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Effect of combined enzyme and amino silicone finishing treatment on moisture characteristics of jute/cotton knitted fabric

R Prathiba Devi[1], R Rathinamoorthy[2,a] & P Senthilkumar[3]

[1] Department of Apparel & Fashion Design, [2] Department of Fashion Technology, [3]Department of Textile Technology, PSG College of Technology, Coimbatore 641 004, India

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This research work aims to increase the utilization of jute fibre in the commercial apparel sector by modifying its properties through silicone finishing treatment. In this work, a 40/60 jute/cotton blended yarn is flat knitted as single jersey fabric. The developed jute/cotton fabric is subjected to a combined enzyme and amino silicone finishing treatment to increase the softness of the fabric. Both the untreated and finished fabrics are evaluated for their moisture management ability as per standards. The findings show that the combined enzyme and amino silicone finishing treatment has significantly ($p>0.05$) influenced the moisture management properties of the knitted fabric. The one-way moisture transport capacity (OWTC) of the finished knitted fabric is rated as "very good" from "poor" (untreated). The overall moisture management capacity (OMMC) rating is also increased from "very poor" to "good" after finishing. The Pearson correlation analysis results reveal that the OWTC and OMMC indices are positively and linearly correlated to each other ($r^2 = 0.999$). The finishing process has modified the fabric properties from water repellent fabric to water absorption fabric. The findings of the research provide a new avenue for jute fibre as a component of day to day apparels.

Keywords: Air permeability**,** Amino silicone finishing, Enzyme finishing, Jute/cotton fabric, Moisture management analysis, Water vapour permeability

1 Introduction

Jute, generally known as golden fibre, is being considered as one of the sustainable fibres in the world and has a lot of potential applications. Jute is also considered as one of the best alternative materials for cotton fibre due to its cheaper cost and abundant availability. India is one of the largest producers of jute fibre and the Indian government has taken numerous steps in establishing research organizations and schemes to increase the use of jute fibre and products. Jute is mainly used in packaging applications due to its physical and chemical properties. As a bast fibre, it is very coarse and stiff. When compared to cotton, jute has a higher amount of hemicellulose and lignin contents in its structure and so it feels stiffer and looks yellowish in color[1]. The typical jute fibre has higher tensile strength and modulus with good dimensional stability. The jute fibre has higher absorption behaviors and possesses higher insulation to heat and sound[2]. Hence, the application of jute in the apparel sector is very limited. Even though there are several attempts made on the development of fine yarn from 100% jute, the properties of the jute fibre are beyond the required limits for fabrication[3]. Hence, the blending of other fibres with a low percentage of jute fibre is one of the better options to improve the usage of this less known fibre. One of the major advantages of fibre blending is to achieve a combined best character of both fibres used in the blending and also to minimize the poor characteristics of anyone fibre. Further, the blending process also makes the fabric manufacturing process more economical[4].

It is believed that the blending of jute fibre with well-known fibre like cotton may create an avenue for the better utilization of the jute fibre. The blended yarn may have advantages of both the cotton and jute fibre and hence enhances the fabric quality[5]. Recently, interest in the development of fabric with jute content is increased tremendously due to the societal change towards sustainable textile materials and products. Studies were conducted towards the development of blended fabrics[6], cotton wrapped jute yarns as core-sheath components[7], and blending with cotton[8], ramie[9], and other fibres. Even after the blending process, studies have been done on multiple after treatments and finishing to improve the properties of the jute cotton fabrics. Sreenath *et al.*[10]. performed bio

[a] Corresponding author.
E-mail: r.rathinamoorthy@gmail.com

polishing using commercial pectinases, xylanases, and cellulose enzymes to achieve a smoother and soft handle for the fabric. Samanta *et al*.[11] evaluated the effect of raw jute and various enzyme-treated jute fibres handle and textile-related physical properties after the amino silicone softener treatments. Their findings revealed that the amino silicone makes the fibre much smoother and brighter without much change in the bundle tenacity and improves the overall properties of the fabric. Other researchers evaluated the potentiality of the blended fabric as a curtain material over 100% cotton fabric[12]. The effect of enzyme bio polishing on the raw jute-cotton (75:25) union furnishing fabric was evaluated with a mixture of enzymes and it was found that the results were not satisfactory in terms of textile applications. However, their research results found that pretreating the jute union fabric with NaOH or bleaching agent may increase the softness and handle of the fabric, Among the two pretreatments, alkali treatment found to be more effective than the bleaching process[13].

