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Exploring the Potential of Andrographis Paniculata Extract as a Natural Antimicrobial Agent on Cotton Fabric: Insights from FTIR, UV Spectroscopy, and Phytochemical Analysis

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Abstract

Consumers' attitude toward hygiene and an active lifestyle have created a rapidly increasing market for antimicrobial textiles, which in turn has stimulated intensive research and development. Being in contact with the skin and a barrier between outer space and the body, it can accumulate and inculcate various bacteria and viruses. A large number of synthetic antimicrobial agents are available but they come with the disadvantages of increasing pollution load, drug resistance factors, and many more. This study focuses on the evaluation of the antimicrobial activity of cotton fabric treated with the herbal bioactive agent Andrographis paniculata. Phytochemical Analysis, FTIR, and UV spectroscopy results showed the presence of active bioactive compounds responsible for antimicrobial activity. The bioactive agent from Andrographis Paniculata was extracted with the Soxhlet extraction technique and applied to cotton fabric. The quantitative antimicrobial activity showed 99.90% bacterial growth reduction against Gram-positive and Gram-negative bacteria.

Keywords: Antimicrobial textiles; Andrographis paniculata; Phytochemical screening; FTIR; UV spectroscopy; Cotton fabric.

Introduction

Recently, the demand for medical textiles has increased rapidly. End users are more inclined toward safety, hygiene, and protection from various pathogens. Natural and regenerated textiles are preferred over synthetic for medical textiles due to the highest level of comfort and sustainability[1] but natural textiles are more susceptible to the growth of microorganisms as they have large surface areas and provide a suitable environment for microbial growth. The growth of microorganisms causes various infections to the wearer and deterioration of the textile itself[2]. Textiles used in hospitals are more likely to be contaminated with HAI (hospital-associated Infections). Antimicrobial treatment of textiles could restrain the cross-infection caused by pathological micro-organisms[3].

Antimicrobial treatment involves an effective antimicrobial agent to be applied to textiles by an appropriate method. Synthetic antimicrobial agents are a treat for both the users and the environment. Synthetic antimicrobial agents are released in water bodies and endanger aquatic life[4]. The contact of such synthetic agents with humans and other species also poses a risk[5]. The global awareness of ecology and bioproducts has caused a swift change in consumer preferences[6].

In contrast, natural antimicrobial agents have fewer adverse effects on humans and are eco-friendly. The advantages of using increased sustainability, environment friendliness, reduced pollution, green chemistry, renewability, and intrinsic biological activity are some attributes, which make natural antimicrobial agents suitable alternatives for functional finishes and coatings on textiles[5]. Chitosan, sericin protein, and alginate are some of the most common natural antimicrobial agents[7]. Hence, using natural antimicrobial agents for finishing is an eco-friendly alternative to address the need for an effective and sustainable antimicrobial agent.

Plant-based antimicrobial agents overcome the drawbacks of synthetic antimicrobial agents and have huge potential to serve their purpose without any ecological side effects[8]. Plants have unique defense mechanisms against microorganisms that have evolved over millions of years. This defense mechanism results in a biologically active natural antimicrobial agent[9]. For textile applications, the active compound present in the plant is to be isolated and characterized to assess the phytochemical possibilities[10]. Plants' phytochemicals were divided into primary or secondary constituents, depending on their role in plant metabolism. The primary constituents include the common sugars, amino acids, proteins, purines, and pyrimidines of nucleic acids, chlorophylls, etc. Secondary constituents are the remaining plant chemicals such as alkaloids, terpenes, flavonoids, lignans, plant steroids, curcumins, saponins, phenolics, flavonoids, and glucosides[11].

The use of plant extracts and other natural compounds for medical purposes is from ancient times as ethnomedicines[12]. Natural herbal products such as Neem, Tulsi, Pomegranate, Aloe Vera, Prickly Chaff Flower, Turmeric, Clove, etc. also exhibit antimicrobial activities[13].

In this study, Andrographis paniculata was screened for its phytochemicals and the natural extract of the herb was cotton fabric to assess its antimicrobial effectiveness. A. paniculata, commonly known as King of Bitters or kalmegh, is an annual, branched, erect handsome herb running half to one meter in height. It is mostly found in Asian countries[14]. Andrographis paniculata, a member of the Acanthaceae (Acanthus) family, has been used for centuries as a medicinal herb for treating various diseases. It has a broad range of pharmacological effects[15]. It is known as King of Bitters (English), Mahatikta (Sanskrit), Kiryato (Gujarati), Mahatita (Hindi), and Kalmegh (Bengali). A wide array of studies has been conducted, especially in Asia. Various reports are widely available about the medicinal properties possessed by this plant. It is a medicinal plant reported to have anti-oxidant, Anti-inflammatory/anti-allergic activities, insecticidal activities, anti-HIV, anti-pathogenic bacteria, and immunoregulatory activities[16]. Andrographolide has an antiviral effect on different viruses such as influenza A, Hepatitis B &C, and chikungunya[17].

