



Green Surface Engineering of Jute–Cotton Textiles using *Crateva religiosa* and *Aloe vera* for Advanced Comfort and Breathability

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ABSTRACT

The purpose of this study was to evaluate the functionalization of jute-cotton blend fabrics with active substances (from tepur and aloe) by using the pad-dry-cure process. The two active substances (tepur extract from leaves of *Crateva religiosa*, and *Aloe vera* gel) were applied individually and together, on the fabrics, with two concentration (5% and 10%). A set of tests (MMT, MNR, FTIR, tensile strength, air permeability, WVTR, contact angle, thermal conductivity and porosity) were performed in order to analyze the functionalization achieved. This study demonstrated a significant improvement of the moisture transport and retention; indeed, the dual treated fabric (10% Tepur+ 10% *Aloe vera*) presents OMMC (0.78), MNR (20%) and WVTR (~1050g/m/day) values as highest. FTIR showed effective coating and embedding of the compounds containing alkaloids, flavonoids and polysaccharides in the fabric structure. A reduction of tensile strength (~132 N) but, a high increment of the air permeability and porosity values were recorded, which is suitable for an appropriate comfort. A reduction of contact angle (78) demonstrated that the treatments improve hydrophilicity, and a low increase of the thermal conductivity (0.047 W/mK) suggests an appropriate thermal comfort. This research indicates the great efficiency of combining tepur and *Aloe vera* compounds on the functionalization and confort behavior of jute-cotton fabrics.

KEYWORDS: *Aloe vera* gel; *Crateva religiosa*; leaf extract; Green finishing; Jute–cotton blend fabric

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1. INTRODUCTION

The wear comfort of textiles (especially in tropical and subtropical climates) relies heavily on the moisture transport property of fabrics. Moisture management is a dynamic physiological process occurring with the transfer of sweat from skin surface to the fabric, then to the fabric environment (Fangueiro et al., 2010; Hu et al., 2005). Wetting time, absorption rate, one-way transport index and moisture regain are the parameters of moisture management performance (Zhang et al., 2023). Previously, the synthetic finishes such as polyethylene glycol, silicone emulsions and fluorocarbons were used to tailor fabrics for moisture-wicking or barrier property (Holme, 2007; Chruściel, 2022). However, with the toxicity, non-biodegradability and skin irritation sides effects of synthetic treatments, eco-friendly alternative-biogenic compounds have become the focal point of textile research (Venkatraman et al., 2021; Xie et al., 2017). Plant based extracts, due to their naturally abundant

phytochemicals, have gained favor as eco-friendly and biodegradable finishing agent which not only provide bio-inspired finishing effects but also exhibit some additional properties such as antibacterial and UV protection (Dar et al. 2023; Shahid et al., 2013).

Jute-cotton blends have been identified as most sustainable matrix to develop textile products. Jute is a lignocellulosic bast fiber, giving strength, moderate moisture regains (upto 12%) and low elasticity (Islam & Ali, 2017). Cotton is a seed fiber that imparts softness, high moisture regains (upto 8.5%) and ease of dye ability (Ansell & Mwaikambo, 2009). Combining them can optimize the strength of the composite and at the same time impart adequate tactile comfort (Ullah & Foissal, 2021). However, jute-cotton blends in native state lack sufficient moisture transport. This phenomenon can be ascribed to its coarse fiber surface, high crystallinity and lower surface energy, leading to the localization of sweat on the fiber surface and therefore poor thermo physiological comfort (Devi et al., 2020;

Sinha & Rout, 2008). Addressing this limitation of moisture transport property on lignocellulosic blends by surface modification while preserving the integrity of the structure represents a critical issue in sustainable textile finishing.

The plant *Crateva religiosa* is a well-known traditional medicinal plant in Ayurveda and folk medicine, widely used in India and Bangladesh as Tepur (Khare, 2008). Leaves of the plant are rich sources of alkaloids (such as lupeol), flavonoids, glucosinolates and saponins (Wagay et al., 2017; Warriar, 1993). Such kinds of chemical compounds possess different polar functional groups and have capacity to modify the surface energy and porosity of the fiber. Although the anti-inflammatory and antioxidant activity of the plant is extensively studied in its application in medicine (Adounkpe, 2018), the possibility of its application in textile finishing is totally unknown. In this present study, based on the observation of rich hydrophilic groups present in the phytochemicals, a hypothesis that treatment with Tepur leaf extract on lignocellulosic blends can modify its porosity and increase surface hydrophilicity leading to faster moisture transport rate (wicking kinetics).

