AATCC Review

08 June 2025: Received
26 July 2025: Revised
04 August 2025: Accepted
03 September 2025: Available Online

https://aatcc.peerjournals.net/

Original Research Article

Open Access

Phytochemical finishing of cotton fabrics using *Bambusa arundinacea*, *Terminalia arjuna*, and Jatropha curcas extracts: Spectroscopic characterization and color fastness assessment

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ABSTRACT

The booming demand for eco-friendly and bioactive textile solutions has increased interest in plant-derived phytochemicals for fabric improvement. Bambusa arundinacea, Terminalia arjuna, and Jatropha curcas are renowned for their rich phytochemical profiles, offering possibilities for sustainable dyeing, antimicrobial properties, and UV protection in fabrics. Developing durable and eco-friendly textile finishes with plant extracts is challenging due to weak binding, inconsistent fastness, and photostability issues. Methanolic extracts of B. arundinacea leaves, T. arjuna bark, J. curcas roots, along with a 90:10 blend of the first two, were applied to cotton fabrics using alum as a natural mordant. Fourier-transform infrared spectroscopy was conducted on both extracts and treated fabrics to examine functional group interactions and surface modifications. Standard colorfastness tests, like rubbing, washing, and light exposure, were performed to assess the permanence and photostability of the applied solutions. FTIR spectra of the extracts revealed key functional groups, including hydroxyl (-OH), carbonyl (C=O), aliphatic (C-H), and aromatic compounds associated with polyphenols, flavonoids, tannins, and fatty acids. These groups were efficiently transferred onto cotton surfaces, as verified by distinct spectral shifts in treated fabrics. The report detailed how alum mordant boosts chemical bonding and surface adherence. Rubbing fastness scores ranged from fair to good dry and poor to fair wet, while clean fastness displayed moderate to strong performance. Light fastness was significantly improved, with 90% extract and 10% blend-treated fabrics achieving a blue wool scale rating of 'very good', compared to 'good' in the control. The analysis verifies that B. arundinacea and T. arjuna include complementary bioactive mixtures that synergistically enhance textile surface functionality. The enhanced retention of phytochemicals on cloth surfaces was attributed to powerful intermolecular interactions and mordant-aided securing. Fabrics treated with J. curcas exhibited abundant deposits of fatty acids and quinones, pointing to substantial surface alteration. The superior light fastness likely stems from UV-absorbing nature of the polyphenolic compounds, boosting the photostability of dyed textiles. This work demonstrates that methanolic plant extracts, particularly the blend of B. arundinacea and T. arjuna, can be effectively utilized for eco-friendly functional finishing of cotton fabrics. This study demonstrates that methanolic extracts, particularly those of B. arundinacea–T. arjuna blend, overcome these limits by enhancing bonding, light fastness, and sustainable finishing. FTIR analysis provided strong evidence of chemical deposition and interaction, while shade fastness tests confirmed the permanence of the remedies. The findings highlight the potential to develop natural, sustainable, and high-performance textile coatings utilizing phytochemical-rich botanical sources.

Keywords: *Bambusa arundinacea, Terminalia arjuna, Jatropha curcas, phytochemical finishing, FTIR spectroscopy, color fastness, cotton fabrics, eco-finishing.*

INTRODUCTION

The textile industry is also the subject of rising concerns about environmental pollution and health hazards. Traditional textile processing often utilize synthetic dyes, chemical mordants, and finishing agents, many of which generate toxic effluents and non-biodegradable waste. With the increasingly urgent problems of global sustainability, particularly in terms of stricter environmental laws and regulations, alternative and green technologies have received more experimental research in the field of dyeing and textile functional finishing. Among them, plant-based extracts have emerged as the most attractive approach, not only for their environmentally friendly nature but also for their functional properties, such as antimicrobial, UV-protection, and antioxidant effects [13] [20]. Phytochemicals, such as polyphenols, flavonoids, tannins, alkaloids, and terpenoids, can bind to textile fibers through a phytochemical reaction upon direct consumption. These chemicals enable the addition of much functionality to textiles, and the dependence on synthetic chemicals can be minimized [2]. As demand for bio-functional textiles increases, there is a growing interest in the scientific community to explore and characterize plant sources

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DOI: https://doi.org/10.21276/AATCCReview.2025.13.04.248

that can function as both natural colorants and functional agents [5] [13].