Silicone softener improves the handle of the fabric significantly by incorporating a very good lubricity, crease recovery, tear strength, abrasion resistance, etc. In industrial practice, the amino-functional silicone softeners are the most efficient finish to improve the fabric handle. Another advantage of the amino silicone softener is that the amino groups are quaternized to cationic species which have a stronger attraction for the negatively charged fabric as the process is performed in acidic conditions[14]. Methyl groups are the most important organic substituents used in commercial silicones. The vast majority of these are polydimethyl siloxanes[15]. Several studies have reported the use of silicone softeners to improve fabric properties[12, 16-19]. Even though many studies have used the jute/cotton woven fabrics, very limited research is available on the application of jute/cotton knitted fabric for the apparel end-use. This study is, therefore, focused on the development of jute/cotton knitted fabric and their application potential in the apparel end-use. Various trials performed in the preliminary phase and noted that 40% is the maximum possible jute proportion that can be successfully run in the knitting machine. The developed fabrics are treated with an enzyme for the bio softening process and finished with amino silicone softeners to enhance the fabric handle and feel. The finished fabrics are evaluated for their moisture management capability in terms of various moisture management indices as per AATCC standard.

2 Materials and Methods

The jute/cotton (40/60) blended yarn was used for this study with a yarn count of 17 Ne. The selected yarn was knitted into a single jersey fabric using 7 gauge, 8 gauge, and 9 gauge on a flat knitting machine. Based on the handle and physical appearance of the fabric, an 8 gauge machine was selected for the knitting process and the fabric was produced through the machine. The physical properties of the fabrics are provided in Table 1.

The chemicals, such as sodium chloride, sodium carbonate, sodium hydroxide, sodium hypochlorite, hydrogen peroxide, hydrochloric acid, acetic acid, and Amino functional polydimethylsiloxane silicone softener, used in this study were of analytical (AR) grade. The enzyme used in the study was the cellulase enzyme (supplied by Resil Chemicals, India). The reactive dye used was a hot brand reactive dye (supplied by Yoshiaki Chemicals Company Pvt. Ltd, India).

2.1 Finishing of Jute/Cotton Fabrics

The knitted jute cotton fabrics were imparted with pretreatment processes like desizing, scouring, bleaching and mercerisation as mentioned by Karmakar[20]. To improve the hand value and moisture management properties, the fabrics were imparted with two types of treatments, namely enzymatic and amino silicone softener finishing. After the pre-treatments, the union fabrics were treated with the enzyme to impart softness with the following recipe:

Cellulase enzyme	: 5% (owm)
Acetic acid	: 0.5% (owm)
Temperature	: 55ºC
Time	: 30 min
MLR	: 1:20 (owm)[21]

2.2 Amino Silicone Softener Finishing

The amino functional-based finishing treatment was imparted by pad-dry-cure method on the reactive dyed jute/cotton fabrics, with 10 gpL softener and 10 gpL polyurethane solution at *p*H 6.0 (maintained by acetic acid) and temperature 40°C for 15 min with the pressure of 1 kg/cm^2 in order to get optimum pick-up of 0.8% on weight of the material. Then the fabrics

Table 1 — Fabric parameters of jute/cotton (40/60) fabrics

Fabric	CPI	WPI	GSM	Thickness, mm
Unfinished	28	30	337	2.20
Finished	52	48	237	0.78

were dried at 100°C for 3 min and cured at 150°C for 4 min in drying and curing chamber respectively[17].

2.3 FTIR and Physical Property Analysis

The FTIR spectrum was measured with the wavenumbers ranging from 4000/cm to 400/cm at the resolution of 1.00/cm. In this study, KBr plate method of testing the sample was used.

The developed knitted fabrics were evaluated for different physical properties as per standards, namely bursting strength[22], air permeability[23], water vapour permeability[24], water absorbency[25], and wicking[26].