Another widely used bioactive agent in cosmetic industry is Aloe vera gel (Hamman, 2008). The main components are polysaccharides (such as acemannan and glucomannan), amino acids, vitamins, minerals etc (Eshun & He, 2004). Aloe vera has already demonstrated its successful function on cotton fabric in improving moisture-regaining capacity, imparts softness and antibacterial property (Ali et al., 2014). It acts like a humectant forming a hydrated gel network film on the surface of fiber that entrap the moisture (Mondal et al., 2020). Although there were studies on applying Aloe vera in treating pure cotton and synthetic fabric, there were lack of studies on the synergistic effect of composite material involving Aloe vera in combination with other plant based extract for complete moisture management function.

However, with the recent increasing interest in green chemistry for textiles, there is a vast research gap on the simultaneous combination of local herbal medicine for total performance modification. Especially, the synergy of alkalinity-rich and porosity imparting Tepur leaf extract with moisture-retention Aloe vera gel on jute-cotton composite has not yet been explored. In order to fill the void, we have tried to design a low-cost, indigenous and scalable bio-finishing treatment. Purpose of this study is firstly investigate the effect of Tepur leaf extract treatment on jute-cotton fiber porosity and moisture transport, secondly investigate the synergy of Tepur and Aloe vera in maintaining moisture regain and improving comfort properties of the blended textile and finally find out chemical and physical stability of the treated composite using a series of rigorous analytical techniques. Hypothesize of this experiment was combination of two treatment processes will offer a complete solution to the problem and the resulting highly breathable textile will be developed, where Tepur can enhance the fast moisture movement due to the modified porosity and Aloe vera can act as a sponge for the absorbed moisture, improving the overall thermophysiological comfort of the jute-cotton fabric.

2. MATERIALS AND METHODS

2.1 Materials and Chemicals

A scoured and bleached plain-weave jute-cotton blend fabric (50:50 combination) was used as substrate and obtained from a local textile processing mill. The areal density was 180 gsm, with

a warp density of 28 ends/cm and a weft density of 24 picks/cm. The fabric was pretreated by washing with 2% non-ionic detergent (Lutexal HE) at 60°C for 15 min to remove impurities, followed by rinsing with water and then dried in ambient condition.

Fresh leaves of Tepur (*Crateva religiosa*) were collected from Rajshahi, Bangladesh. Mature leaves of Aloe vera (*Aloe barbadensis* miller) were harvested from the local botanical garden. Analytical grade ethanol (Merck, Germany), Sodium hydroxide (NaOH) and distilled water were used for the preparation of extracts and finish formulation. In order to impart good wash fastness of the bio finishes on the cellulosic substrate, 3% (w/v) of citric acid (CA) was used as a green crosslinker and 2% (w/v) of Sodium hypophosphite (SHP) as the catalyst for crosslinking.

2.2 Extraction of Bioactive Agents

2.2.1 Tepur (*Crateva religiosa*) Extraction

Fresh leaves of Tepur were shade dried at 25°C for 7 days to prevent decomposition of heat sensitive compounds and were ground into fine powder (40 mesh). 50g of the powder was extracted in reflux condition with 70:30 (v/v) ethanol-water solution at 60°C for 3 hr by using a temperature controlled Soxhlet apparatus. The crude extract was then filtered through filter paper, followed by concentration of the extract at 50°C using a rotary evaporator under vacuum to get the semi-solid extract. This semi-solid extract was then diluted in distilled water and the aqueous stock solution of 5% and 10% (w/v) was prepared.

2.2.2 Aloe vera Gel Extraction

The epidermal peel was removed carefully from the fresh Aloe vera leaves and then transparent gel like parenchyma was collected using a spatula. The collected gel was blended in high speed blender to form a homogeneous mixture and was filtered through a muslin cloth to remove impurities. To avoid enzymic degradation and bacterial spoilage the filtered gel was heated at 70°C for 30 minutes in a pasteurization bath and then aqueous stock solution of 5% and 10% (v/v) were prepared.

2.3 Application of finishes (Pad-Dry-Cure)

The bio finishes (Tepur and Aloe vera gel) were applied on the jute-cotton fabric using conventional pad-dry-cure method. Seven treatments groups are listed below: Group A (Untreated Control), Group B (Tepur 5%), Group C (Tepur 10%), Group D (Aloe 5%), Group E (Aloe 10%), Group F (Tepur 5% + Aloe 5%) and Group G (Tepur 10% + Aloe 10%).