Andrographis paniculate contains various bioactive phytoconstituents that are useful in treating various diseases. Different parts of a plant have different phytochemicals. It has been studied that flavonoids are obtained from roots and leaves. The aerial part of the plant is rich in alkanes, ketones, and aldehydes[18]. Researchers have found that the bitter nature of plants is due to the presence of lactone andrographolide in the leaves[19]. Plant extracts were screened for the presence of major secondary metabolite classes such as Alkaloids, Flavonoids Saponin, Terpenoids, Tannin, Glycosides, Phytosterol, and Proteins, according to common phytochemical methods. The presence of phytochemicals imparts different attributes to the plants. Phenol present in the plants offers resistance and anti-oxidant properties. Flavonoids are responsible for anti-allergic, anti-inflammatory, anti-microbial, and anti-cancer activities present in plants[14]. Andrographolide, a therapeutically significant active component of kalmegh, is found in the aerial portions. It is referred to as diterpene lactone and is tasteless, crystalline, and colorless. Additionally, it contains sub-components of andrographolide, dihydroxy-di-methoxyflavone, monohydroxy trimethyl flavones, 5-hydroxy 7, 8, 2', and 3'-tetramethoxy flavone, as well as skullcaflavone. Additionally, diterpenoids from plant aerial parts have been reported[21].

Table-1: Medicinal use of A. paniculata[14].

Part	Medicinal uses
Whole plant	Snakebite and insect sting treatment, dyspepsia, influenza, dysentery, malaria, and respiratory infections
Leaf	Fever, colic pain, loss of appetite, irregular stools and diarrhea, common cold, cough, fever, hepatitis, tuberculosis, mouth ulcers, bronchitis gastrointestinal disorder, and sores.
Aerial part	Common cold, hypertension, diabetes, cancer, malaria and snakebite, urinary tract infection
Roots	Febrifuge, tonic, stomachic, and anthelmintic

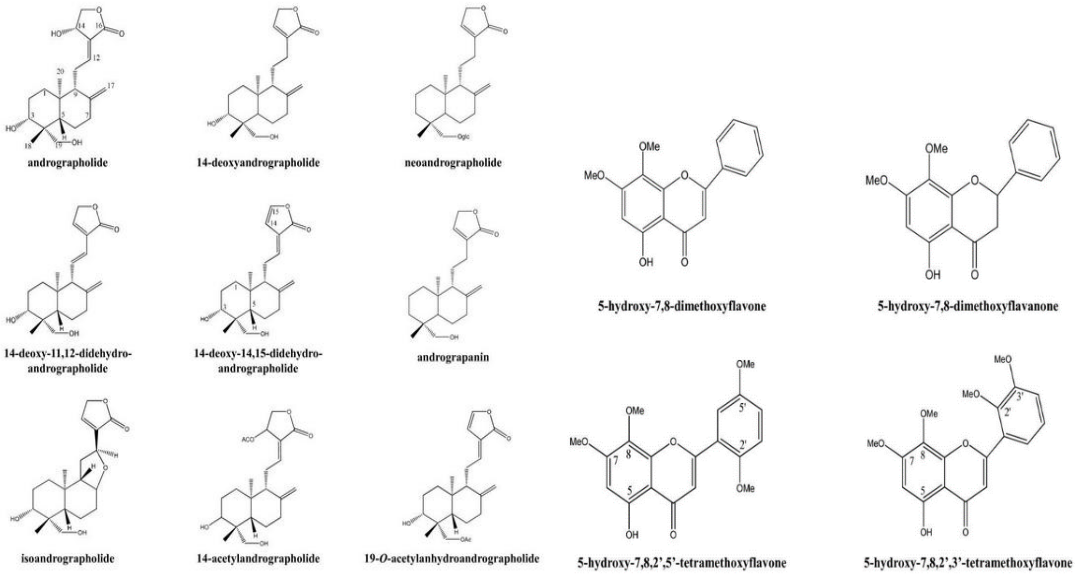


Figure-1: Different chemical constituents present in Andrographis Paniculata[22].

Materials and Methods

Andrographis paniculata leaves are collected from the local market of Ahmedabad. Cotton fabric with specifications shown in Table-2 is purchased from the local market. The active biocomponent is extracted from Andrographis paniculata leaves are extracted with the Soxhlet extraction method. Then, the cotton fabric was treated with different concentrations of the prepared extract.

