

## Moisture management characteristics of knitted casein fabric

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In this research, thermal comfort and moisture management characteristics of knitted casein fabric have been evaluated and compared with cotton fabric for the application of undergarment. The fabric is analyzed for wicking, air permeability, thermal conductivity and water vapour permeability using physical test methods. The moisture management tester (MMT) was used to evaluate the parameters like wetting time, spreading rate, absorption speed, wetting radius, one way transport capacity and overall moisture management capacity (OMMC). It is observed that overall performance of casein fabrics is slightly better than that of cotton fabric. The thermal conductivity, air permeability and wicking values of the casein fabric are prominent as compared to the cotton fabric having same structural parameters, whereas the water vapour permeability values remain roughly same in both the fabrics. The MMT test results reveal that the casein fabric has an absorption rate of 66.2707 % on top side of the fabric and 70.6461 % on bottom side. For cotton fabric, the absorption rate is 50.046 % on the top and 43.6618 % at the bottom. The spreading rate of casein is found 5.0169 mm on the top and 5.0335 mm at the bottom surface, and for cotton it is 3.7921 mm on the top and 4.3019 mm at the bottom. The overall OMMC index of casein fabric is noted as 0.75, and for cotton it is found 0.7. The cotton fabric is found to be better than the casein fabric, based on the other parameters like maximum wetting radius and one way transport capacity values.

**Keywords:** Casein fabric, Cotton yarn, Knitted fabric, Moisture management testing, Overall moisture management capacity index, Thermal conductivity

### 1 Introduction

The term comfort is defined as “the absence of displeasure or discomfort” or “a neutral state compared to the more active state of pleasure”<sup>1</sup>. Clothing comfort includes three main considerations, namely psychological, sensorial and thermo-physiological comfort<sup>2</sup>. Moisture transmission through textiles has a great influence on the thermo-physiological comfort of the human body which is carried out through perspiration both in vapour and liquid form. The clothing to be worn should allow this perspiration to be transferred to the atmosphere in order to maintain the thermal balance of the body<sup>3</sup>. Particularly in the case of intimate apparels, the moisture management property is highly important as it helps to remove excessive wetness and carry heat away from the skin. Under conditions of low activity, the body loses about 75% of its heat from the surface of the skin by a combination of conduction, convection, and radiation of dry heat<sup>4</sup>. Thus, the resistance of these intimate apparels which worn very next to the skin, to the transfer of dry heat has considerable influence on the wearer’s comfort. Experimental work has been directed by number of analysts to focus on the impact of diverse material

parameters, i.e. surface change, fibre and fabric finish, fibre type, thickness and also the porosity of the material as encompassing temperature and pressure have an effect on moisture vapor transmission characteristic of textile materials<sup>5,6</sup>. Because various fibres differ little in thermal transmittance behaviour, fibre’s physical structure affects the overall insulation/transmission capacity of a fabric and the thermal physiological comfort of the user or wearer more than its chemical structure. However, cotton is noted as the most preferred fibre in the case of intimate apparels by the end users over manmade fibres<sup>7</sup>.

During early 1930's, an Italian chemist Antonio Feretti patented the “milk casein” fibre which can be used in many clothing and household items<sup>8</sup>. Milk protein fibre is bio degradable with bright colours due to good dye ability and blends well. It also has good moisture absorption and conduction property, thus being both comfortable and permeable. The milk protein fibre moistens skin and it is healthy and bacteriostatic. It can nourish and lubricate the skin. The milk protein contains the natural humectants factor, which can capture moisture and maintain the skin’s moisture. It makes the skin tender and smooth and reduce wrinkles<sup>9</sup>. However, casein fibre fell out of use after World War II ended and newer, cheaper

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synthetics such as nylon grew in popularity. The fibre was blended with other natural fibres and known under the various brand names<sup>10</sup>.

Now in the recent years, casein fibres are back into market again due to their higher environment friendliness and more comfort nature. A recent study also states that consumers do have a similar commitment of purchasing cotton intimate apparels as they wish to have styles and brands. Two-thirds of shoppers mentioned that it is important that their intimate apparels should be made of cotton due to their comfortable, soft, breathable, best-fitting and versatile nature. More than half of the customers are concerned about the increase in manmade fibres in their underwear<sup>7</sup>. Hence, this study is framed to analyse and evaluate the potential use of casein fibre in the intimate apparel sector. In this research, the thermal and moisture management characteristics of 100% casein and cotton weft knitted fabric have been evaluated to analyse the suitability of casein fabric for the application of intimate apparels. The knitted casein fabrics have been tested for the physical properties like thermal conductivity, air permeability, water vapour permeability and wicking and then compared with the existing cotton knitted fabric. Both the cotton and casein knitted fabrics are also analysed for their absorption rate, spreading rate, wetting radius, one way transport capacity and optimum moisture management capacity (OMMC) index using moisture management tester.