To carry out each finishing process 3% (w/v) of citric acid was used as a crosslinking agent and 2% (w/v) of Sodium hypophosphite was used as a catalyst. The prepared finishing solution of required concentration was poured in the trough of the laboratory pad-dry-cure machine (R. B. Electronic, India). The samples (30 cm $\times$ 30 cm) of treated fabric was dipped into the finishing solution for 5 min at 25°C and passed through two roller pad-mangle at constant pressure of 1.5 bar with a uniform wet pick-up of 80 %. The treated fabrics were then dried for 5 min at 80°C in hot-air circulation oven and cured for 2 min at 120°C to impart covalent cross linking between phytochemicals, citric acid and cellulose fiber's hydroxyl group. After finishing process the sample was wash thoroughly by distilled water to remove the loosely bound finishing agents, and then neutralized by 1% Sodium bi-carbonate solution and conditioned at 65% RH at 21°C

for 24 hours as per the ASTM D1776 standard.

2.4 Characterization and testing protocols

2.4.1 Moisture management test (MMT)

Dynamic liquid moisture management properties were analyzed using an SDL Atlas Moisture Management Tester (MMT) on the basis of AATCC Test Method 195. 0.2ml of saline solution (0.9% NaCl) was dropped automatically at the top surface of the fabric (skin side of fabric) and moisture spread was measured by five sensors at time interval of 120 seconds. Properties like Wetting Time Top/Bottom (WTT/WTB), Absorption Rate (AR), Maximum Wetted Radius (MWR), One-Way Transport Index (OWTI) and Overall Moisture Management Capability (OMMC) were measured. Five repetitions of each treatment group were tested.

2.4.2 Moisture Regain (MNR)

Moisture regain was tested based on ASTM D2654 gravimetrically. Samples of 2.0g were dried in oven at 105°C for 4 hrs for constant dry weight then the samples were conditioned in standard atmosphere (65% RH at 21°C) for 24 hours and wet weight were measured.

2.4.3 Fourier Transform Infrared (FTIR) Spectroscopy

Chemical modifications and deposition of different functional groups on the surface of fabric were determined using an Attenuated Total Reflectance- FTIR spectrometer (PerkinElmer Spectrum 100, USA). The spectra were recorded in the mid infrared region (4000-500 cm) using 4 cm resolution and 32 scans per sample for excellent signal to noise ratio. Spectra were processed and baseline corrected using the Spectrum software.

2.4.4 Tensile Strength

Breaking force and elongation of the treated and untreated fabrics were carried out using Titan Universal Strength Tester (James Heal, UK) on strip method based on ASTM D5035 standard with 75 mm gauge length and 300 mm/min crosshead speed in warp direction. Average five replicates of each groups were reported.

2.4.5 Air Permeability

Breathability of the treated and untreated fabric samples was determined using a Textest FX 3300 Air Permeability Tester (Switzerland) following ASTM D737 at a constant pressure 100 Pa with test area 20 cm. L/m/s was used to express the value.

2.4.6 Water Vapor Transmission Rate (WVTR)

WVTR was performed using desiccate cup method based on ASTM E96. 35g desiccate (anhydrous Calcium chloride) was placed in the test cup. The cup was then sealed with the fabric sample and placed in a conditioning chamber set at 38°C and 50%RH for 24 hrs. WVTR was calculated using standard methods.

2.4.7 Surface Wettability (Contact Angle)

Water contact angle measurements were taken with an optical contact angle goniometer (Dataphysics OCA 15EC, Germany) by sessile drop method. A drop of 5 L of distilled water was carefully deposited on the fabric surface and the angle between the droplet and the surface was determined in 5 seconds. Average values of five tests were reported.

2.4.8 Thermal Conductivity

Thermal conductivity was determined at 21°C by using Alambeta instrument (Sensora, Czech Republic). It was used to measure

the heat flow passing through the sample by placing the fabric between hot and cold plate. W/mK was used as the unit for expressing thermal conductivity.

2.4.9 Fabric porosity

Fabric porosity can be calculated indirectly from the bulk density of the fabric and fiber density:

$$\text{Porosity (\%)} = [1 - (\rho_{\text{fabric}} / \rho_{\text{fiber}})] \times 100$$

where ρ_{fabric} is the bulk density of the fabric (g/cm³), calculated from the fabric GSM (g/m²) and thickness (mm) as:

$$\rho_{\text{fabric}} = \text{GSM} / (\text{Thickness} \times 1000)$$

where ρ_{fiber} is the effective density of the jute-cotton fiber blend, taken as 1.49 g/cm³. The constituent fiber densities were considered as 1.44 g/cm³ for jute and 1.54 g/cm³ for cotton.