Material: The cotton fabric in its raw form is purchased from the local market. The fabric is tested for its physical properties as listed in Table-2. The cotton fabric is scoured with the conventional scouring method.

Table-2: Physical properties of the Cotton fabric.

Type of weave	Plain
Fabric weight g/m^2	110
Fiber Type	100% Cotton
Yarn density, picks/cm weft	38
Yarn density, picks/cm Warp	40

In the finishing experiments, Andrographis paniculata are collected from the local market. Leaves are dried in sunlight. The dried leaves of the plant were well-grinded before the finishing process. The dried leaves and grinded powder of the plant are shown in Figure-2. The prepared powder was used to extract the active component.

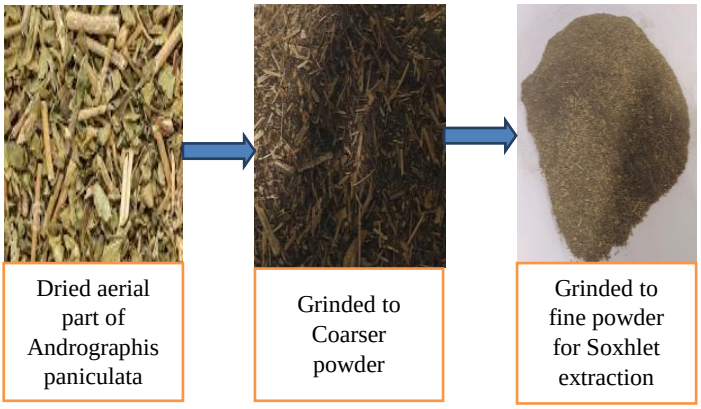


Figure-2: Andrographis Paniculata herb in Dry form.

Method: For the finishing of cotton fabric, the extract of Andrograhis Paniculata was used. In the first stage, the extraction of active biocomponent present Andrographis paniculata was completed. The detailed method is under.

Preparation of powder: The dried leaves of Andrographis paniculata were procured from the local market. The dried leaves were further dried under sunlight to remove any moisture residues. The dried leaves are ground into a fine powder. Any large-sized particles were removed through a sieve. The powder is ready for the Soxhlet extraction.

Soxhlet extraction of powder: Soxhlet extraction is an effective technique for extracting powder-form materials. In this setup, the solvent/water circulated many times through the extractor. The solubility of the compound in the desired solvent is the primary requirement for the extraction. A Soxhlet extractor extracts the components using the condensed vapors of the solvent. The condensed vapors come in contact with the powder and the soluble part in the powder gets mixed with the solvent.

As shown in Figure-3, a round bottom flask was kept on the heating mantle. The 500 ml water was taken with 50 grams of Andrographis paniculata herb in the round bottom flask. Distillation, thimble, and siphon units are placed over the round bottom flask. The condenser was kept on the top of the thimble unit. Cold water circulating tubes were connected to a condenser. The sample was kept inside the thimble wrapped around a filter paper and covered from the top. When the condensed vapors fall into the thimble the powder interacts with water/solvent and the bioactive component gets along with it. The water sample extract mixture filled slowly into the siphon and overflowed back into the round bottom flask. A total of five cycles were performed. The extract was collected and stored in a borosilicate glass bottle. The extraction was conducted using distilled water at pH: 7+- 0.2. The duration for the extraction process was 2 h.

Finishing treatment of the cotton fabric: Extraction of Andrographis paniculata is used for finishing treatment of cotton fabric. In the finishing stage, scoured cotton is treated with different concentrations of extract without any mordant. The concentrations used are 10%, 20%, and 30% (v/v).

The finishing of the cotton fabric was managed in a laboratory water heating bath, exhaustion method. The samples were added to the baths with a material-to-liquor ratio of 1:40. The bath containing cotton fabric and Andrographis paniculata extract was treated for 45 minutes. The varying parameters were Concentration and temperature. After 45 minutes samples are padded in a padding mangle with 3 dip and 3 nip. Then the samples are wrapped around the sticks and covered by PVC films for saturation and development for 24 hours. In the final step, a 2-minute rinse step was followed by a 5-minute wash at 40^{0}C. Samples were allowed to dry at room temperature with a final rinsing. By this process, it was assumed to develop color characteristics and bring antibacterial activity so after the processes, the fabrics were analyzed both for the obtained color parameters and antibacterial activities. This study aims to analyze the Andrographis paniculata aerial part and investigate its usability in textile finishing. A total of 6 samples were prepared with varying parameters as showed in Table-3.