2.4 Moisture Management Testing

The fabric samples were tested on SDL ATLAS M290 - Moisture Management Tester (MMT) according to AATCC Test Method 195[27]. To measure moisture management properties of fabrics accurately and objectively moisture management tester was used. The liquid moisture management properties of union fabrics are evaluated by placing a fabric specimen between two horizontal (upper and lower) electrical sensors each with seven concentric pins. A predetermined amount of test solution that aids the measurement of electrical conductivity changes are dropped onto the center of the upward-facing test specimen surface. The test solution is free to move in three directions, viz radial spreading on the top surface, movement through the specimen from the top surface to the bottom surface, and radial spreading on the bottom surface of the specimen. During the test, changes in the electrical resistance of the specimen are measured and recorded. The electrical resistance readings are used to calculate fabric liquid moisture content changes that quantify dynamic liquid moisture transport behaviors in multiple directions of the specimen. The summary of the measured results is used to grade the liquid moisture management properties of a fabric by using predetermined indices as provided by AATCC Test Method 195[28].

2.5 Statistical Analysis

Two-way analysis of variance (ANOVA) was performed at a confidence level of 95% to obtain p-values for all the test samples. The p-value of less than 0.05 was considered significant for the statistical evaluation of test results. The strength and direction of the association among the different moisture management indices were determined by Pearson's correlation coefficient.

3 Results and Discussion

The finish imparted fabric has been analysed for its strength loss after the finishing treatment to understand the fabric's endurance. The bursting strength results reveal that the enzyme treated finished knitted fabric shows a strength value of 7.2 kg/cm^2, whereas the unfinished fabric has a bursting strength value of 11.9 kg/cm^2. The loss in the strength in the finish imparted fabric is expected due to the enzyme hydrolysis. However, the noted strength value of the finish imparted fabric is good enough for normal apparel end uses in comparison with previous research works[29,30]. Similarly, the wash fastness of the finish imparted fabric is also found durable after multiple washes due to the curing process performed. The curing process enhanced the cross linking of silicone softener and provided durability for the finish[31, 32].

3.1 FTIR Analysis

The FTIR spectra (Fig.1) show an identical peak for cotton and jute fibre in the region of 3330 cm^{-1}, which represents the –OH stretch in the carboxylic groups of cellulosic fibres (common for both jute and cotton). The bands at 1750 cm $^{-1}$ and around 1650 cm^{-1} may be related to C = O stretching of cellulose and these regions could be attributed to the vibration of the alpha-keto carbonyl for cellulose in jute fibre[33]. An identical peak at 1300-1350 cm^{-1} represents the CH_3 bending and –CO- stretching of lignin content in the jute material and also corresponding to the vibrations of the C-H and C-O groups respectively, of the aromatic rings in cellulose (cotton)[34]. These peaks confirm the presence of both jute and cotton composition in the fabric. The peaks related to silicone softener confirm the softener treatment on the fabric. An absorption peak at 2900-2950 cm^{-1} confirms the asymmetric CH_3 stretching in Si-CH_3 in the silicone softener. At the lower end a strong peak at

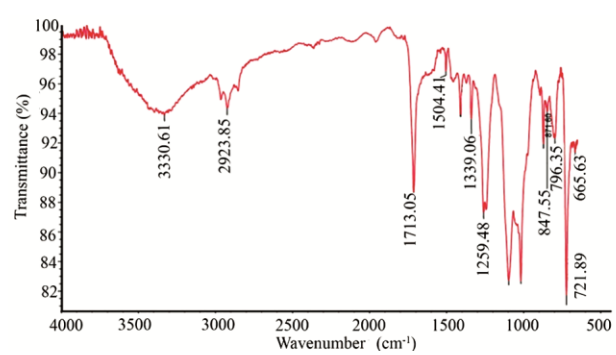

Fig. 1 — FTIR spectra of enzyme treated and amino silicon finished jute/cotton knitted fabric

1260 cm^{-1} represents the CH_3 deformation in Si-CH_3 and peaks in the region of 1020 – 1150 confirm the Si-O-Si stretching of silicon softener molecules[35]. The vibration at 796.35 cm^{-1} denotes the –C-H- rocking and Si-C stretch, which represents the presence of silicone components on the fabric.

3.2 Moisture Property Evaluation

The moisture-related fabric properties have been analysed for the developed knitted fabric before and after treatments. The test results (Table 2) are the average value of five individual readings in all the tests.