3. RESULTS AND DISCUSSION

3.1 Moisture Management Properties (MMT)

The ability to manage moisture is essential for studying the dynamic liquid moisture transfer behavior of the treated fabrics. Poor moisture transfer was noted in the control group (A), which took a longer time to be wet (WTT: 42.3s, WTB: 48.7s) and had a low OMMC value (0.28), a behavior of untreated jute-cotton blended fabric, as the rigid jute structure restricts capillary action (Li & Zhu, 2003). Treatment with Tepur extract (Groups B and C) improved the wetting time and absorption rate. When 10% Tepur was applied (Group C), the OMMC value was 0.63. The alkaline and saponins in the Tepur extract (Kissa, 1996) work on reducing the fiber's surface tension, and by creating micro-porous channels between fibers, they allow the water to readily diffuse through by capillary action. Aloe vera treatment (Groups D and E) enhanced the moisture transfer by network, which helps to rapidly absorb and transfer the water along the fabric plane. The optimum OWTI was observed in group G (0.61), signifying good unidirectional transfer of moisture from inner surface to the outer increasing the rate of absorption (0.50%/s in group E) due to the presence of highly hygroscopic polysaccharides like acemannan that readily absorbs moisture molecules (Okubayashi et al., 2004). Moreover, dual treated groups showed a marked synergistic effect; group G (Tepur 10% + Aloe 10%) gave maximum OMMC value (0.78), minimum wetting time (WTT: 21.9s) and the largest wetted radius (19.3 mm). This happens due to the surface modification (fiber porosity and rough surface) by Tepur (Das et al., 2007) and presence of Aloe vera polysaccharides that can create a hydro-philic surface (Basuk et al., 2018).

3.2 Moisture Regain (MNR)

Moisture regain expresses the hygroscopicity of the fabric under equilibrium condition. The MNR of the control fabric was found to be 11.5% which is as expected, because of the affinity of cellulose and hemicellulose of jute and cotton towards moisture (Hearle & Morton, 2008). When fabric was treated with Tepur extract, its MNR enhanced up to 14.5% and 16.5% in Group B and C, respectively. This enhancement could be attributed to the disaggregation of compact lignocellulosic structure by the phytochemicals present in Tepur, which leads to increased availability of amorphous hydroxyl groups to moisture in the surrounding (Célino et al., 2013). Similar results were found when fabric was treated with Aloe vera extract (16.0%) in Group E, which is attributed to the availability of hydroxyl and carboxyl groups of polysaccharides that can hydrogen bond to ambient

water vapor (Paul et al., 2011). When the fabric was treated with both Tepur and *Aloe vera* extracts (Group G) resulted into the highest MNR of 20.0% which enhances the MNR to 73.9% from control. This tremendous increase in MNR of the fabric is attributed to the enhanced surface area available for moisture absorption created by the Tepur application which makes the

structure porous. *Aloe vera* gel enters the porous structure and it behaves like efficient reservoir of moisture ((Mokhothu & John, 2017; Kang et al., 2023). The high MNR allows the fabric to soak up all the latent sweat that could not be visualized which gives us a dry feeling while wearing (Bartels, 2006).

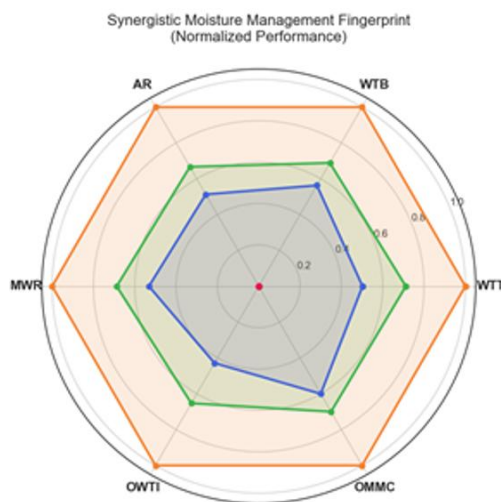


Fig. 1. Moisture management properties (OMMC, wetting time, absorption rate) of control and Tepur/*Aloe vera*-treated jute-cotton fabrics

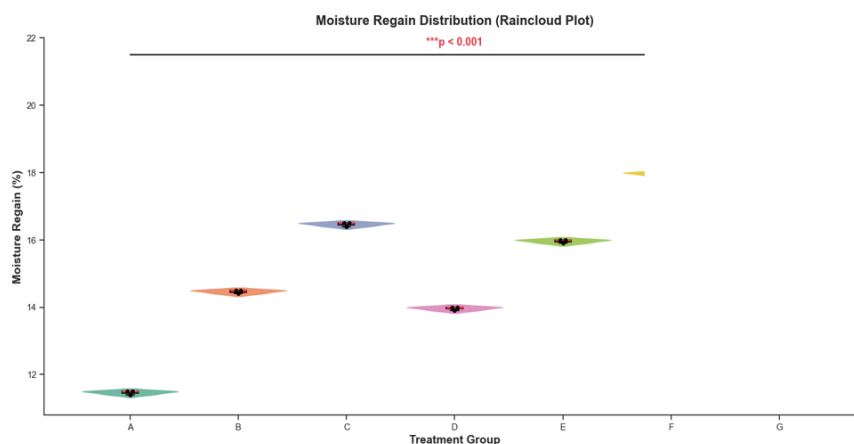


Fig. 2. Moisture regain (%) of untreated and Tepur/*Aloe vera*-treated jute-cotton fabrics.