## 2 Materials and Methods

### 2.1 Sourcing of Yarn

The 100% cotton yarn was purchased from local outlet in Coimbatore, India. 100% casein yarn was sourced from Euroflex Industries Pvt Ltd, Mumbai, India. The count of the purchased yarns were 40's. The yarns were weft knitted with interlock structure, the resultant cotton fabric was 174 g/m<sup>2</sup> with 54 courses/inch and 48 wales / inch. In the case of casein fabric, the grams per square meter was 170 with the course/inch of 48 and wales / inch of 36.

### 2.2 FTIR Analysis

FTIR spectra for knitted fabric were measured with a SHIMADZU spectrophotometer to identify the presence of functional substance related to casein protein in the fabric. The spectra were obtained in the range of 400 - 4000 cm<sup>-1</sup>.

### 2.3 Physical Parameters

The knitted fabrics were evaluated for the physical parameters like air permeability (BS 3424), water

vapour permeability (BS 7209), wicking (AATCC 197) and thermal conductivity<sup>11</sup>. ANOVA tests were performed using Microsoft excel, to identify the statistical significance between the values.

### 2.4 Moisture Management Testing

Knitted fabric samples were tested on SDL ATLAS M290 - moisture management tester (MMT) according to AATCC test method 195–2009. The liquid moisture management properties of a textile are evaluated in this tester 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, namely radial spreading on the top surface, movement through the specimen from top surface to the bottom surface, and radial spreading on the bottom surface of the specimen. During the test, changes in electrical resistance of 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 are used to grade the liquid moisture management properties of a fabric by using predetermined indices.

## 3 Results and Discussion

### 3.1 FTIR Studies

The sourced yarns have been characterised to identify the chemical groups of casein components. The results are given in Fig 1. It can be seen that the absorption peak is 1647 cm<sup>-1</sup>, representing C = O structure in amide I bond which confirms the presence of protein<sup>12</sup>. Peak at 1540 cm<sup>-1</sup> represents strong amide

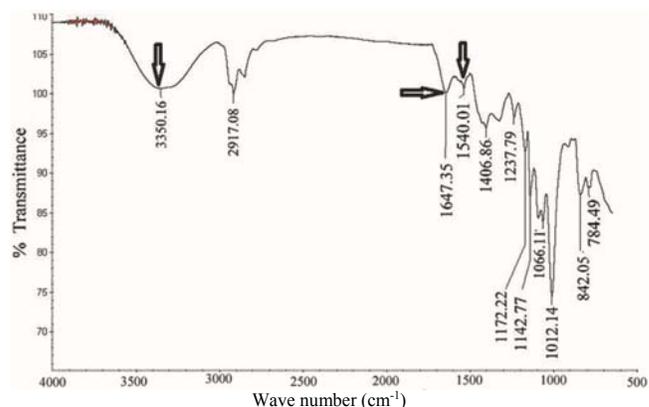


Fig. 1 — FTIR spectrum of casein fabric

II bond which is formed due to N-H bonding of C-N - H group<sup>13</sup>. The peak  $3350\text{ cm}^{-1}$  represents strong absorption due to N-H structure. These absorption peaks are the essential and identification spectrum of casein fibre. This confirms that the fibre material used in this structure is casein<sup>14</sup>.

### 3.2 Physical Property Analysis

Table 1 compares various comfort related physical properties of cotton and casein fabrics of same structural parameters. The values are the average of five independent readings of each test result.

#### 3.2.1 Thermal Conductivity

The thermal conductivity results of casein and cotton fabric are shown in Table 1; the average of 5 reading is taken. The casein fabrics have a thermal conductivity value of  $0.060\text{ W/mK}$  which is slightly higher than cotton fibre, which has the value of  $0.056\text{ W/mk}$  in average<sup>9</sup>. Thermal conductivity of the fabric mainly depends upon the thickness, porosity moisture content, yarn twist and hairiness. In order to examine the influence of the fibre on fabric thermal properties, it is necessary to eliminate the thickness variable. Hence, in this study both the fabrics were prepared with same grams per square meter and with the minimal difference in the fabric thickness. The higher thickness of the cotton fabric may be attributed to the random arrangement of fibre in the cotton yarn, this could be a possible reason for the lower thermal conductivity of cotton<sup>15</sup>. The relative porosity of the casein fabric is observed as 99.75% which is very high than the cotton fabric (84.7%). The slightly increased ( $p < 0.05$ ) thermal conductivity values noticed might be the results of the difference in porosity of the fabric and also due to the casein fabrics inherent properties<sup>16</sup>.

