(REFEREED RESEARCH)

# A STUDY ON MODAL FABRIC TREATED WITH FORMIC ACID

# TRANS-PASİFİK ORTAKLIĞININ TÜRKİYE'NİN TEKSTİL VE KONFEKSİYON İHRACATINA OLASI ETKİSİ

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**ABSTRACT**

Modal is a bio-based rather than natural made from the spun reconstituted cellulose polymer of beech trees. Modal is a second generation regenerated cellulosic fiber and a variation of rayon. They are wear resistant and strong while maintaining a soft, silky feel. Fabric made from modal drape well and do not pile like cotton. Modal fabrics resist fading, shrinking and the buildup of hard water mineral deposits even after repeated washing. In this study, modal fabrics (woven and knitted) are selected and conventionally pretreated and subjected with 98% formic acid which is a used for the bio process of cellulose polymeric materials, in different concentrations. The formic acid treated modal fabrics were then undergone different testing such as; physical properties, absorbency, wicking, K/S value, fastness properties, water vapour permeability, air permeability, and SEM analysis. These treatments on modal fabrics were correspondingly compared with those of cotton for its effectiveness.

**Keywords:** Modal fabrics, Formic acid, Wicking, Water vapour & Air Permeability, SEM

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## 1. Introduction

Modal® is made from sustainably harvested beech trees in PEFC (Programme for the Endorsement of Forest Certification schemes) certified European forests. Basically the wood fibers taken from beech trees are pulped into liquid form and forced through tiny holes to make the fiber, which is then woven to make the fabric [1,2,3]. Lenzing started selling modal fibers in 1964. In 1977, Lenzing started using an environmentally friendly bleaching method for pulp for their cellulosic fibers [4]. Modal is a second generation regenerated cellulosic fiber and a variation of rayon with high wet strength and extra softness [5, 6, 7, 8]. Modal fibers have found a wide variety of uses in clothing, outerwear and household furnishings. Modal is about 50% more hygroscopic, or water-absorbent, per unit volume than cotton [9, 10]. It's designed to dye just like cotton and is color-fast when washed in warm water. Even after repeated washing, modal remains absorbent, soft and supple. The softness makes it especially ideal for body contact clothing such as lingerie and under garments [11 12].

Modal fibers are dimensionally stable and do not shrink or get pulled out of shape when wet like many rayons [13, 14]. They are often blended with cotton, wool or synthetic fibers and allow easy tone-in-tone dyeing [15, 16]. In this study, modal fabrics (woven and knitted) are selected and conventionally pretreated to get rid of the basic impurities. The pre-treated fabrics were then subjected with 98% formic acid in different concentrations. Formic acid is used in this study due to its involvement in many bio process of cellulose polymeric materials [17, 18, 19]. The formic acid treated modal fabrics were then undergone for different testings, such as, physical properties, absorption, wicking, K/S values, fastness properties, water vapour permeability, air permeability, and SEM analysis. These treatments on modal fabrics were correspondingly compared with those of cotton for its effectiveness.

## 2.0 Experimental

### 2.1 Materials

The specification of modal (M) and cotton (C) (woven and knitted) fabrics used in this study are given in the following Table 1.

Natural dyes [annatto (bixa orellana), onion (allium cepa), pomegranate (punica granatum), indigo (indigofera tinctoria), myrobalan (terminalia chebula), bar berry (berberis vulgaris)] and synthetic dyes [reactive dye (C.I. No. Red 24), and sulphur dye (C.I. No. sulphur Black 1)] used were in the commercial grade. The chemicals mentioned elsewhere for this study were in AR grade.