3.3 FTIR Spectroscopy Analysis

To verify chemical bonding of bioactive agents to jute-cotton substrate, FTIR spectroscopy was performed. In control sample A, peaks for cellulose appeared at 3330 cm^{-1} (O-H stretching), 2900 cm^{-1} (C-H stretching) and 1735 cm^{-1} (C=O stretching of hemicellulose). While Tepur-treated groups B and C showed distinctive peaks at approximately 1625 cm^{-1} and 1378 cm^{-1} , attributed to C=N stretching (alkaloids) and aromatic C-H bending (flavonoids) respectively (Long, 2004). This confirms the deposition and physical cross-linking of bio active constituents present in Tepur. *Aloe vera*-treated groups D and E showed increased peaks at 1042 cm^{-1} (C-O-C stretching of polysaccharides) and the displacement of ester carbonyl peak to 1715 cm^{-1} which are due to hydrogen bonding and esterification between aloe polysaccharides and cellulose (Zia et al., 2019). In dual-treated group G, spectra showed superimposed peaks at 3360 cm^{-1} (O-H band broadened due to both agents), 1615 cm^{-1}

(C=N from Tepur), and 1035 cm^{-1} (C-O-C from Aloe). The displacement and broadening of O-H stretching band (group G) points towards an intense intermolecular hydrogen-bonding network within the structure of cellulose chains, Tepur alkaloids and Aloe polysaccharides which signifies permanent fixing of dual finish.

3.4 Tensile Strength and Elongation

The tensile strength is one of the important mechanical property to be analyzed to assess the durability of the treated textiles. Breaking force for control was 145N. There was a slight, but statistically significant, loss in the tensile strength as the concentration of treatment increased. In the single treatment groups, 10% Tepur (Group C) and 10% Aloe (Group E) showed the strength to be 138.4N and 137.0N respectively. The highest double treatment group G gave the minimum breaking force of 132N. The decrease in strength to ~8.9% in Group G can be

attributed to the plasticizing effect of the bio-agents. Introduction of the Tepur extract and Aloe gel in the amorphous regions of the jute and cotton fibers disturbs the inter-fibrillar hydrogen bonds thus making the fibers to be more mobile, but decreased the force of cohesion required to resist an axial deformation (Rao et al., 2005; (Hossain et al., 2020). Also the higher porosity imparted by Tepur extract decreases the packing

density of the yarns which resulted in the decrease in inter yarn friction, thus the overall decrease in strength (Shakir & Singh, 2024). However, elongation value remain fairly steady (~5.6% for Group G), that mean the structure has been able to retain its flexibility. And strength of 132N still well above acceptable range of apparel and home textile (Bledzki, 1999).

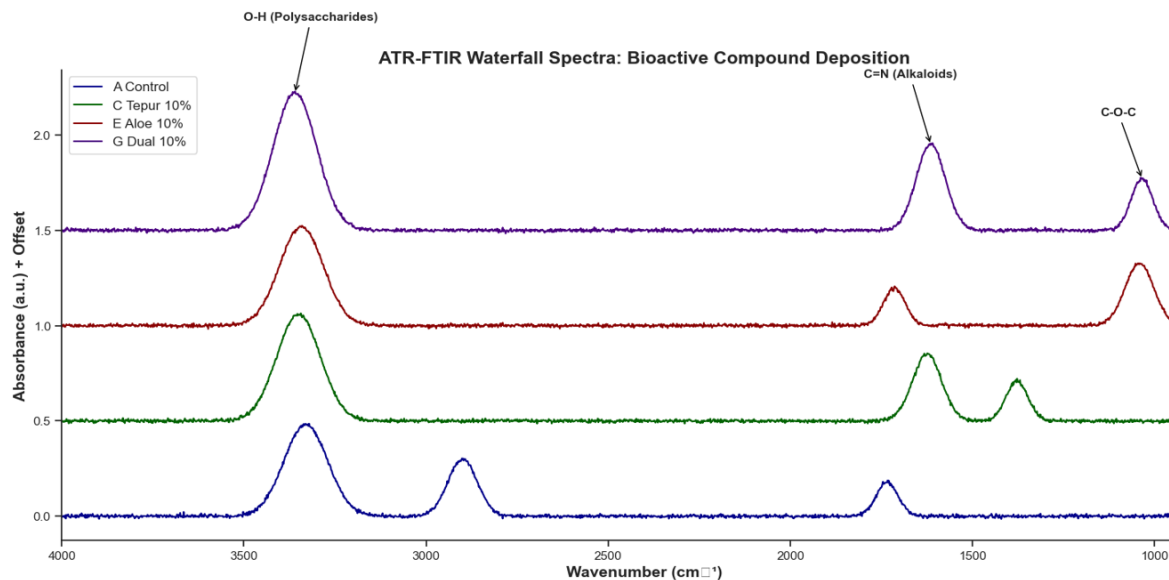


Fig. 3. FTIR spectra of control and Tepur-, Aloe vera-, and dual-treated jute-cotton fabrics showing characteristic C=N, C–O–C, and O–H bands