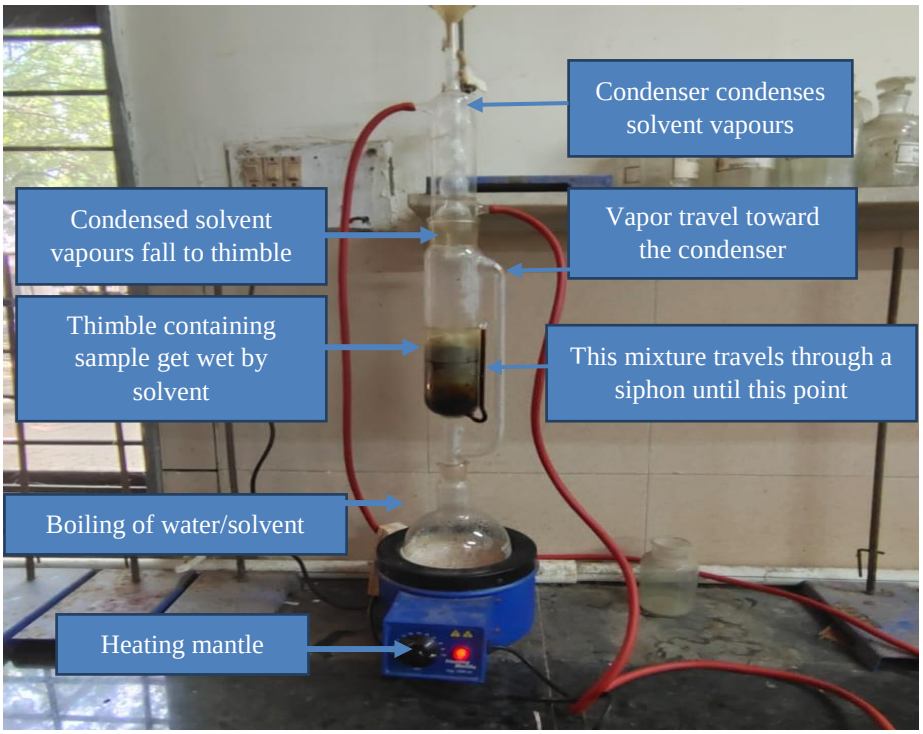


Figure-3: Soxhlet Extraction Set up.

Figure-4: Andrographis paniculate extraction.

Table-3: Sample code with varying concentration and Temperature.

Sample No.	Conc. v/v)	pH	Temp	Sample Code
1	10%	10.55	30^0C	A1C
2	20%	10.32	30^0C	A2C
3	30%	10.56	30^0C	A3C
4	10%	10.55	60 ^{0}C	A1H
5	20%	10.54	60 ^{0}C	A2H
6	30%	10.56	60 ^{0}C	A3H

The treatment process was conducted at 30^0C & 60^0C. 3 samples with varying concentrations of 10%, 20%, and 30% (v/v) were processed at 30^0C for 60 minutes, and 3 samples were treated in a finishing bath for 60 minutes at 60^0C. The pH of the extract was 10.56 at 29^0C. After impregnation, the fabric is padded in paddle mangle (80% expression) by two dips and two nips. The finished fabric was then wrapped around a glass rod covered properly with a PVC sheet and kept for 24 hours. After 24 hrs, the rolled fabric was washed with 0.5% mild detergent and dried in shade.

Characterization of extract: Characterization of the extract was conducted to harness the potential of the herb. In this study, the characterization of the extract includes phytochemical analysis, FTIR analysis, and UV spectrophotometry.

Phytochemical analysis: The prepared extract is screened for qualitative phytochemical analysis. Phytochemical research involves the identification of chemical constituents of the plant. Plant extracts were screened for the presence of major secondary metabolite classes such as Alkaloids, Flavonoids Saponin, Terpenoids, Tannin, Glycosides, Phytosterol, and Proteins, according to common phytochemical methods shown in Table-4. They were known to show medicinal activity as well as exhibiting physiological properties.

Table-4: Phytochemical Analysis of the prepared extract.

Metabolite	Test performed
Alkaloids	+ Dragendorff's reagent[1]
Flavonoids	Alkaline test
	+Lead acetate
Sterols (Libermann test)	+ $CHCl_3$ + Acetic anhydride + Conc. H_2SO_4
Terpenoids (Libermann test)	+ $CHCl_3$ + Acetic anhydride + Conc. H_2SO_4
Anthraquinone (Borntrager'stest)	+ $FeCl_3$ + Conc. HCl + diethyl ether + Ammonia
Anthocyanin	HCl Test
Proteins	+ 2% Ninhydrin reagent
Phenolic compounds	+5% neutral $FeCl_3$

FTIR of Andrographis paniculata Extract: The FTIR spectroscopy of fine Andrograhis paniculata powder was conducted on Bruker ALPHA II Compact FT-IR Spectrometer. The peaks obtained were analyzed by using a standard IR spectra table.