### 2.2 Methods

#### 2.2.1 Treatment on modal and cotton fabrics

The modal and cotton fabrics (woven and knitted) were pretreated with 10 gpl sulphuric acid, 45 min, ambient temperature (27$^o$C) (desizing - for woven fabric only); scouring with 2% (owm) Sodium hydroxide, 2 hours, at boil; and bleaching with hydrogen peroxide 1.5% (owm) hydrogen peroxide, at pH 10.5 (maintained by NaOH & $Na_2CO_3$), 1 hour at 90$^o$C (for both woven and knitted fabrics); the fabrics were thoroughly washed with deionized water between the completion of every process [20, 21, 22]. The pre-treated modal and cotton fabrics were subjected with 98% formic acid with the concentration of 1%, 2%, 3%, 4% & 5% (owm) for 30 minutes at ambient temperature (27$^o$C).

#### 2.2.2 Measurement of physical properties of modal and cotton fabrics

The physical properties such as tensile strength [20], stiffness [23], crease recovery angle [24, 25] and mean drape coefficient of woven fabric [22]; and bursting strength and mean drape coefficient of knitted fabric [26, 27] of the modal and cotton fabrics was measured by the standard established methods.

#### 2.2.3 Absorbency of modal and cotton fabrics

Absorbency is the time taken for a water drop to penetrate into the textile material. The wettability of modal and cotton fabrics was determined as per AATCC test method 79 [28].

#### 2.2.4 Wicking behaviour of modal and cotton fabrics

The wicking height of the modal and cotton fabrics was determined [29, 30]. Fabric samples measuring 10 cm 2.5 cm were taken. Each of the sample pieces was clamped to a scale and held at a position such that the tip of the sample just touched the water taken in a beaker. 1% reactive dye (Reactive Red M8B, CI No.: Reactive Red 11) was added for tracking the movement of water. The height of water reached after five minutes was measured [31].

#### 2.2.5 Dyeing and K/S analysis of modal and cotton fabrics

The dyeability of modal and cotton fabrics (woven and knitted) was investigated using natural and synthetic dyes. Dyeing was carried out with the concentration of 2% (owm) for synthetic dyes and 25 gpl (gram per litre) for natural dyes at boil for two hours with a material to liquor ratio of 1:20 as per the established technique of dyeing for natural and synthetic dyes [21, 32, 33]. The dyed samples were washed with deionized water, soaped with 2% (owm) non-ionic soap powder and 1% (owm) $Na_2CO_3$, 60$^o$C, 20 minutes, and dried. The K/S values ('K' and 'S' indicate the absorption coefficient and scattering coefficient respectively of the colorant that predict the behavior of the dyes on the textile materials) of natural and synthetic dyed modal and cotton fabrics were determined by AATCC Test Method -135 [34] using a Datacolor SF 600 plus spectrophotometer interfaced to a PC. Measurements were taken regarding colour presence, brightness, dullness and colour intensity with the specular component of the light excluded and the UV component included using illuminant D65 and 10° standard observer. Each fabric was folded once so as to give two thickness and average of five readings were taken each time.

#### 2.2.6 Color fastness analysis of the modal and cotton fabrics

The natural and synthetic dyed samples were washed under condition IIIA of AATCC Test Method 124-2001 to determine the color change effect of dyed fabrics [35, 36]. Light fastness tests (AATCC, 2003), were carried out according to AATCC Test Method 16 E-1998 [37]. The samples were exposed to 5, 10 AFUs (AATCC Fading Unit) to determine the color change AATCC 16-1998 [38]. AATCC standardized crock meter was used to determine the rubbing fastness of natural dyed fabrics under wet and dry condition to assess the color change and staining property AATCC 61-1996 [39, 40].