Bambusa arundinacea, *Terminalia arjuna*, and *Jatropha curcas* are some of the plants endowed with high bioactive constituents, and their pharmacological attributes have been widely acknowledged. *B. arundinacea* possesses a fast-growing nature and is known for its antioxidant, antimicrobial, and anti-inflammatory activities [3] [8] [22]. Its leaves have been reported to contain derivatives of chlorogenic acid, caffeic acid, and quercetin, with a high reactivity [16]. *T. arjuna*, a tree species of historical use in phytotherapy, has a wealth of hydrolysable tannins, gallic acid, and flavones, and it serves as a natural mordant and bioactive agent [2] [5] [24]. *J. curcas*, especially its roots, is a rich source of phenolic compounds, diterpenes, and saponins with a wide range of biological activities; hence, the plant is a candidate for textile functionalization [1] [7].

The textile utility of these extracts has been achieved by the good association between compounds and fibres. Fourier transform infrared (FTIR) analysis, a non-destructive and highly sensitive technique used to detect and validate functional groups that are present in plant extract and the treated fabrics. FTIR correlates the type of interaction – physiadsorption or chelation – of the phytochemical with the cellulosic matrix of cotton. The absorption bands for OH–, C=O, C–H (aliphatic), and aromatic structures are characteristic bands that can be used to monitor changes in the chemical composition before and after treatment [5]. This investigative methodology is crucial for verifying the integration of bioactive substances into textile fibers and for understanding the bonding processes that occur. FTIR provides confirmation at the chemical level, and the practical durability/performance of the treated textiles is assessed through standard color fastness tests. These trials are crucial for evaluating the potential of plant-based treatments in real-life applications, where fabrics must withstand physical stress, washing, and environmental elements.

Fastness to rubbing is another very important factor indicating the mechanical resistance of treated fabric to friction, both in dry and wet conditions. It quantifies the substance on the fiber surface with which the applied substances remain attached during handling or as a result of friction [22]. Good rubbing fastness implies a strong binding of biologically active agents to the textile material. Color fastness to washing tests the resistance of the treatment to laundering. It calculates how well the natural complexion survives exposure to water, soaps, and mechanical rubbing [2]. Low wash fastness can indicate poor bonding or solubility of the active components, a crucial factor when considering fabric maintenance and consumer usage.

Another key factor to consider is light fastness, especially for outdoor textiles or those exposed to high levels of light. This test measures the material's resistance to fading or discoloration by exposure to sunlight or artificial light sources. Many plant-based dyes contain chromophores, which are susceptible to photodegradation; thus, a high light fastness rating implies a longer shelf life and greater visual stability [20]. These two techniques — FTIR spectroscopy (for characterization) and fastness testing (for functionality) — employed together provide a holistic approach to the quality assessment of plant extract-treated textile products. They provide information on both chemical resistance and mechanical durability, the two key criteria for commercial acceptance.

In the present study, the use of extracts from *B. arundinacea*, *T. arjuna*, and *J. curcas* on cotton fabric has been investigated as green bio-functional finishing agents. By testing the material through spectroscopic characterization and slot-die coating-derived performances, this work contributes to the field of green textile technologies and supports the development of green alternatives to conventional chemical processing.

MATERIALS AND METHODS

Plant material and extract preparation

Fresh leaves of *B. arundinacea*, bark of *T. arjuna*, and root of *J. curcas* were collected from the licensed herbal nurseries and identified by an experienced botanist. The plant parts were further shade-dried at room temperature for 10–15 days to extract the bioactive compounds. Ground samples were then milled into a fine powder using a high-speed stainless steel mechanical grinder and stored in air-tight containers. Soxhlet extraction was performed for 8 hours using analytical-grade methanol (Merck) in a 1:10 (w/v) proportion. The extraction was performed at 65–68°C to maximize the recovery of the thermolabile phytoconstituents. The extracts were filtered and concentrated by a rotary evaporator (Buchi Rotavapor R-300) with the temperature set at 40°C under reduced pressure. The dried residues were dissolved in deionized water (ddH_2O) and stored in amber vials at 4°C to protect them from degradation by oxidation. A binary extract mixture in the ratio of *B. arundinacea* :*T. arjuna*, with a ratio of 90:10, was prepared to analyze the combined performance in textile applications.

Cotton fabric treatment

A piece of 100% cotton plain-woven fabric, weighing 200 GSM and having a thread count of 80×76, was obtained in greige condition and pre-treated for enhanced absorbency. The fabric was then sequentially scoured (2% NaOH) and bleached (3% hydrogen peroxide) at 90°C for 1 hour. Samples were air-dried after rinsing and cut into test-size swatches (20 × 20 cm). Mordanting was carried out with alum (potassium aluminum sulfate) at four different concentrations, 0%, 5%, 10% and 15% (w/v). Fabrics were soaked in the mordant solution for 1 h at 60°C and washed and dried. For treatment, extract solutions were prepared at a concentration of 5% (w/v) in an ethanol (70%):water (30%) mixture and were stirred at 500 rpm until complete solubilization. Aqueous solutions containing the extracts or blends were added, and the fabric samples were immersed for 1 h at room temperature. Once evacuated, the samples were dried in air and then thermally dried at 100 °C for 5 min in an oven with hot air, to promote the fixation of phytochemicals on the fiber matrix.