UV spectroscopy of the Extract: UV-1800 SHIMAZDU UV spectrophotometer was used for conducting UV spectroscopy of prepared herb extract. Peaks are obtained and further analyzed.

Characterization of the finished fabric: The cotton fabric is treated under different parameters and prepared samples are characterized. By the characterization, the samples were analyzed for the obtained antibacterial activities.

FTIR: The FTIR spectroscopy of fine Andrograhis paniculata treated cotton fabrics and untreated cotton fabric was conducted on a Bruker ALPHA II Compact FT-IR Spectrometer. The peaks obtained were analyzed by using a standard IR spectra table. Samples were prepared by cutting the fabric into fine pieces and then fine powder.

Antibacterial Activity: For the quantitative evaluation of the antibacterial efficiency of the antimicrobial agents against Gram-positive bacteria (Staphylococcus aureus) and Gram-negative bacteria, antimicrobial testing was conducted using AATCC Test Method 100:2004 (Escherichia coli). From the test fabric, swatches with a diameter of 4.8×0.1cm were cut. After stacking the cut pieces in a 250 ml wide-mouth glass jar with a screw top, the items were sterilized for 15 minutes at 121°C. The bacterial solution was diluted by adding 0.5ml to each swatch, allowing one swatch to absorb the entire amount. The jar was incubated in the incubator at 37±2°C for 24 hours. Each jar received 50cc of sterilized saline water after 24 hours, and each one was then shaken vigorously for 15 minutes. Moreover, three sequential dilutions were performed using Eppendorf micro test tubes filled with 100µl and 900µl of saline water. A 100µl sample of this diluted bacterial solution was added to nutrient agar plates, which were then incubated for 24 hours at 37±2°C. The amount of bacterial CFU of the bacteria generated on the agar plate was counted after 24 hours. Each time, the control sample was a piece of untreated cotton.

Results and Discussion

Phytochemical Analysis of Extract: The phytochemical study showed that Andrographis paniculata contains various secondary metabolites such as flavonoids, alkaloids, tannins, polysterols, polyphenols, etc. listed in the Table-5. These phytochemicals impart different attributes to the plant and play a vital role in the inherent defense mechanism of the plant. Therapeutically, alkaloids present in plants are particularly well-known as anesthetics, cardioprotective, and anti-inflammatory agents[23]. The presence of alkaloids is crucial for developing antimalarial, antimicrobial & antiprotozoal attributes in plants[24]. Tannin compounds present in A. paniculata plant extracts inhibit some viruses and microorganisms. Phenolic compounds in plants act as antioxidants for scavenging activity and promote anti-inflammatory actions[25]. In this extraction, processed water is used as the extraction medium and it has been reported that the aqueous extraction of Andrographis paniculata is due to the presence of a higher amount of free hydroxyl groups containing flavonoids, which can scavenge the free radicals more efficiently[26]. Amongst the metabolites, terpenoids are Notable among these metabolites are the terpenoids which account for various therapeutic activities due to their antioxidant nature[27].

Table-5: Results for qualitative analysis of Andrographis Paniculata powder.

Metabolite	Test performed	Observation	Result
Alkaloids	+ Dragendorff's reagent	Presence of a reddish-brown precipitate	Presence
Flavonoids	Alkaline test	Intense yellow color with dilute. NaOH that turns colorless on adding dilute. HCl	Presence
	+Lead acetate	Presence of white precipitate	Presence
Sterols (Libermann test)	+ $CHCl_3$ + Acetic anhydride + Conc.H_2SO_4	Absence of Reddish-brown ring	Absence
Terpenoids (Libermann test)	+ $CHCl_3$ + Acetic anhydride + Conc. H_2SO_4	Presence of green color	Presence
Anthraquinone (Borntrager's test)	+ $FeCl_3$ + Conc. HCl + diethyl ether +Ammonia	Presence of reddish - orange color	Presence
Anthocyanin	HCl Test	No Colour change	Absence
Proteins	+ 2% Ninhydrin reagent	Absence of Purple color	Absence
Phenolic compounds	+ 5% neutral $FeCl_3$	Presence of a bluish-green coloured solution	Presence

