor-control/applications/medical-textiles
[28] https://www.technicaltextile.net/articles/medical-textiles-types-and-applications-9409

Licensed Under Creative Commons Attribution CC BY

[29] P. Gayatri, K. Uttaradevi, S. Gayathri, D. Venkata Kiran, and M. Shihabudheen, "A comprehensive review on antimicrobial face masks: an emerging weapon in fighting pandemics", Royal Society of Chemistry, vol.11, pp. 6544-6576, 2021.
[30] P.S.Mahapatra, S. Chatterjee, M. K. Tiwari, R. Ganguly, C. M. Megaridis, "Surface Treatments to Enhance the Functionality of PPEs", Trans Indian Natl. Acad. Eng., vol.5(2), pp. 333–336, 2020.

Author Profile

Mrs. Radhika Damuluri did her PG in Textiles and Clothing. Her career graph includes entrepreneurship and teaching at various schools and training organizations. She is working as Assistant Professor, at the Dept. of Apparel and Textiles, College of Community Science, PJTSAU, Hyderabad for the past four years. Currently, she is pursuing a Ph.D. in Textiles and Apparel Designing (in-service), at the Dept. of Textiles and Apparel Designing, College of Community and Applied Sciences, MPUAT, Udaipur. Her areas of interest include technical textiles, eco-friendly textile finishes, natural dyes, dyeing and printing, textile application of nanotechnology, pattern development, and apparel designing, accessory designing, and fashion illustration.

Prof. Sudha Babel did her Ph.D. in Textiles and Apparel Designing. Her career path is versatile with teaching, research, and extension experience of 30 years at different colleges. She is the former head, and currently, she is working as Professor (Textiles and Apparel Designing) &Principal Scientist in AICRP on Women in Agriculture, College of Community and Applied Sciences, MPUAT, Udaipur. Dr. Babel has authored more than 150 Research papers, and popular and technical articles sharing her expertise. Reading, writing, creative apparel designing, making contributions through research and training related to women empowerment, waste utilization, environment cleanliness, value addition of traditional textiles and embroideries, etc. are her areas of interest.

Licensed Under Creative Commons Attribution CC BY