The air permeability results indicate that the untreated and knitted jute/cotton fabric is more porous and allows more air through the structure. In the case of finished knitted fabric, there is a reduction in air permeability. This is evident from the fabric parameters, even though the thickness and GSM values are reduced, and the CPI and WPI of the finished fabric are increased noticeably ($p<0.05$). The water vapour permeability results show that there is a slight increment in the vapour permeability of the finished jute/cotton fabric than in the unfinished fabric. The results were contradicting while comparing to the data in Table 1. As per the fabric specification, the course per inch and wales per inch values of the finished jute/cotton fabric are significantly increased due to the treatments than in unfinished fabric. This represents the reduction in the opacity of the fabric. This should result in a reduction of vapour permeability but it increases. This increment in the vapour permeability value is associated with the enzyme treatment and silicon finishing. The first reason is the enzyme treatment, which has reduced the individual yarn thickness and so the overall fabric thickness and weight. Secondly, the silicon finishing introduces some water repellent effect on the finer surface, and hence the fibre sorption behavior is altered and permeability is increased. Further, in untreated fabric, the lower moisture transport can also be related to the higher moisture retention ability of jute fibre.

Table 2 — Moisture related property of jute/cotton (40/60) knitted fabric

Fabric	Air permeability $cm^3/cm^2/s$	Water vapour permeability $g/m^2/day$	Vertical wicking in 1 min, cm	Water absorbency, s
Unfinished	804	497.96	1.4	28.95
Finished	600	548.78	4.3	14.27

The absorbency test results show that the unfinished knitted fabric has a very long (slower) absorption time (28.95 s) as compared to the finished fabric. The longer absorption time of the unfinished fabric is due to the incorporation of jute content. The higher hemicelluloses and lignin content in the jute might be the reason for the longer time. In the case of finished fabric, there is a significant reduction observed in the time ($p<0.05$). The finished fabric shows an absorption time of 14.27 s. This increment might be attributed to the enzyme treatment process. The enzyme treatment softens the jute fibre by removing its impurities like lignin and hemicelluloses, known as bio polishing. The biological treatment increases the absorbency of the fabric significantly, which is also supported by previous findings[36,37]. The repellent property of the fabric is imported by the methyl groups in the softeners, due to its higher orientation and its attachment with fibre surface by silicon linkage[14]. Similarly, the wicking characteristics of knitted jute fabric before and after treatment are evaluated. In line with the absorbency results, the vertical wicking height of the fabric is noted very low (1.4 cm/min) in the case of untreated knitted fabric. The finishing treatment slightly improves the wicking height to 4.3 cm/min than the untreated fabric.

3.3 Moisture Management Testing

3.3.1 Water Content Analysis

Figure 2 represents the water content status of the jute/cotton blended knitted fabric before and after

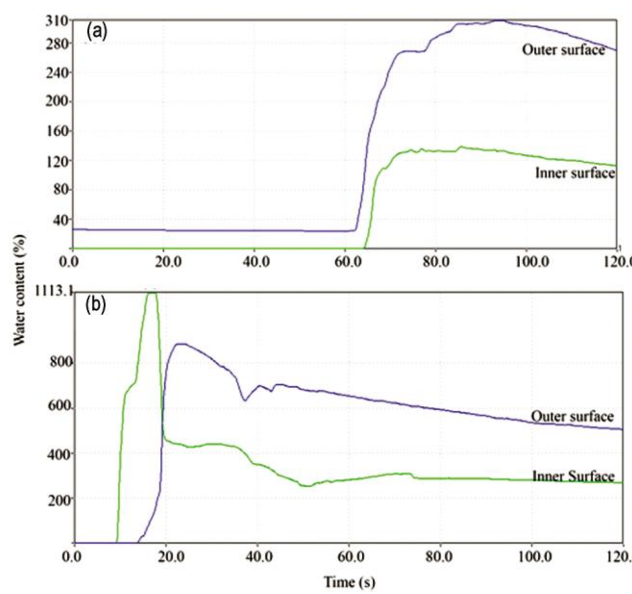

Fig. 2 — Water content analysis on top and bottom side of jute/cotton knitted (a) untreated and (b) treated fabrics

enzyme and silicone finishing. It can be observed that the untreated fabric does not absorb any water (both top and bottom side) till 60 s. In the case of finished fabric, the absorption time is significantly reduced. From the bottom (outer) side, it is noted as 8 s and from the top side (inner) it is noted 13 s. It is also observed that the untreated fabric has higher moisture content on the bottom side. However, after treatment, the moisture content in the top side increases significantly and after 20 s the moisture content on the outer side attains the maximum. The higher moisture content in the top surface represents an effective transfer of moisture from the bottom side of the fabric (closer to the skin) to the top side. However, after 20 s, the moisture content on the bottom side becomes higher than on the top side. So, it is not advantageous overall but when compared to the unfinished fabric, the finishing process has a slight improvement in the water content.