#### 3.2.2 Wickability

The average vertical wicking value of casein fabrics noted after 5 min is 8 cm and for cotton fabrics it is 6.8 cm ( $p < 0.05$ ). It is observed that the liquid moisture transport in vertical direction is higher in the case of casein fabric as compared to that in the case of cotton

fabric. This is mainly due to the properties of fibre and the yarn characteristics. Changes in fibre properties caused by wetting action of the liquid can significantly alter liquid transport characteristics in a fabric. Physically, wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. This type of flow in any porous medium, caused by capillary action, is governed by the properties of the liquid, liquid-medium surface interactions, and geometric configurations of the pore structure in the medium. The rate of travel of water is governed by the fibre arrangement in yarns which controls capillary size and continuity. In general, cotton is hydrophilic in nature and has strong affinity towards water which helps easy wetting of structure but it binds the water molecule within the structure, leading to slow transport of moisture than protein structure<sup>17</sup>.

The yarn spun with natural cotton fibre may have very irregular capillaries due to various factors such as fibre roughness, cross sectional shape and limited length, which interrupt the flow along the length of the yarn. In yarns with fibres arranged in a relatively disorderly manner, capillary continuity is poor, and this causes changes in the water transport rate over the length of the yarn. But in the case of casein, the diameter of the fibre is same throughout and hence the staple length is maintained during manufacturing. Hence, the possibilities of uniform capillary space are higher in the case of casein fabric than in cotton fabric. Another important factor which affects the wicking process is yarn twist. The twist per inch (TPI) of cotton is 32 which is higher than casein's yarn TPI (26) (ref.18). The improved TPI in the cotton fabric reduces the intra yarn space within the fibre and thus reduces the wicking of water through the structure.

#### 3.2.3 Air Permeability

The result shows that the casein fabrics have higher air permeability of  $155\text{ m}^3/\text{cm}^2/\text{s}$ , than cotton fabric ( $59.5\text{ cm}^3/\text{cm}^2/\text{s}$ ). In general, air permeability mainly depends upon material thickness, yarn density and fabric porosity. The difference in air permeability of casein and cotton is also due to their structural property.

Table 1 — Comfort related physical properties of casein fabric

Fabric	Thickness mm	GSM	Physical properties			
			Thermal conductivity W/mK	Wicking cm	Air permeability $\text{cm}^3/\text{cm}^2/\text{s}$	Water vapour permeability $\text{g}/\text{m}^2/\text{day}$
Casein	0.68	170	0.060	8	155	1945
Cotton	0.80	174	0.056	6.8	59.5	1998
p value	-	-	0.049	0.0003	$4.38 \times 10^{-8}$	0.000044

The fibre related factors such as cross-section and moisture absorption properties have very less influence. The measured relative porosity values (99.7%) of the casein fabric are much higher than the cotton fabric (85.7%). Since the count, structure and GSM of the both fabrics are similar; this could be the possible reason for significantly improved air permeability ( $p > 0.05$ ). Fabric thickness is another important factor which affects the air permeability values. Even though the yarn count and GSM are maintained similar, there is a slight increase in the fabric thickness in the case of cotton fabric due to yarn bulkiness<sup>19</sup>.

**3.2.4 Water Vapor Permeability**

The moisture vapour resistance mainly depends on the air permeability of the fabric and represents its ability to transfer the perspiration coming out of the human skin. The resistance provided by the fabric is lower than that of the external boundary layer and often much lower than the inner confined air layer<sup>3</sup>. The casein fabrics have a water vapor permeability value of 1945 g/m<sup>2</sup>/day and cotton has 1998 g/m<sup>2</sup>/day. The result shows that both the casein and cotton fabric has very

close water vapor permeability values, however the values are found to be significantly different ( $p > 0.05$ ).