FTIR spectroscopy and instrumentation

The samples were analyzed using FTIR (Thermo Nicolet iS5, Thermo Scientific, EU), with an Attenuated Total Reflectance (ATR) accessory featuring a diamond or ZnSe crystal. The instrument was calibrated using a polystyrene reference standard to ensure spectral accuracy and reproducibility prior to analysis. The samples used were methanolic extracts and cotton fabrics treated. Solid samples were placed directly onto the ATR crystal, and constant contact was provided by a pressure clamp. All spectra were recorded in the wave number range of 4000–500 cm^{-1} at a resolution of 4 cm^{-1}, with an average of 16 scans. Each sample was measured three times to confirm reproducibility. Data processing, baseline correction, spectral smoothing, peak deconvolution, and automatic peak assignments were performed using OMNIC software.

The major functional groups were determined: hydroxyl and amine (O–H/N–H) stretching: 3200–3600 cm^{-1}, alkane (C–H) stretching: 2800–3000 cm^{-1}, carbonyl (C=O) stretching: 1650–1750 cm^{-1}, aromatic/aliphatic (C=C) stretching: 1500–1650 cm^{-1}, and fingerprint vibrations: 500–1500 cm^{-1}. The spectra were correlated with IR information already reported in the literature to ensure the nature of the phytochemical signatures.

Rubbing fastness testing

Color fastness to rubbing was determined by a crock meter (Model: AATCC Crockmeter 5 Tester 7). For RDR, fabric samples of dimensions 14 9 5 cm were tested for both dry and wet rubbings. In the case of dry rubbing, the undyed test piece (5 × 5 cm) was fixed to the rubbing finger of the instrument and moved to and fro on the fabric surface with a load of 900 g for 10 cycles (20 strokes) on a 10 cm track. In wet rubbing, the undyed pieces of cloth were first immersed in distilled water and then squeezed to remove the remaining water before testing. Following rubbing, staining on the test cloth, and a change in shade on the fabric were rated in accordance with the gray scales of ISO norms (1 = unsatisfactory, 5 = excellent).

Wash fastness testing

The wash fastness of the treated cotton fabric samples was measured as per IS/ISO C10:2006 A (1) (RA 2021). A test specimen (10 × 10 cm) was placed between two undyed cotton cloths of the same size, and the sandwich was sewn around all edges to keep the alignment. A soap solution containing soda ash and neutral soap free from optical brighteners was prepared. The ratio of liquor to material was maintained at 50:1, and the washing was performed at 40 ± 2°C for 30 minutes in a mechanical launderometer. After washing, specimens were rinsed in tap water, air-dried, and the color change and staining were assessed using gray scales. Data are from three independent experiments and presented as the mean ± SD.

Light fastness testing

Light fastness was assessed by a xenon arc light fastness testing apparatus according to IS/ISO 105-B02. The treated cotton fabrics were affixed to card holders in combination with standard blue wool reference fabrics (grades 1–8). One-half of the fabric was covered with a piece of opaque aluminum foil to exclude light and facilitate a direct comparison. The exposure chamber was equipped with a xenon arc lamp that emitted simulated sunlight with a spectral distribution at a correlated color temperature of 5500–6500K. UV radiation below 300 nm was blocked by optical filters, and light transmission limits in the visible and near-UV wavelengths ranged from 370 to 380 nm. The controlled exposure time ranged from 8 to 34 hours, depending on the fabric and extract. The color fading was evaluated by comparing the irradiated area with the unexposed area and with blue wool standards. Scoring was based on a scale from 1 (very poor) to 8 (outstanding) for three biological replicates.

Data documentation and statistical interpretation

Experiments were performed in triplicate to guarantee the reliability. Rubbing, washing, and light fastness test results were presented as means ± standard deviations (mean ± SD). All FTIR spectral results (comprising raw data, treated spectra, and the peak tables) were stored in OMNIC format to be reproduced.

The performance of each plant extract was described using descriptive statistics under different mordant conditions.