3.3.2 Wetting Time Analysis

In moisture analysis, the wetting time represents the time in which the top and bottom surfaces of the material start to be wetted[14, 38]. Figure 3 represents the wetting time (WT) of untreated jute/cotton union fabrics before and after the enzyme treatment and finishing process. From the results, it can be noted that the wetting time of jute/cotton knitted fabric is 63 s on the top side and 61 s on the bottom side. The higher wetting time of jute/cotton blended fabric is mainly attributed to the presence of higher lignin and hemicelluloses contents in the blended fabric. In the case of enzyme-treated and amino silicone finished fabric, the wetting time is noted as 8.4 s on the top and 13.1 s on the bottom side. The reduction in wetting time is mainly attributed to the enzyme treatment and silicone finishing. The enzyme treatment softens the jute fibre by removing the loose fibres on the surface[39]. The enzymes hydrolyze the glucose bonds of cellulose and weaken the fibre. Those week fibres are removed from the surface by some external pressure like surface rubbing and completing the bio polishing activity[16].

From the standards, a wetting time of 5 - 19 s shows the ‘medium performance’ of the fabric. The finished knitted fabric is rated for medium performance, whereas the untreated knitted fabric possesses a higher wetting time at both top and bottom surfaces. In the treated fabric, the bottom wetting time is higher than the top side. As the jute has a lot of binding sites for the water molecules, the water molecules tend to be retained in the hydrophilic fibres, and so it takes a long time to wet the bottom surface of the fabric. This is evident from the higher wetting time of 13.1 s at the bottom sides of the fabric. The untreated fabric is rated as slow as per standard. There is a significant reduction ($p<0.05$) in the wetting time of finished fabric on both the top and bottom sides of the fabric.

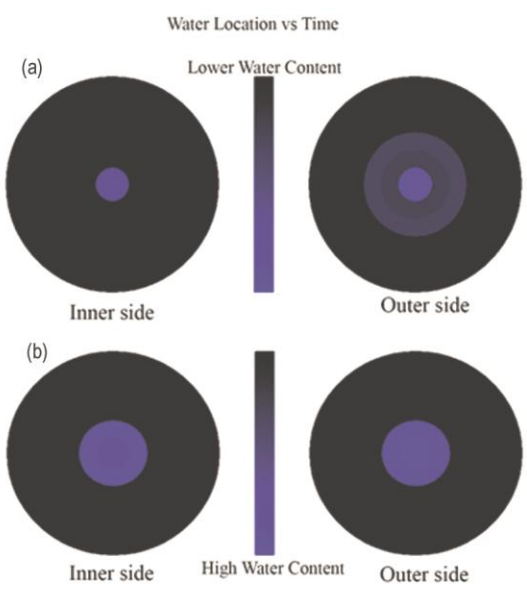

Fig. 3 — Top and bottom wetting time of (a) untreated and (b) treated knitted fabrics

3.3.3 Absorption Rate

The type of fibre along with yarn and fabric structure is an important factor that influences the absorptions rate of the textile material. The degree of transfer of liquid on the fabric surface is measured by the absorption rate. Absorption rates on the top and bottom surfaces (%/second) are the average moisture absorption ability of the specimen, in the measurement time. The absorption rate of the developed knitted fabric is 15.2 %/s on the top side and 22.3%/s on the bottom side. The addition of jute content in the yarn is an important reason for the reduction in the developed fabrics’ absorption rate. As per standard, it can be interpreted that the untreated fabric has a lower absorption rate and rated as ‘slow’.