**3.3 Moisture Management Tester (MMT) Results**

**3.3.1 Maximum Wetting Radius**

The maximum wetting radius of casein fabrics [Fig. 2 (a)] is 25 mm on the top and 25 mm at the bottom and for the cotton fabrics, the top wetting radius [Fig. 3 (a)] is 20 mm and bottom wetting radius is also 25 mm. This difference between casein and cotton fabrics happens when the structure allows more dispersion of liquid. From the grading, for the top and bottom side, the casein fabric has “Excellent” wetting radius (>22 mm) than the cotton fabric (17-22mm, fast).

**3.3.2 Wetting Time**

The wetting time of casein [Fig. 2(b)] is observed as 3.469 s on the top surface and 3.656 s on the bottom surface. This value is found to be higher than that of cotton [Fig. 3(b)], which is found as 2.156 s at the top surface and 1.196 s at the bottom surface. With respect to wetting time, the good performance is noticed with cotton. Table 2 represents the grading specifications of

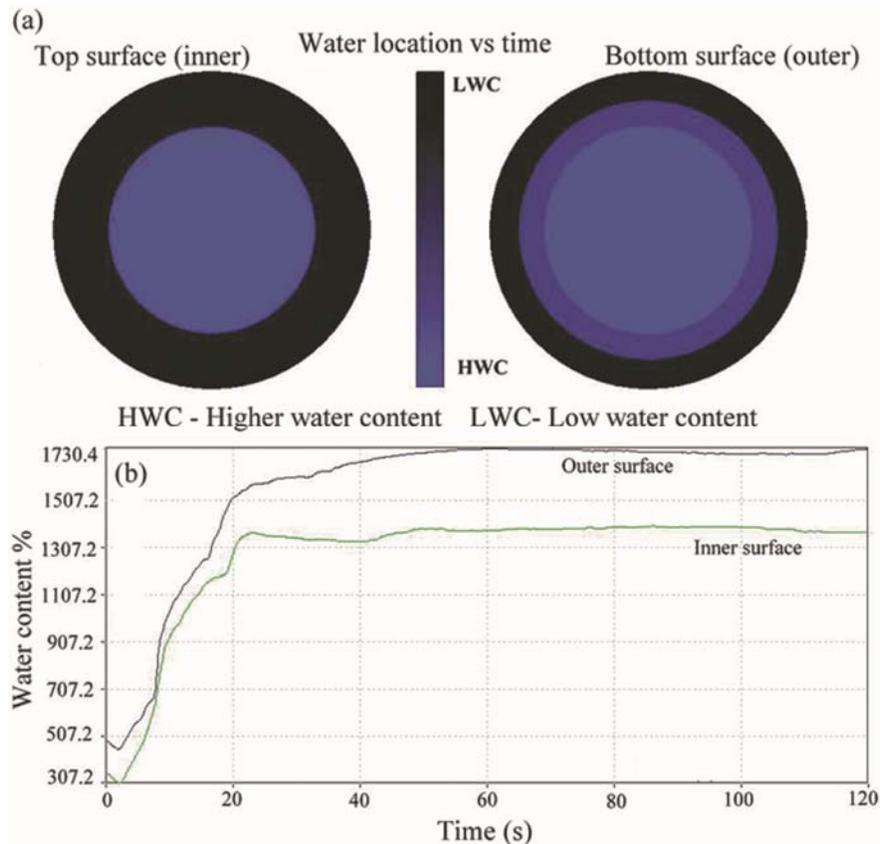


Fig. 2 — (a) Wetting radius and (b) wetting time (water content vs time) for cotton fabric

MMT test results as per AATCC 195-2009<sup>20</sup>. From the grading (Table 2), it can be noted that the wetting behaviour of the casein fabric is ‘fast’ if the values are taken between 3 s and 5 s but for cotton it is observed as “Very fast”.

### 3.3.3 Absorption Rate

The casein fabric has an absorption rate of 66.2707%/s on the top surface and 70.6461 %/s at the bottom surface which is higher than cotton (50.046 %/s on the top and 43.6618 %/s at the bottom).