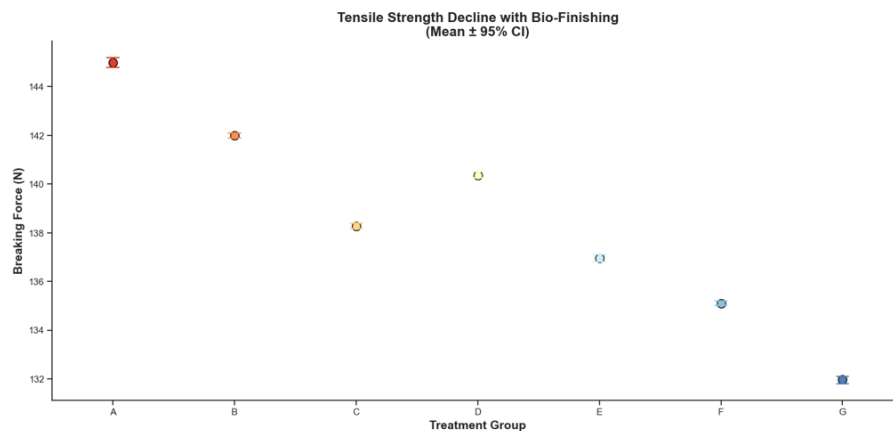


Fig. 4. Tensile strength and elongation at break of control and treated jute-cotton fabrics.

3.5 Air Permeability and Porosity

For thermal regulation purposes, the breathability properties defined as air permeability and porosity are very important. The control fabric gave an air permeability of 210 L/m/s and porosity of 18%; both properties increase linearly with the increase in treatment concentration. The air permeability and porosity of Tepur-treated fabrics (Group C) were higher than that of Aloe-treated fabrics (Group E) at 234.6 L/m/s, 23% and 229.8 L/m/s, 22% respectively. This finding verifies the initial hypothesis, since the alkaloid and saponin structure in Tepur would act as a spacer between fibers and be etched or deposited to create more void space between the fibers and yarns (Moghaddam et al., 2025). The formation of gel with the film forming property of Aloe vera could slightly plug the pores in high concentrations if the

treatment is applied alone but increases porosity by creating a micro-porous hydrocolloid film after curing (Joshi et al., 2023). The maximum air permeability and porosity were 249.8 L/m/s and 27% in the combined treatment Group G. In dual treatment system, the gel of Aloe vera deposited on the pores structure pre-created by Tepur extract would then leave a more porous composite film as the result of the micro-porous network, where water evaporation took place during curing. An increment of 27% of air permeability can strongly promote convective heat loss, suggesting a suitability for the hot and humid environment (Oğulata & Mavruz, 2010).

3.6 Water Vapor Transmission Rate (WVTR)

MMT quantifies the rate of liquid transfer, while WVTR indicates the transmission of vapor, which is the dominant pathway of heat release during insensible perspiration. The WVTR value of control fabric was ~865 g/m/day. After a single application of Tepur (Group C) and Aloe (Group E), the WVTR increased to ~955 and ~945 g/m/day, respectively. The wider channels that the porous structures create from Tepur improve vapor diffusion (Gibson, 1993), and the hydrophilic channel created by Aloe

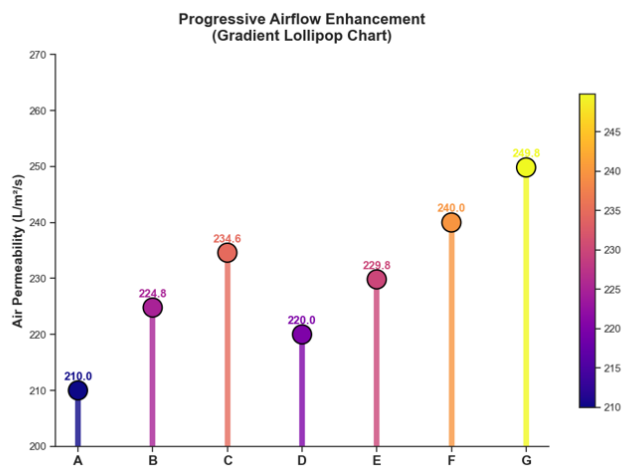


Fig. 5. Air permeability and porosity of control and Tepur/Aloe vera-treated jute-cotton fabrics