**Table 1**. Specifications of modal and cotton fabrics

| Woven Plain Fabric (Modal (M) and Cotton (C)) | | | | | | | | | | Knitted fabric (Modal (M) and Cotton (C)) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ends / Inch | | Picks / Inch | | Gram / Square Metre [GSM] | | Yarn Count (Ne) | | | | Yarn count (Ne) | | Gram/ Square Metre [GSM] | | Loop length (mm) | |
| | | | | | | Warp | | Weft | | | | | | | |
| M | C | M | C | M | C | M | C | M | C | M | C | M | C | M | C |
| 84 | 94 | 94 | 74 | 146 | 137.2 | 27 | 30 | 27 | 30 | 27.5 | 30 | 137 | 142 | 2.6 | 2.6 |

### 2.2.7 Water vapour and air permeability of modal and cotton fabrics

Water vapour permeability (WVP) is the speed or rate at which moisture vapor moves through a fabric. The ASTM E96 moisture vapor test (open cup test) was used for measuring the WVP rate of the modal and cotton fabrics [41]. ASTM – D737 method was used for measuring the air permeability of modal and cotton fabrics. This test gave the rate of airflow through a material under a differential pressure between the two faces of a fabric [42]. These tests are important to know the ability of a fabric to allow moisture vapor to be transmitted through the material which facilitates its suitability for different end products. Air Permeable fabrics tend to have relatively high moisture vapor transmission [43].

### 2.2.8 SEM study of modal and cotton fabrics

The surface morphology of modal and cotton fabrics was observed in SEM (JOEL JSM-6360 model microscope, Japan) [44, 45].

## 3.0 Results and Discussion

### 3.1 Physical properties of modal and cotton fabrics

The physical properties such as tensile strength, stiffness, crease recovery angle and mean drape coefficient of woven fabric; and bursting strength and mean drape coefficient of knitted fabric for modal and cotton fabrics are shown in Table 1. The modal fabric shows higher values of tensile strength (431 N (warp) and 370 N (weft) – untreated) and crease recovery angle (117 (warp) and 119 (weft) – untreated) respectively both in warp and in weft directions compared to that of the cotton fabric. However, the stiffness (0.99 cm (warp) and 0.97 cm (weft) – untreated) and mean drape co-efficient (65%) are less in modal fabric over that of cotton fabric. In the case of knitted fabric, cotton shows greater values than that shown by modal fabric for bursting strength and mean drape coefficient respectively. The modal fabric after treatment with formic acid (98%) at different concentrations for 30 minutes at room temperature show changes in the physical properties. The tensile strength and stiffness of formic acid treated modal fabric are reduced marginally upto the formic acid treatment of 4% (owm), and at 5% (owm) the loss is significant similar to that of cotton fabric. However, the crease recovery and mean drape co-efficient of formic acid treated modal fabric is increased considerably up to the concentration of 4% (owm), and at 5% (owm) it is only marginal. In the case of knitted modal fabric the bursting strength is decreased correspondingly with respect to the concentration of formic acid, while the mean drape co-efficient is increased considerably upto 4% (owm).