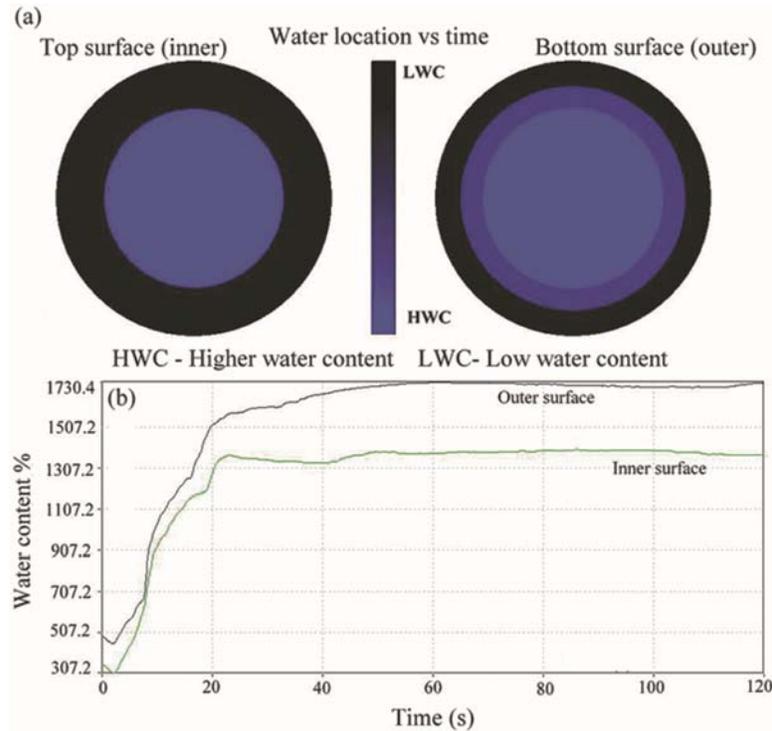


Fig. 3 — (a) Wetting radius and (b) wetting time (water content vs time) for casein fabric

Table 2 — Grading specifications of MMT test results as per AATCC 195-2009

Parameter	Surface	Grade				
		1	2	3	4	5
Wetting time, s	Top	>= 120 No wetting	20-119 Slow	5-19 Medium	3-5 Fast	<3 Very fast
	Bottom	>= 120 No wetting	20-119 Slow	5-19 Medium	3-5 Fast	<3 Very fast
Absorption rate %/s	Top	0-10 Very Slow	10-30 Slow	30-50 Medium	50-100 Fast	>100 Very fast
	Bottom	0-10 Very slow	10-30 Slow	30-50 Medium	50-100 Fast	>100 Very fast
Max. wetted radius, mm	Top	0-7 No wetting	7-12 Small	12-17 Medium	17-22 Fast	>22 Very fast
	Bottom	0-7 No wetting	7-12 Small	12-17 Medium	17-22 Fast	>22 Very fast
Spreading speed, mm	Top	0-1 Very slow	1-2 Slow	2-3 Medium	3-4 Fast	>4 Very fast
	Bottom	0-1 Very slow	1-2 Slow	2-3 Medium	3-4 Fast	>4 Very fast
One way transport capacity	-	<-50 Very poor	-50-100 Poor	100-200 Good	200-400 Very good	>400 Excellent
	OMMC	0-0.2 Very poor	0.2-0.4 Poor	0.4-0.6 Good	0.6-0.8 Very good	>0.8 Excellent

The absorption of liquid by a fabric may be influenced by the type of fibre, yarn structure, fibre structure, and openness in the structure. The increase in the absorbency rate for casein fabric is because of their high porosity. Another potential property that affects the absorption rate of the fabric is surface protruding fibres. In the case of casein yarn, the hairiness is observed to be higher than cotton. The hairiness index of cotton is noticed as 5, whereas that of casein is 5.8. This causes the casein fabric to absorb faster than the cotton fabric. The absorption rate of the casein fabric comes under the category of “Fast” but for the cotton it is ‘medium’ (Table 3).

### 3.3.4 Spreading Rate

The spreading rate of casein is 5.0169 mm/s on the top and 5.0335 m/s at the bottom surface. Cotton has 3.7921 mm/s on the top and 4.3019 mm/s at the bottom. The casein fibre has very less holding capacity of liquid, thus allows such trans-planer movement and thus casein has higher spreading rate<sup>21</sup>. This difference is due to inter and intra fibre alignment and also the yarn thickness. Smoothness and softness of the fibre and yarn also contribute to the spreading rate. Here, the studied fabrics of casein and cotton have the same structural parameters and hence the difference may be due to the yarn structural factors. First of all, the cotton yarn is found to have higher twist per inch level compared to casein. This compact nature of the yarn reduces the transport of the water inside the intra yarn space. Secondly, higher hairiness in the casein yarn and the increase in the surface roughness lead to faster spreading rate along the surface. This is mainly governed by the surface troughs offered by the rough surface, as apparently the wetting angle gets reduced. This yarn structural factor must be the valid reason for lower spreading rate in cotton. These results are also supported by the faster wicking ability of the casein fabric than the cotton fabric where the wetting time of the cotton fabric is high as compared to the casein

fabric. However, the spreading rate and spreading area are low in the case of cotton fabric, confirming the theory that the swelling of the fibres can reduce the capillary transport of liquid by either restricting the movement or by closing off of capillaries, which in turn causes the flow in those capillaries to be slow or even stopped.