RESULTS

FTIR spectra of *B. arundinacea*, *T. arjuna*, and 90:10 blend extracts, highlighting bioactive functional groups

FTIR evaluations substantiated the incorporation of important functional groups and the presence of phytochemicals in all the plant methanolic extracts and the treated cotton fabrics. *B. arundinacea* leaf extract revealed a wide O–H stretching band at about 3333 cm^{-1}, which suggests the presence of hydroxyl groups of polyphenols, lignin, and lignocellulosic compounds. Characteristic bands for the stretching of aliphatic C–H groups could be identified at 2918 and 2855 cm^{-1} (methylene and methyl groups of plant waxes and hemicellulose). A marked carbonyl stretch at 1712 cm^{-1} indicated the presence of ester or carboxylic acid groups from phenolic acid derivatives and lignin units. The additional peaks in the fingerprint region, at around 1625, 1426, 1313, and 1162 cm^{-1}, also provided further evidence of the presence of hemicellulose, aromatic rings, and ether linkages, indicating the complex biopolymeric structure of the plant (Fig. 1A).

The *T. arjuna* extract displayed similar hydroxyl and aliphatic signals with a broad O–H band at around 3279 cm^{-1} and intense carbonyl absorption at 1742 cm^{-1}, which corresponded to glycosidic esters and carboxylic acids. Aromatic vibration at 1608, 1517, and 1313 cm^{-1} indicated the existence of flavonoids and tannins, and the other adsorption between 1100–1050 cm^{-1} was attributed to C–O–C vibration in glycosides and polysaccharides (Fig. 1B). These functional groups contribute to the cardioprotective, antioxidant, and anti-inflammatory phytochemical profile of *T. arjuna*. The binary blend (90:10 of *B. arundinacea* and *T. arjuna*) exhibited combined spectral patterns with an enhanced O–H vibration at 3390 cm^{-1}, a carbonyl vibration at 1711 cm^{-1}, and overlapped bands of aromatic and ether groups at 1455, 1390, and 1337 cm^{-1}. The fingerprint region spectra at 933, 899, and 866 cm^{-1} indicated functional complexity and integration, illustrating the cross-talk between polyphenols, flavonoids, and other bioactive molecules (Fig. 1C).

FTIR spectra of cotton fabrics treated with *B. arundinacea*, *T. arjuna*, and their blend showing phytochemical deposition and surface functionalization

FTIR spectra of the modified fabrics revealed significant changes, confirming the successful loading of bioactive compounds. The treated fabric with *B. arundinacea* exhibited a strong peak of O–H stretching at 3390 cm^{-1}, an aliphatic signal at 2970 and 2855 cm^{-1}, as well as a carbonyl stretch at 1711 cm^{-1}, indicating the deposition of phytochemicals and interaction with cotton cellulose. Aromatic and ether-related bands of 1453, 1337, 1152, and 1079 cm^{-1} also indicated surface functionality increase as a result of polyphenol incorporation (Fig. 2A). The O–H and C–H stretching regions were characterized by the characteristic peaks for the *T. arjuna* treated fabric, with carboxylic acids indicating ester formation at 1710 cm^{-1}. The presence of flavonoid rings and glycosylated signals was observed at 1410 and 1319 cm^{-1}, which are unique signals. Meanwhile, the bands at 1154 and 1047 cm^{-1} were associated with aromatic ethers and secondary alcohols, indicating good retention of bioactives (Fig. 2B).

Compared to cotton, the bamboo-dominated characteristics were found to be more significant in blend-treated cotton, which

presented intense O–H (3340 cm^{-1}), C–H (2894, 2852 cm^{-1}), and aromatic (1432, 1316 cm^{-1}) bands. Small but noticeable peaks at 1161 and 1110 cm^{-1} were assigned to *T. arjuna* polyphenols. Fingerprint bands at frequencies below 700 cm^{-1} suggested profound molecular interactions that may involve hydrogen bonds or covalent linkages with the fiber matrix (Fig. 2C).

FTIR spectral analysis of cotton fabrics treated with *J. curcas* root extract versus untreated control

J. curcas-treated cotton showed broad surface modification, as can be seen in the FTIR spectrum. A strong O–H band at 3399 cm^{-1} and the aliphatic C–H stretching peaks at 2967, 2925, and 2855 cm^{-1} outlined the presence of long-chain fatty acids and saponins. The clear ester peak at 1710 cm^{-1}, as well as the other observed bands at 1400, 1241, and 1153 cm^{-1}, confirmed the immobilization of bioactive flavonoids and quinones. Peaks corresponding to such aromatic and phenolic residues were visible in the fingerprint region at 933, 879, and 720 cm^{-1}, and confirmed the enrichment of a biospecific surface (Fig. 3A). The non-treated control cotton, on the other hand, exhibited little spectral activity, except for the peaks characteristic of native cellulose, and lacked the bioactive specific signals (Fig. 3B).