After the enzyme and finishing treatment, the finished jute/cotton knitted fabric has shown a significant increment in the absorption rate ($p<0.05$) on both the top and bottom sides. After finishing, the top surface of the treated fabric shows a higher absorption rate than the bottom top surface of the fabric. For the top surface, a maximum of 127.6%

absorption rate is observed, and 88.3% is observed as the maximum absorption rate for the bottom surface. After finishing treatment, the standard rating of the finished knitted fabric is increased to 'fast' at the bottom and 'very fast' at the top side.

3.3.4 Maximum Wetting Radius

The maximum wetting radius on the top and bottom surfaces of the fabric represents how widely the liquid moisture spreads on the surface of the fabric. In real-time, it represents the drying behavior of the fabric. As per standard, a high wetting radius shows better drying behavior of the fabric. The results represent that the untreated jute/cotton knitted fabric shows a wetting radius of 5 mm/s on both the top and bottom sides. As per standard, the fabrics having 0 – 7 mm/s wetting area is rated as 'no wetting'. The lower wetting radius of the jute blended fabric might be associated with the higher absorption behavior of the jute fibre. As jute has higher moisture regain percentage as compared to cotton, the liquid gets absorbed by the fibre structure and trapped inside the structure instead of spreading. This might be the reason for a very less wetting radius.

After the enzyme and finishing treatment, all the different jute/cotton union fabrics show a significant improvement in the wetting radius ($p<0.05$). In the case of finished jute/cotton knitted fabric, the top and bottom surface wetting radius are noted as 10 mm/s. As per standard, the jute/cotton blended treated fabric alone shows "small" wetting radius (7-12 mm/s) than untreated jute/cotton fabric. Both the top and bottom surfaces of the finished fabric show a significant improvement ($p<0.05$) in the wetting radius statistically from no wetting to small wetting.

3.3.5 Spreading Speed

Liquid spreading speed indicates how fast the liquid evaporates from the fabric surface. From the results, it can be seen that the untreated jute/cotton knitted fabrics have different spreading speeds, i.e. 0.078 mm/s on the top side and 0.08 mm/s on the bottom side. The standard fabric grading chart represents that the spreading speed in the range of 0 – 1 mm/s is considered as 'very slow' fabric. The slower spreading speed of the fabric is attributed to the higher hydrophilic nature of the untreated jute fibre. This is further evident from lower MWR on both sides of the fabric.

After the enzyme treatment and finishing, the spreading speed of the fabric has increased significantly ($p<0.05$) to 0.705 mm/s on the top side and 0.544 mm/s on the bottom side. From the grading chart, it can be seen that the value of 0 - 1 mm/s is very slow. This is comparatively lower than that of the 100% cotton fabric, where it is rated very fast.

3.3.6 Accumulative One-way Moisture Transport Capacity

One way transport capacity (OWTC) is the difference in the cumulative moisture content between the two surfaces of the fabric in the unit testing time. The results indicate that the jute/cotton knitted fabric alone shows an OWTC value of 87.31, due to the similar values between the top and bottom surface MWR and SS values. The OWTC value of jute/cotton knitted fabric after finishing treatment is noted as 208.62. As per the standard rating, the untreated fabrics are rated 'poor'. However, the finished fabrics are classified as 'very good'. This is mainly due to the lesser difference in the cumulative moisture content between the two surfaces of the treated fabric.

3.3.7 Overall Moisture Management Capacity

The overall moisture management capacity (OMMC) is an index to indicate the overall ability of the fabric to manage the transport of liquid moisture, which includes three aspects of performance, viz spreading speed or drying speed, the moisture absorption rate of the bottom side and one–way liquid transport-ability. Higher overall moisture management capacity indicates better overall moisture transport-ability of the fabric. The OMMC value of untreated jute/cotton knitted fabrics is observed as 0.1868. As per the standard, the untreated jute/cotton fabric is rated as 'very poor'. However, the finished fabric shows a significant improvement in the overall moisture management ability with an increased OMMC value of 0.505. The fabric is rated as 'good' as per standard. Figure 4 shows the corresponding fingerprint analysis results.