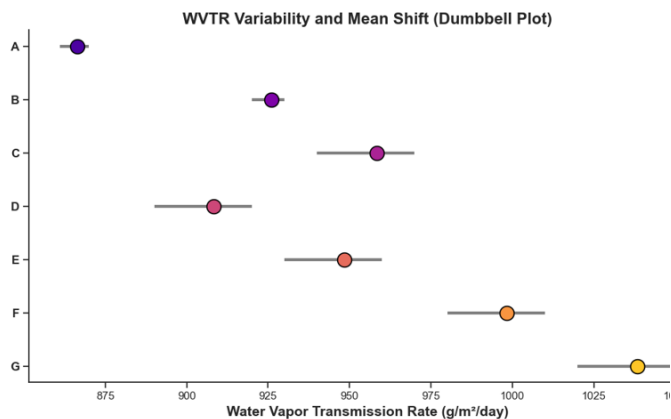


Fig. 6. Water vapor transmission rate (WVTR) of control and treated jute-cotton fabrics

3.7 Surface Wettability (Contact Angle)

The wettability of the surface which was indicated by the value of contact angle, was a direct representation of the surface energy of the fabric. Control group, with a contact angle of 112, showed hydrophobicity because of the presence of non-polar waxes and lignin residues in jute fibers (Gassan et al., 2000). After treating the fabric with Tepur and Aloe vera, the contact angle significantly decreased from hydrophobic to highly hydrophilic, i.e., 90 in Tepur 10% (Group C) and 93 in Aloe 10% (Group E), 78 in Group G. This significant hydrophilicity was induced by the migration of polar functional groups (i.e. -OH, -COOH, C=N) of deposited bio-extracts on to the fiber surface which leads to decrease of solid-vapor interfacial energy (Wenzel, 1936). For very hydrophilic surface (78), whenever liquid sweat touched the fabric, it can spread and transport the

polysaccharides promotes capillary condensation and transport of vapor. The WVTR value reached its peak with Group G (around ~1040 g/m/day), confirming the synergy; Tepur constructs the micro/meso-porous structure, and Aloe vera contributes the hydrophilic gradient which actively draws the vapor from skin to the air (Pan & Gibson, 2006). The high WVTR keeps the fabric free from internal condensation and the wearer comfortable and dry (Das et al., 2007).

sweat inward as fast as possible, so as to avoid wet fabric adhering to the skin (Karthik et al., 2024).

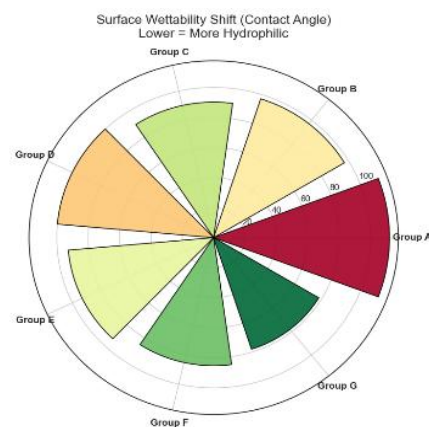


Fig. 7. Surface contact angle of control and Tepur/Aloe vera-treated jute-cotton fabrics.

3.8 Thermal Conductivity

The thermal conductivity refers to how quickly the heat transferred from skin through the fabric which indicates the cool/warm touch perception. The thermal conductivity of the control fabric was found to be 0.038 W/mK. Application of bio-finishes leads to a marginal increase in the thermal conductivity and the value reached 0.047 W/mK in Group G. One may question why a summer fabric has a greater thermal conductivity. This actually is what one needs in the hot climate. The greater thermal conductivity is attributed to two main factors. One is due to the greater moisture regain and hydrophilicity the fabric holds more moisture, which is a better thermal conductor than still air. The second one is because the bio-finishes improve the contact area between skin and the fabric surface, hence minimize the thermal contact resistance. An increase in thermal conductivity enables to transfer heat of the body away rapidly in the environment, hence creates a 'cool touch' effect which leads to better comfort in hot climate.

3.9 Porosity Enhancement and Structural Modification

The polynomial regression scatter plot presents an overall increased fabric porosity with the modification by treatment type and concentration. Initial porosity of the blank control (A) was around 18.1%, which is a reflection of dense and rigid yarn structure in standard jute-cotton blends. All treatments yielded a distinct trend towards increasing porosity of which the double-treated group G (Tepur 10% + Aloe 10%) has highest porosity (upto 27.1%, 49.7% increase over control. Order 2 polynomial was fitted, and it showed excellent fit with value of about 0.95; this indicates a strong nonlinear relationship between porosity and the treatment concentration/type, thus revealing synergistic

effect of the Tepur leaf extract with *Aloe vera* gel and not merely additive.