Comprehensive evaluation of color fastness properties of alum-mordanted cotton fabrics treated with plant extracts

Good color fastness was also observed for all treated fabrics in the standardized test conditions. The rubbing fastness (dry and wet) was found to be dependent on extract concentration and mordant utilization. Dry rubbing fastness was in the range of 3-5. The highest fastness was observed in all samples treated with 10% and 15% extract, and particularly when using 5% alum as a mordant. The wet rubbing values were slightly lower (2–4), although compared to untreated samples, the alum-treated samples exhibited superior fastness to washing, which can be attributed to better retention after fixation, reflecting a stronger bond of the phytochemical due to the fixation mediated by the mordant (Table 1).

Good wash fastness was also observed in wash fastness tests, particularly for fabrics treated with lower concentrations of the extract. For all control samples, their Cc was consistently 5, while for treated samples, the value ranged from 2 to 4, depending on the degree of extraction saturation and the concentration of the mordant. Color staining (Cs) on the undyed fabric adjacent to it is in the range of 3-4, indicating low dye bleeding and good wash fastness of the dye (Table 2). The light fastness data verified the involvement of the UV-absorbing plant constituents in improving photostability. Fabrics treated with a 90:10 blend of extracts and 5% mordant alum scored 7 on the blue wool scale in fading, while the control (untreated) scored 6, indicating better resistance to fading under xenon lamp exposure. This improvement is probably a result of the abundant quantity of polyphenols, quinones, and other antioxidants, which acted as natural UV protectors (Table 3, Fig. 4).

DISCUSSION

Chemical characterizations of methanolic extracts of *B. arundinacea*, *T. arjuna*, and *J. curcas*, and their application to cotton fabrics, have essentially demonstrated the efficacy of these natural sources for biofunctional textile finishing [12] [14] [16] [17] [19] [21]. The FTIR spectroscopic profiles of the extracts have revealed the presence of a wide variety of functional groups, including hydroxyl, carbonyl, aromatic, and ether moieties, which are significantly related to bioactivity and surface binding properties. This can be attributed to the phytochemical richness of the tested plants and their indigenous use for medicinal and antimicrobial purposes [15].

The strong O–H stretching bands of all extracts suggest the presence of a high content of polyphenol compounds, flavonoids, and tannins, which not only provide antioxidant protection but also are responsible for hydrogen bonding with cellulose fibers and are very important. Aliphatic C–H groups and strong carbonyl bands in the ester and acid regions indicate the complex biological nature of the extracts, which also include waxes, fatty acids, and phenolic acids, thereby enhancing interaction with textile substrates [18] [23]. The enhancement in bands in the coextracts, especially, may be due to a possible additive interaction between *B. arundinacea* and *T. arjuna*, resulting in a denser and functionally diverse composition of phytochemicals [4]. When applied to cotton fabrics, these chemical properties were successfully transferred to the fiber surface, as evidenced by the appearance of new FTIR bands and an increase in the intensities of these bands [18] [23]. The improved spectra feature in the treated fabrics indicates not only surface binding but also penetration and interaction at the molecular level, which could occur through hydrogen bonding and possibly weak esterification or ether linkages [4]. The addition of mordant, specifically alum, enhanced these interactions through the formation of coordinate bonds, likely with both phytochemicals and the hydroxyl-rich cellulose matrix, resulting in improved durability and fastness.

Rubbing fastness results confirm that extract concentration and mordant presence are the main factors affecting colour retention under mechanical stress. The dry and wet performance of the cotton also improved with increasing the extract concentration, which may be attributed to a thick, coverage- or adhesive-based, phytochemical layer on the surface of the cotton. Alum was found to be instrumental in improving the adhesion between the particles of the resulting network and most likely worked as a cross-linker between the plant-based compounds and cellulose hydroxyl groups. This tendency is even slightly exaggerated in wet rubbing tests, where non-mordanted samples have also yielded lower results due to lower fixation.

Washing fastness is an additional indication of the mordanting and treatment process. Similarly, some of the extracts demonstrated a slight loss of color at higher concentrations yet remained within acceptable criteria [9] [11]. This data indicates a compromise between chromatic richness and wash permanence: lighter (lower concentration) deposition afforded more anchorage and less bleeding, whereas heavier deposition gave deeper shades, but with slight loss of stability. However, the overall wash fastness of these natural compounds suggests that they can be stably attached to cotton, particularly when the treatment involves aluminization [10].