**Table 1.** Physical properties of modal and cotton fabrics

| S. No. | Textile materials | Woven fabric | | | | | | | Knitted fabric | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tensile strength (N) | | Stiffness [Bending length cm] | | Crease recovery angle (°) | | Mean drape coefficient (%) | Bursting strength | | | Mean drape coefficient (%) |
| | | Wp | Wt | Wp | Wt | Wp | Wt | | Test area ($cm^2$) | (kPa) | Mean height at burst (mm) | |
| 1 | I. MODAL Modal (UT) | 431 | 370 | 0.99 | 0.97 | 117 | 119 | 65 | 7.1 | 497 | 10.1 | 47 |
| 2 | Modal (T) 1% (owm) | 428 | 366 | 0.99 | 0.97 | 118 | 120 | 65 | 7.1 | 496 | 10.1 | 47 |
| 3 | Modal (T) 2% (owm) | 425 | 359 | 0.97 | 0.98 | 120 | 122 | 67 | 7.0 | 494 | 10.0 | 49 |
| 4 | Modal (T) 3% (owm) | 420 | 354 | 0.95 | 0.95 | 122 | 123 | 68 | 6.9 | 493 | 9.9 | 50 |
| 5 | Modal (T) 4% (owm) | 416 | 348 | 0.94 | 0.94 | 125 | 126 | 70 | 6.7 | 489 | 9.7 | 53 |
| 6 | Modal (T) 5% (owm) | 405 | 338 | 0.89 | 0.90 | 127 | 128 | 71 | 6.6 | 488 | 9.6 | 54 |
| 7 | II. COTTON Cotton (UT) | 360 | 314 | 1.05 | 1.04 | 110 | 112 | 79 | 6.9 | 626 | 11.8 | 61 |
| 8 | Cotton (T) 1%(owm) | 359 | 312 | 1.05 | 1.03 | 110 | 113 | 80 | 6.9 | 624 | 11.7 | 61 |
| 9 | Cotton (T) 2%(owm) | 356 | 309 | 1.04 | 1.02 | 112 | 114 | 81 | 6.8 | 622 | 11.6 | 62 |
| 10 | Cotton (T) 3%(owm) | 353 | 307 | 1.02 | 1.01 | 114 | 115 | 81 | 6.7 | 620 | 11.5 | 63 |
| 11 | Cotton (T) 4%(owm) | 348 | 301 | 0.99 | 0.98 | 118 | 118 | 84 | 6.5 | 614 | 11.2 | 66 |
| 12 | Cotton (T) 5%(owm) | 340 | 292 | 0.97 | 0.97 | 119 | 119 | 85 | 6.4 | 612 | 11.1 | 67 |

Wp → Warp Wt → Weft UT → Untreated Cotton and Modal Fabrics T → Treated with 98% Formic acid

### 3.2 Absorbency of modal and cotton fabrics

The data of absorbency of modal and cotton woven and knitted fabrics are given in Table 2. It is seen from this table that the overall absorbency exhibited by woven fabric (modal and cotton) is more than those of knitted fabric. The absorbency is more for cotton than that of modal fabrics both in the case of woven and knitted fabrics. In the formic acid treated modal fabrics (woven and knitted) the water drops are absorbed in less time which indicates that as the concentration of formic acid increases, the absorbency on the modal fabric is also increased considerably upto the concentration of 4% (owm), and at 5% (owm) the increase is only marginal. The similar trend is also seen for cotton fabrics.

**Table 2.** Absorbency of modal and cotton fabrics

| S. No. | Textile materials | Drop absorbency (in seconds) | |
|---|---|---|---|
| | | Woven | Knitted |
| 1 | I. MODAL Modal (UT) | 14 | 15 |
| 2 | Modal (T) 1% (owm) | 13 | 14 |
| 3 | Modal (T) 2% (owm) | 12 | 14 |
| 4 | Modal (T) 3% (owm) | 11 | 12 |
| 5 | Modal (T) 4% (owm) | 08 | 09 |
| 6 | Modal (T) 5% (owm) | 07 | 08 |
| 7 | II. COTTON Cotton (UT) | 13 | 14 |
| 8 | Cotton (T) 1%(owm) | 12 | 12 |
| 9 | Cotton (T) 2%(owm) | 11 | 11 |
| 10 | Cotton (T) 3%(owm) | 10 | 10 |
| 11 | Cotton (T) 4%(owm) | 07 | 08 |
| 12 | Cotton (T) 5%(owm) | 06 | 07 |

### 3.3 Wicking of modal and cotton fabrics

The data of wicking behaviour of modal and cotton (woven and knitted) fabrics are given in Table 3. From table 3, it is clear that the wicking behaviour of all the samples is good, however woven fabrics show some increase over the knitted fabrics, due to the uniform and linear arrangement of the fiber polymer in the former one [46]. The wicking behaviour shown by cotton is higher than that of modal fabrics both in the case of woven and knitted fabrics, since cotton is a natural staple fiber with uniform arrangement of amorphous and crystalline phases[ 47, 48]. The modal fabric after treatment with formic acid (98%) at different concentrations for 30 minutes at room temperature shows improved wicking compared with the untreated one. The increase in wicking is significant upto 4% (owm) formic acid treatment, and afterwards the increase is only marginal. The similar trend is also observed for cotton fabrics.