Table 3 represents the Pearson correlation coefficient analysis results. It is observed that OWTC and OMMC indices are positively and linearly correlated to each other (0.999). From the correlation analysis, it can be noted that OMMC values are positively correlated with spreading speed (0.88 for SSt and 0.85 for SSb), and maximum wetted radius (0.95 for MWRt and 0.92 for MWRb); and a week negative correlation is noted in the wetting time (WTt - 0.95 and WTb - 0.97). Similarly, OWTC values are also positively correlated with spreading speed, and wetting

Table 3 — Pearson correlation analysis of the interaction between the MMT indices

MMT indices	Wetting time s		Absorption rate %/s		Max. wetted radius mm		Spreading speed mm/s		One way transport capacity	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
Wetting time, s										
Top	1.0000									
Bottom	0.9964	1.0000								
Absorption rate, %/s										
Top	-0.6731	-0.6080	1.0000							
Bottom	-0.6841	-0.6199	0.9999	1.0000						
Max. wetted radius, mm										
Top	-0.8131	-0.8595	0.1168	0.1317	1.0000					
Bottom	-0.7569	-0.8096	0.0262	0.0412	0.9959	1.0000				
Spreading speed, mm/s										
Top	-0.6993	-0.7573	-0.0580	-0.0430	0.9847	0.9965	1.0000			
Bottom	-0.6567	-0.7182	-0.1157	-0.1008	0.9730	0.9899	0.9983	1.0000		
One way transport capacity	-0.9543	-0.9762	0.4213	0.4348	0.9500	0.9177	0.8810	0.8521	1.0000	
OMMC	-0.9509	-0.9737	0.4111	0.4247	0.9534	0.9220	0.8862	0.8579	0.9999	1.0000

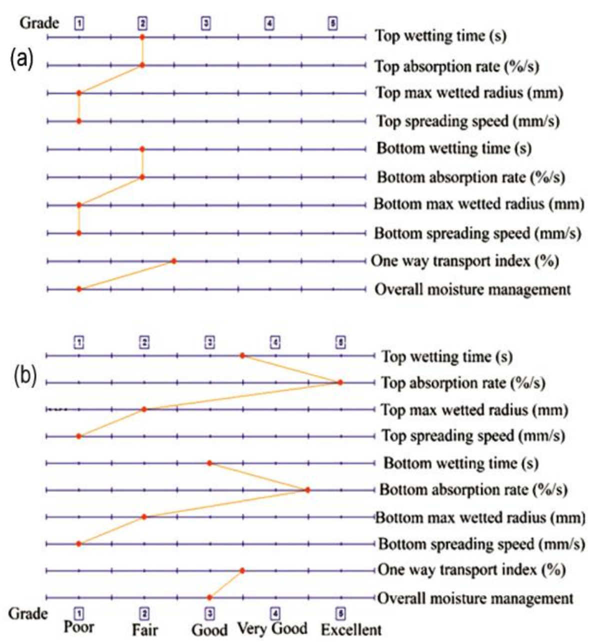

Fig. 4 — Fingerprint analysis of jute/cotton union fabric against various MMT indices

radius, and negatively correlated with wetting time. The findings represent that the better moisture management behavior of the finished fabric mainly depends on the higher spreading speed, maximum wetted radius, and lower wetting time concerning to the developed fabric. The fingerprint analysis reports the untreated fabric as "water repellent fabric" and designated the finished as "water penetration fabric".

4 Conclusion

The research findings reveal that the developed jute/cotton knitted fabrics can be used for apparel manufacturing after enzyme treatment and amino silicone finishing. Even after the strength loss by enzyme treatment, the fabric possesses enough strength for apparel end use. The combined enzymatic and silicone finishing significantly modifies moisture management properties of jute/cotton knitted fabrics. In untreated fabric, the overall moisture management capacity (OMMC) values are noted as ‘poor’. After enzymatic treatment and amino silicon finishing, the moisture management indices are significantly altered. There is a reduction in wetting time (Wt) as compared to untreated union fabric. Due to the reduction in the wetting time, the finishing increases the maximum wetted radius (MWR) in the treated fabric, but still, it is not up to the level of 100% cotton fabric. The increment in absorption rate (AR) and improvement in the spreading speed (SS) of the finished fabric ensure the improved moisture handling of the finished fabric. The one-way transport capacity values are rated ‘good’ as per standard. The overall moisture management ability of the treated fabric is observed as ‘good’ over the untreated fabric which is rated ‘poor’. These findings suggest the potential scope of jute fibre in the apparel sector as wearable products.

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