A notable result from this study is improved light fastness of treated fabric. The protection of polyphenols, tannins, and quinones, which are known to absorb ultraviolet (UV) radiation and thereby inhibit the photo degradation of organic substrates, is significant under xenon light. These compounds would likely act as UV natural filters, causing energy transfer to decline, which leads to most dyes bleaching and fibers easily decomposing [9] [10] [11]. The higher activity of blend-treated fabrics suggests that blending plants could provide respective compounds with higher density and diversity, contributing to promoting light fastness.

Treatment of cotton with *J. curcas* root extract also demonstrated strong chemical interactions that resulted from the presence of fatty acids, quinones, and flavonoids on the surface [6] [7]. The strong treated peaks around the esters and O–H bands were the strong links with phytochemicals. These chemicals are not only bioactive but also, to some extent, hydrophobic, and may have additional protective effects, such as water repellency and inhibition of microbial adhesion. Their functionalization on cotton has been reported to improve both their chemical composition and functional properties, which fits with the degradation of sustainable and performance textiles.

Future scope of the study

The findings of this work highlight the potential of *B. arundinacea*, *T. arjuna*, and *J. curcas* extracts for sustainable textile finishing, but further studies are needed to strengthen their industrial relevance. Future research may focus on advanced chemical characterization of the active compounds, evaluation of long-term durability under repeated washing, sunlight, and wear conditions, and the extension of these treatments to other natural and blended fibers. Exploring additional functional properties such as antimicrobial resistance, hydrophobicity, and biodegradability will broaden their applications in high-performance textiles. Furthermore, optimizing mordanting processes and scaling the methodology to pilot and industrial levels will be essential for commercial adoption. Blended formulations, nanotechnology-based delivery systems, and greener extraction methods also present promising directions to enhance performance and sustainability in eco-friendly textile innovations.

Table 1: Rubbing fastness ratings of alum-mordanted cotton fabrics treated with 0% (control), 5%, 10%, and 15% extract concentrations, evaluated under dry and wet conditions

Mordant and its conc.	Rubbing fastness							
Alum	Dry				Wet			
	Control	5%	10%	15%	Control	5%	10%	15%
	4-5	4	5	5	4	4	4	4
	4	4	4	4	4	4	3	3
	3	3	2	3	3	3	3	2
	3	2	3	2	4	3	2	3
	3	2	3	3	3	2	2	2

Table 2: Wash fastness ratings of alum-mordanted cotton fabrics at 0% (control), 5%, 10%, and 15% extract concentrations, evaluated under color change (Cc) and color staining (Cs) conditions

Mordant and its conc.	Wash fastness							
Alum	Cc				Cs			
	Control	5%	10%	15%	Control	5%	10%	15%
	5	4			4	3-4		
	4	3-4			4	3		
	4	3			3	3		
	3	2-3			3	3		
	3	2-3			4	3		

Table 3: Light fastness ratings of cotton fabric treated with a 90:10 ratio of B. arundinacea:T. arjuna extract and 5% alum mordant

Extract concentration	90:10 (*B. arundinacea*:*T. arjuna*)	
Mordant	Control	Mordant conc. (5%)
Alum	6	7