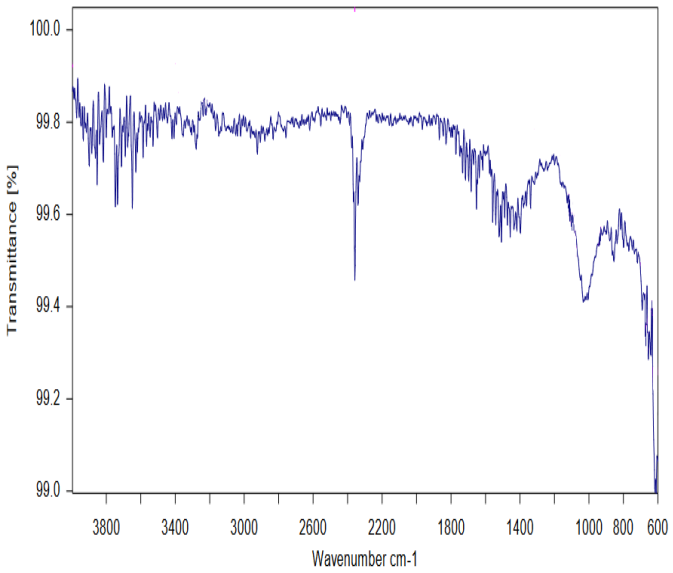


Figure-5: FTIR of Andrographis Paniculata powder.

In Figure-5, the peak on the graph suggests the functional group that FTIR Spectroscopy was used to identify in the Andrographis paniculata. Alkynes, nitriles, amides, nitro, carbonyl, alcohol, carboxylic acids, and these other functional groups were all recognized. A significant and wide peak was seen at wave number 3352.28cm^{-1}, which corresponds to the stretching vibration of the alcohol or phenolic group (O-H). At wavelength 2918.3cm^{-1}, a strong appearance of carboxylic acid (O-H) was seen. At wavelengths of 2324.22cm^{-1} and 2227.78 cm^{-1}, which correspond to alkynes (C=C) and nitriles (CN), respectively, the weak and spectra were obtained. Wave number 1678.07cm^{-1} was a representation of the C=C stretching.

According to the peak value of 1406.11cm^{-1}, the peak exhibits a significant nitro asymmetric stretch (NO_2), and at wavelength 1033.85cm^{-1}, a strong vibration of the carbonyl group (C=O) was identified. Because they include hetero atoms, functional groups including phenol, carboxylic acids, carbonyl, and amide are anticipated to have antioxidant effects.

Table-6: FTIR wavelength and possible compounds in Andrographis Paniculata.

Wavelength (cm^{-1})	Possible compounds
3352.28	Alcohol or phenolic group (O–H) stretching
2918.3	carboxylic acid (O–H)
2324.22	Alkynes (C=C)
2227.78	Nitriles (C≡N).
1678.07	C=C stretching
1406.11	N-O stretching nitro compound
1033.85	carbonyl group (C=O)

UV spectroscopy of the extract: Figure-6 shows the UV-Vis spectra of the Andrographis Paniculata extract solution. Absorption peaks appeared in the range of 279–360nm. The peaks resulted from the absorption of carbonyl chromophore with an electron transition from n→π*. The carbonyl group from andrographolides and flavonoids could contribute to this absorption peak.

Chromophores are commonly found in plant dyes. A chromophore must have a conjugate structure that allows it to absorb visible electromagnetic radiation within the UV-visible range, resulting in electron transition. To get a better understanding of the presence and types of the plant secondary metabolites present in the extract of Andrographis Paniculata, A UV-visible spectroscopy is used.

Figure-6 shows that the Andrographis Paniculata Extract is well absorbed in the ultraviolet (UV) range (200–400nm), with strong absorption peaks at 279nm and 268nm, and a weaker absorption peak around 360 nm.

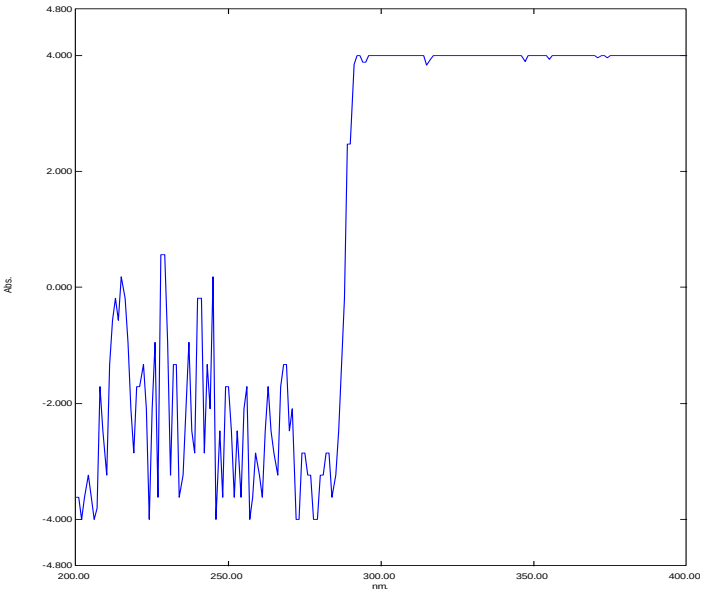


Figure-6: UV Spectroscopy graph of Andrographis Paniculata Extract.