From the grading chart (Table 2), it can be seen that the value of >4 is very fast, whereas for casein, both top and bottom layer spreads 5 mm/s, which indicates very excellent performance. One way transport capacity is the difference in the cumulative moisture content between the two surfaces of the fabric in the unit testing time. The value for casein is 252.51% and cotton is 285.82%. The grade chart indicates that the values of 200-400 % indicate “very good” on way transport capacity. Here both the fabrics come under same category.

### 3.4 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 hence drying speed, moisture absorption rate of bottom side and one-way liquid transport ability. Higher overall moisture management capacity indicates better overall moisture transport ability of the fabric. The OMMC grading of casein fabrics is more than that of cotton fabrics. The grade table (Table 2) indicates that the OMMC value from 0.6-0.8 comes under the class of “Very good”. Here for casein fabric, the value noted is 0.75 and for cotton it is 0.7. Hence, it can be concluded that casein fibre also has comparable moisture management properties with cotton fabric and in some specific parameters like spreading area and absorption rate, the casein fabric performs better than cotton. The finger print analysis test results provided by MMT also show that OMMC grading for cotton is ‘fair’, while the grading of casein fabrics is ‘excellent’. The finger print charts are provided in Fig. 4.

Table 3 — Moisture management test results of casein and cotton fabrics

Parameter	Casein		Cotton	
	Top surface	Bottom surface	Top surface	Bottom surface
Wetting time, s	3.469	3.656	2.156	1.969
Absorption rate, %/s	66.2707	70.6461	50.0463	43.6618
Max wetted radius, mm	25	25	20.0	25.0
Spreading speed, mm/s	5.0169	5.033	3.7921	4.3019
One way transport capability, %	252.5101		285.8282	
OMMC	0.7546		0.7168	

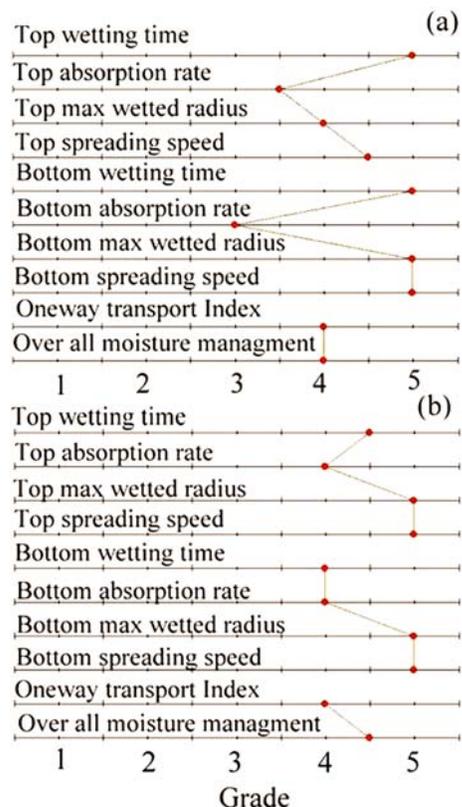


Fig. 4 — Fingerprint of moisture management properties of (a) cotton fabric and (b) casein fabric

#### 4 Conclusion

The findings of the study reveal that the casein fabric possesses slightly higher thermal conductive behavior than the cotton fabric with the same structural parameters. The wicking and air permeability values are also found to be better for casein fabric over cotton fabric. The moisture management test results discover that the overall moisture management capacity index value is high (7.5) for casein fabric which rated excellent than the cotton (7). This is further supported by moisture management tester's finger print analysis rating results. The water absorption rate and spreading rate of the casein fabric are better in performance than

cotton and rated as 'very fast' and 'excellent' respectively. This study suggests that the higher thermal and moisture management properties of casein fibre will provide improved comfort to the wearer compared to cotton intimate apparels. Along with these comfort properties, the ecofriendly nature of the casein fibre will endow a new era in the intimate apparel sector.

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