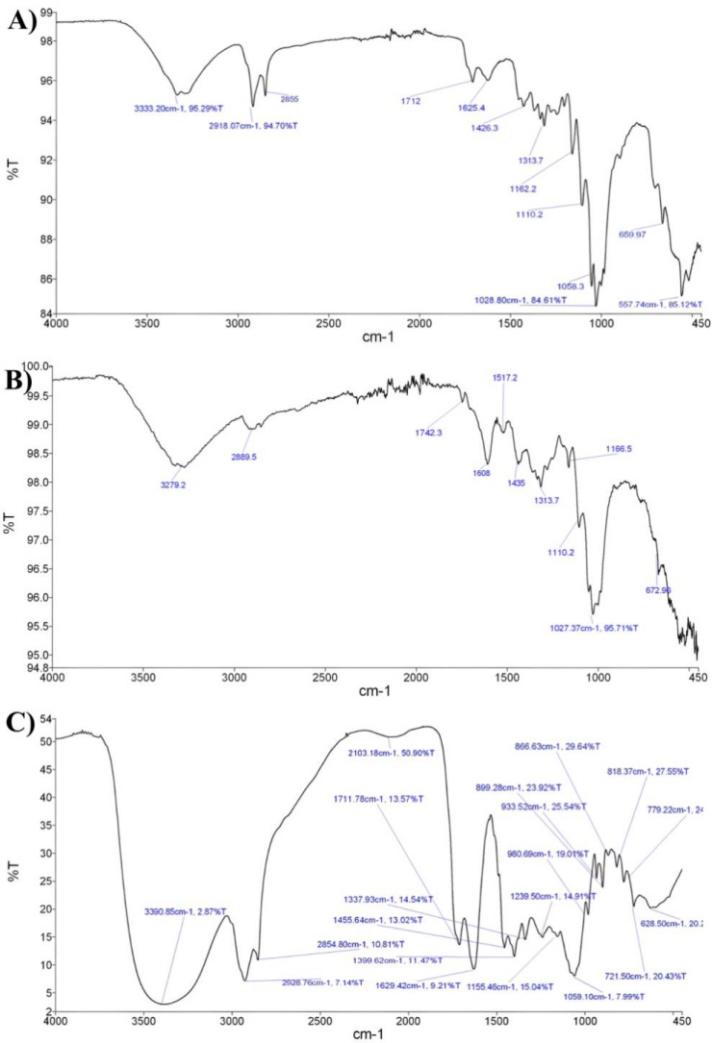
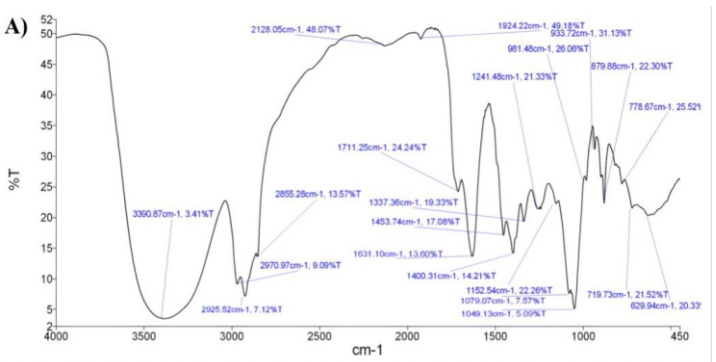


Figure 1: FTIR spectra of (A) 100% *B. arundinacea* leaf extract, (B) 100% *Terminalia arjuna* bark extract, and (C) their 90:10 mixture, highlighting key functional groups such as hydroxyl, carbonyl, and C–H stretching, along with the presence of major bioactive compounds, reflecting the complementary properties of both extracts.



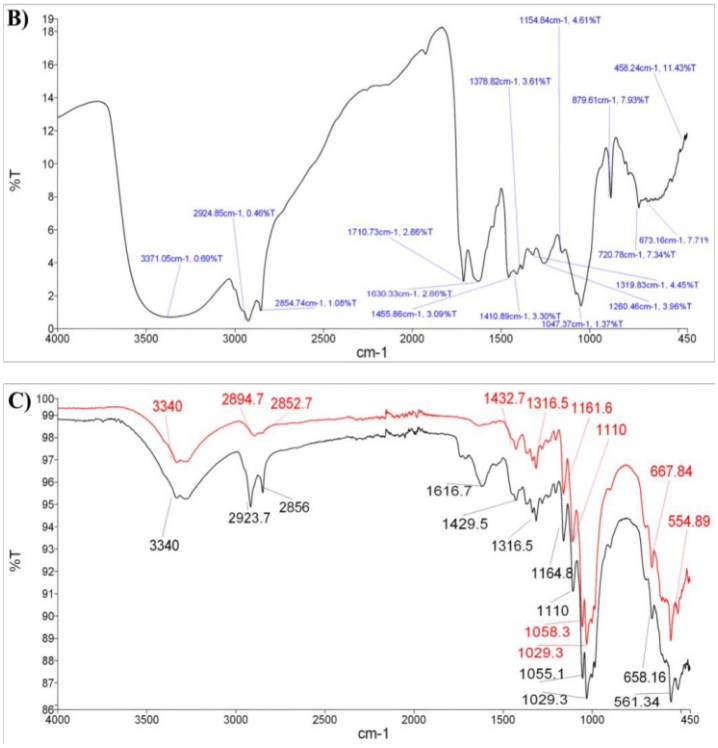


Figure 2: FTIR spectra of cotton fabrics treated with (A) *B. arundinacea*, showing O–H, aliphatic, carbonyl, and aromatic bands, indicating the presence of bamboo bioactives; (B) *T. arjuna*, with notable shifts in hydroxyl, aliphatic, and aromatic regions, reflecting enhanced functional properties; (C) a 90:10 *B. arundinacea:T. arjuna* mix, dominated by bamboo features with minor aromatic and C–O signals from *T. arjuna*, suggesting the presence of polyphenols and flavonoids.