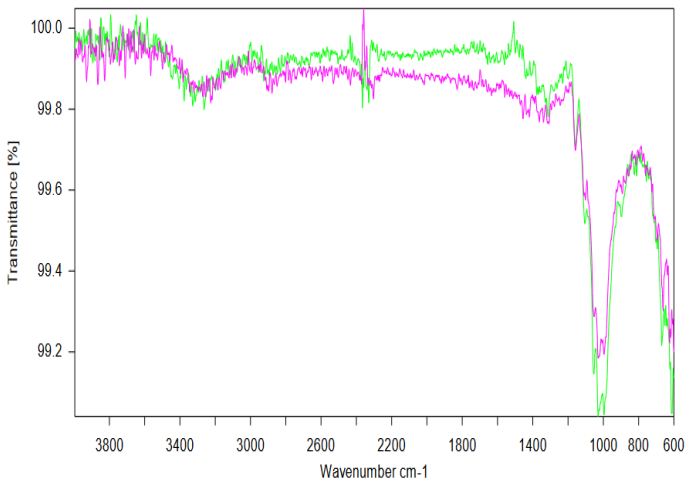


Figure-7: FTIR graph of untreated and Andrographis paniculata extract treated fabric. Pink: Untreated cotton fabric; Green: Andrographis Paniculata treated cotton fabric.

Figure-7 shows the comparison of untreated cotton fabric FTIR (pink) and 30% (v/v) treated cotton fabric (sample code A3H). A medium appearance of O-H stretching was observed at 3748 cm^{-1} wavelength. A weak peak appeared at 3200cm^{-1} possibly due to intramolecular bonded O-H. A medium peak at 2357cm^{-1} corresponding to the alkene group showed up in 30% (v/v) AG treated cotton fabric which was not untreated cotton fabric.

A medium peak at 1732cm^{-1} wavelength had disappeared in 30% (v/v) AG-treated cotton fabric which was present in untreated cotton fabric. This could happen due to new bond formation in treated fabric.

A weak peak at 1456cm^{-1} showed the presence of methylene group in treated cotton fabric possibly due to Andrographis paniculata extract treatment. A strong appearance at 1033cm^{-1} confirmed the presence of the carbonyl group (C=O).

Antibacterial Activity of treated cotton fabric: Using the Quantitative test-AATCC 100, gram (-Ve) Escherichia coli and gram (+Ve) Staphylococcus aureus resistance of cotton fabric samples treated with the Andrographis paniculata have been analyzed. Escherichia coli and Staphylococcus aureus were selected for antimicrobial testing due to their prevalence in all environments and even in human bodies.

It is observed that after the treatment, the growth of the bacterium is reduced even at a low concentration of 10% (v/v) treated at 60^0C, pH 10. Although at room temperature antimicrobial activity was less. This may be due to less extraction of herb at room temperature. An increase in temperature enhanced the extraction of herbal bioactive compounds hence at higher temperature.

Table-6 displays the test findings for colony count in relation to contact time. The fabric sample treated with *Andrograhis Paniculata at* 60^0C demonstrated the highest level of protection against gram (-Ve) bacteria, according to the table.

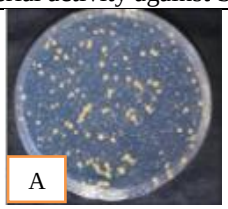
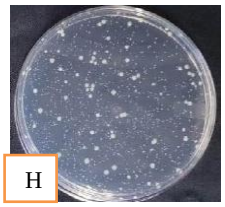
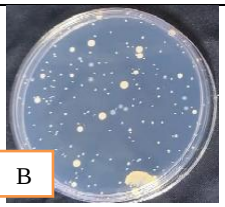
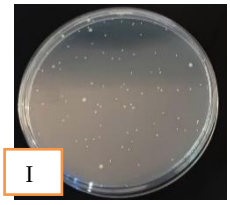
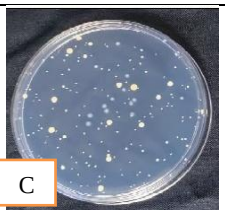
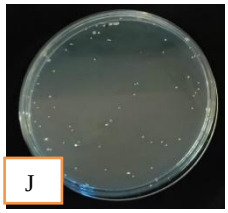
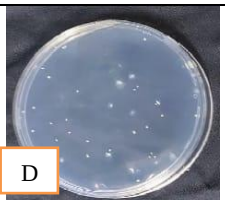
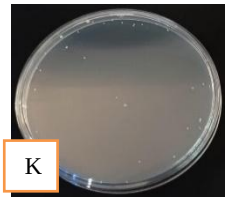
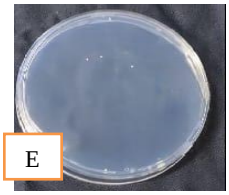
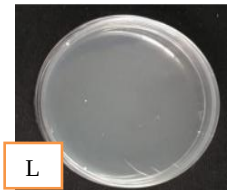
The colony count statistics for the gram (+Ve) bacteria show that the samples treated with *AndrograhisPaniculata at* 60^0C performed best in terms of reducing the growth of gram (+Ve) bacterium. It can be stated that at higher temperature migration and fixation of bioactive compound from extract resulted in excellent antimicrobial protection against E. Coli and S. Aureus.