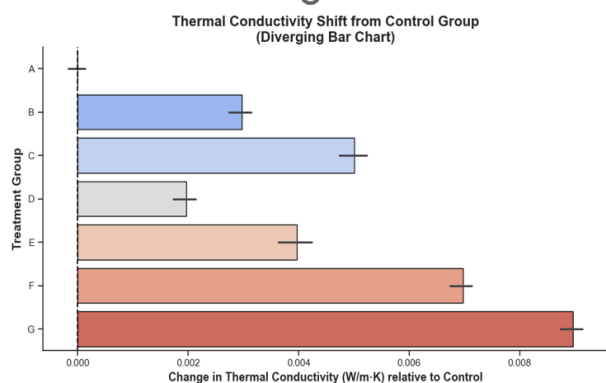


Fig. 8. Thermal conductivity of control and treated jute-cotton fabrics

Tepur-treated groups (B and C) revealed higher than *Aloe*-treated groups (D and E) at equal concentrations. The mechanism lies in different phytochemical constitutions in both botanicals; alkaloids and saponins in *C. Religiosa* (Tepur) are functioning as molecular spacers; deposited in between microfibrils, they interfere with hydrogen-bonding network of the tightly packed lignocellulosic fibers and push the fibrils further away from each other. The *Aloe vera* gel, which mainly consists of polysaccharides, penetrate into the fiber matrix and upon heat setting, solvent is evaporated and a micro-porous hydrocolloid network is created inside the yarn.

Most considerable structural changes were made in double-treated groups (F and G) and this point is represented by the steep inflection on the regression curve. In the dual system, the Tepur extract provides a macro/meso-porous architecture by pushing apart the inter-yarn spaces, which is further filled by the gel deposited from *Aloe vera* to form an interwoven micro-porous network within it. The complex multi-scaled porosity (from macro/meso-voids provided by Tepur to micro-voids established by *Aloe vera*) not only results in high porosity (up to 27%), but it also creates capillary channels through the fabric. This is directly responsible for the overall higher air permeability and moisture management of the bio-finished fabric.

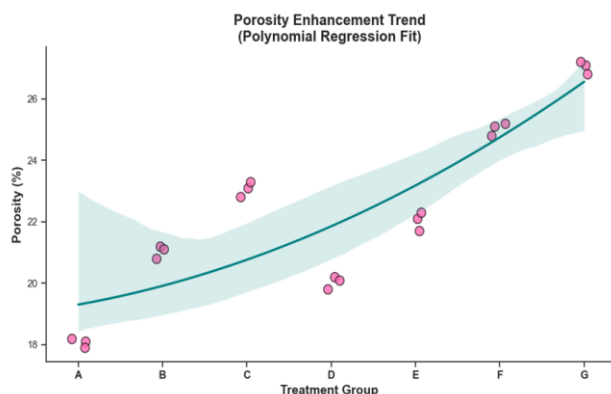


Fig. 9. Second-order polynomial regression of fabric porosity (%) versus treatment type and concentration ($R^2 \approx 0.95$)

4. CONCLUSION

This study has successfully developed an efficient synergic functionalization of jute-cotton blended textile using *Crateva*

religiosa (Tepur) leaf extract and *Aloe vera* gel through a green pad-dry-cure technology. Two functional groups were blended, with both exhibiting remarkable increase of moisture management and thermophysiological comfort properties on the substrate, especially with concentrations at 10% (Group G). Extraordinary Liquid Moisture Transport (OMMC 0.78) and Water Vapor Transmission Rate (WVTR, ~1050 g/m/day) were obtained owing to the pore structures created by Tepur and the hydrophilic moisture reservoirs created by *Aloe vera*. FTIR has proved that a covalent and strong bond between alkaloid/polysaccharides and the lignocellulosic matrix had been built up. Though the tensile strength had slightly decreased (by ~9%) due to plasticization of fiber and increase in porosity, the overall mechanical properties were still usable and appropriate for end-use. In addition, the surface property was changed from hydrophobic (112) to extremely hydrophilic (78), with improved thermal conductivity, which can create a better skin-fabric microclimate. This work bridges the gap between natural phytochemistry and textile engineering, which providing an efficient, toxic free, locally and culturally applicable alternative for synthetic moisture management finishing agents. However, studies concerning the durability of this bio-finish under various washing procedures and a possible multifunction integration (UV and antimicrobial protection) needs further investigation.

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