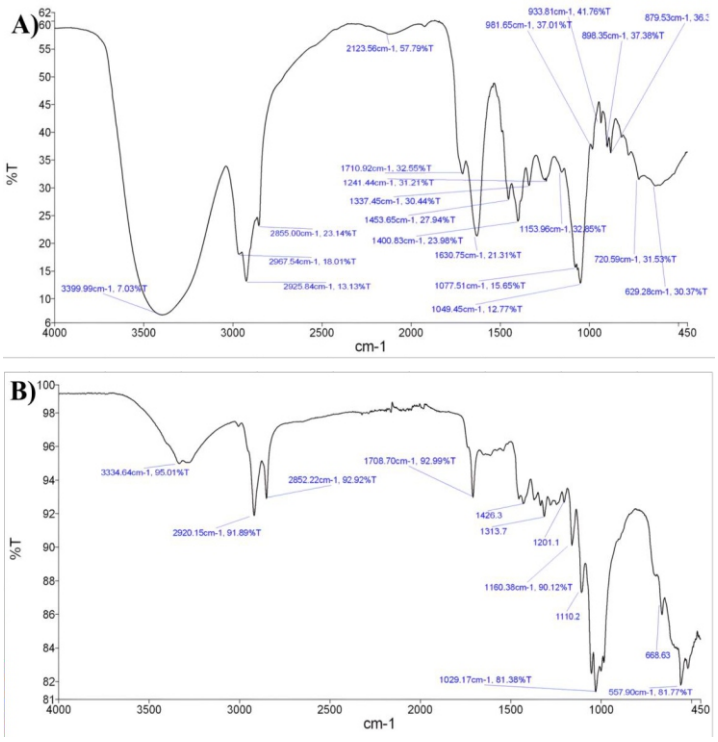


Figure 3: FTIR spectra of *J. curcas*-treated cotton fabrics: (A) with root extract, showing chemical modifications and bioactive deposition; (B) highlighting changes in hydroxyl, aliphatic, carbonyl, and aromatic regions, indicating improved antimicrobial, bioactive, and UV-protective properties.

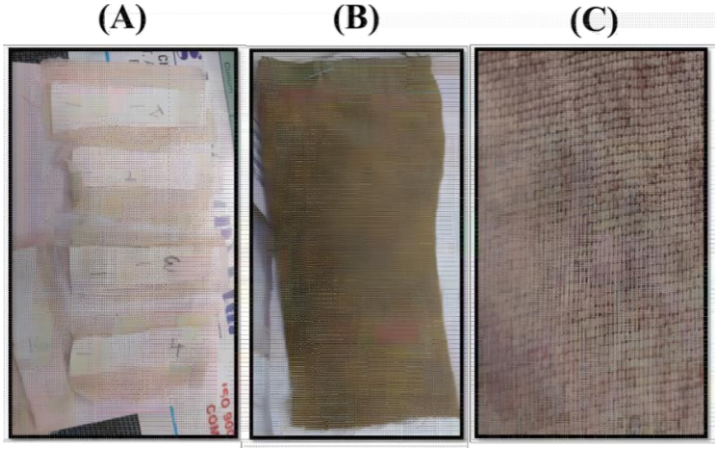


Figure 4: Evaluation of color fastness in cotton fabric treated with *B. arundinacea* and *T. arjuna* extracts: (A) fabric sample arranged for Laundrometer testing, (B) treated fabric before washing, and (C) samples after washing.

CONCLUSION

The present study clearly demonstrates that the excellent surface functionalization of cotton fabrics can be achieved using methanolic extracts of *B. arundinacea*, *T. arjuna*, and *J. curcas*. FTIR vibrational study substantiated the existence and effective functionalization of significant bioactive reactive sites, hydroxyl, carbonyl, and aromatic functionalities onto the cotton matrix, strongly suggesting effective phytochemical interaction and modification. The rubbing, washing, and light fastness results demonstrate the strength and fixability of these natural treatments. Better performances, especially when alum mordant is employed, demonstrate the significant role of mordanting in enhancing adherence and fastness. The 90:10 blend of *B. arundinacea* and *T. arjuna* exhibited synergistic properties, as evidenced by enhanced photostability and surface wet-out. Similarly, the enriched chemical and bioactive retained sample (fabric treated with *J. curcas* extract) stood out. These results provide support for the potential of *B. arundinacea*, *T. arjuna*, and *J. curcas* as sustainable sources of biofunctional textile finishes. These plant-based systems may thus provide a green, non-hazardous alternative to more conventional polymeric finishes and are particularly suitable for the emerging market of high-performance, environmentally responsible textile products.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research.

ACKNOWLEDGEMENTS

The authors did not receive any funding or external support for this research and have no acknowledgments to declare.

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