Phenols and phenolic acids, among the simplest bioactive phytochemicals, are known to be toxic to microorganisms. various reports of phenols being responsible for the antimicrobial activity in medicinal plants are available. Other metabolites that play an active role in antimicrobial activity are terpenoids & flavonoids[26].

Singha et al. reported that the antimicrobial activities present in Andrographis paniculata are the cumulative effect of arabinogalactan proteins (AGPs) and andrographolide (AND)[18].

Table-7: Colony counts for different treated & untreated modal fabric samples

Sample	Colony Count for gram (-Ve) bacterium Escherichia coli (CFU/ml)	Colony Count for gram (+Ve) bacterium Staphylococcus aureus (cfu/ml)	Contact Time (Hr.)
Control sample	6.95×10^{6}	5.35×10^{6}	24
A1C	1.80×10^{5}	2.00×10^{5}	24
A2C	1.73×10^{3}	1.94×10^{5}	24
A3C	1.69×10^{2}	1.1×10^{3}	24
A1H	<100	<100	24
A2H	<100	<100	24
A3H	<100	<100	24

Sample Code	Antibacterial activity against S. Aureus	Antibacterial activity against E. Coli
Control sample	 A	 H
A1C	 B	 I
A2C	 C	 J
A3C	 D	 K
A1H	 E	 L

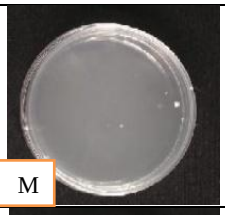
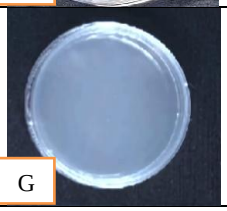
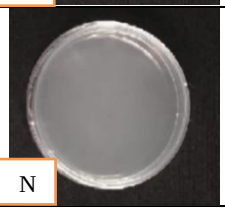
A2H	 F	 M
A3H	 G	 N

Figure-8: Antibacterial activity against s. Aureus (Figure-8A-8G) and against E. Coli. (Figure-8H-8N).

Conclusion

Due to globalization, there is a dire need for an eco-friendly sustainable antimicrobial textile to restrain the transmission of various pathogenic diseases. Among various antimicrobial applications on textiles, natural/herbal antimicrobial treatment has gained interest due current scenario of environmental consciousness. Andrographis paniculate is a medicinal plant and is reported to have anti-oxidant, Anti-inflammatory/anti-allergic activities, insecticidal activities, anti-HIV, anti-pathogenic bacteria, and immunoregulatory activities. In this study, the extract of Andrographis paniculata is prepared and applied to cotton fabric. The prepared extract is tested for phytochemical study and found to contain crucial metabolites such as alkaloids, phenolic compounds, flavonoids, terpenoids, and phytosterols, responsible for antimicrobial activities. FTIR graph also confirmed the presence of vital chemical constituents responsible for various anti-pathogenic activities. The antimicrobial activity of Andrographis paniculate was tested on cotton fabric against E. coli and S. aureus bacteria and found that the treated fabric showed excellent antimicrobial activity even at low concentrations but at moderate temperature. As a summary of this study, Andrographis paniculate contains vital phytochemicals for antimicrobial actions, and testing on cotton fabric confirms the antimicrobial activity against gram-positive (S. Aureus) and gram-negative bacteria (E. coli.).

Future scope of the study: The medicinal plant Andrographis paniculata has been widely studied for its properties. However, very few studies are available on its textile application. Natural antimicrobials have enormous advantages over synthetic ones, but still, some aspects require further research to enhance the overall efficiency. A few important possibilities are listed as follows: i. The usability of the plant as a natural dye source can be explored. ii. Fabric modifications such as mordanting with different mordants can be done and studied for antimicrobial activity. iii. The antimicrobial activities of Andrographis paniculata against other bacteria can be investigated. iv. In this study only 2 parameters i.e. concentration and temperature were studied. Other parameters could be studied to fully understand the plant's bioactivity.

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