**Table 3.** Wicking of modal and cotton fabrics

| S. No. | Textile materials | Wicking (cm) | |
|---|---|---|---|
| | | Woven | Knitted |
| 1 | I. MODAL Modal (UT) | 13 | 11 |
| 2 | Modal (T) 1% (owm) | 14 | 12 |
| 3 | Modal (T) 2% (owm) | 15 | 12 |
| 4 | Modal (T) 3% (owm) | 16 | 13 |
| 5 | Modal (T) 4% (owm) | 19 | 16 |
| 6 | Modal (T) 5% (owm) | 20 | 17 |
| 7 | II. COTTON Cotton (UT) | 14 | 13 |
| 8 | Cotton (T) 1%(owm) | 15 | 14 |
| 9 | Cotton (T) 2%(owm) | 16 | 15 |
| 10 | Cotton (T) 3%(owm) | 17 | 15 |
| 11 | Cotton (T) 4%(owm) | 19 | 18 |
| 12 | Cotton (T) 5%(owm) | 20 | 19 |

### 3.4 K/S values of dyed modal and cotton (woven and knitted) fabrics

The K/S values of the formic acid treated modal and cotton (woven and knitted) fabrics dyed with the dyes such as annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye, and sulphur dye are given in Table 4. The formic acid treatment was identified effective at the concentration of 4% (owm), hence that condition was considered as optimum parameter. For dyeing, the modal and cotton fabrics were given formic acid treatment only with 4% (owm) concentration for 30 minutes at ambient temperature. From this table it is observed that woven fabrics show overall high K/S values than the knitted fabrics. The K/S value of formic acid treated modal fabric is high when compared those of the cotton fabrics (woven and knitted). The higher K/S value on the formic acid treated modal fabric is influenced by the higher swelling action of formic acid treatment which is revealed by the good absorbency as well as wicking performance of that fabrics [18, 19, 47]. Among the dyes applied on the formic acid treated modal fabrics, there is only a marginal differences in the K/S values; however reactive dye shows the maximum K/S values. Even though the woven and knitted modal and cotton fabrics posses only a small differences in the K/S values for the dyes (annatto, onion, pomogranate, indigo, myrobalan, bar berry, reactive dye, and sulphur dye) applied on these fabrics; there is a uniform trend maintained in these values and the values of woven fabric give an edge over the knitted fabric. The untreated (no formic acid) modal and cotton fabrics were also dyed with the mentioned dyes as given in the Table 4. From this table, it is evident that the overall K/S values of formic acid (4% owm) treated and dyed modal and cotton fabrics are significant compared with that of the untreated dyed fabrics.

**Table 4.** K/S values of modal and cotton (woven and knitted) fabrics

| S. No. | Dyes | Colours obtained | K/S values of the (formic acid treated) dyed fabrics | | | |
|---|---|---|---|---|---|---|
| | | | Modal | | Cotton | |
| | | | Woven | Knitted | Woven | Knitted |
| 1 | Annatto | Orange | 13.98 | 13.10 | 13.72 | 12.77 |
| 2 | Onion | Orange Red | 14.50 | 13.17 | 13.70 | 12.98 |
| 3 | Pomogranate | Brown | 14.47 | 13.52 | 13.76 | 12.84 |
| 4 | Indigo | Blue | 14.60 | 14.33 | 14.01 | 13.45 |
| 5 | Myrobalan | Green | 14.45 | 13.62 | 13.66 | 13.76 |
| 6 | Bar berry | Yellow | 14.54 | 13.41 | 13.95 | 13.32 |
| 7 | Reactive Dye | Red | 15.07 | 14.95 | 14.42 | 14.25 |
| 8 | Sulphur Dye | Black | 14.65 | 14.32 | 14.21 | 13.65 |
| S. No. | Dyes | Colours obtained | K/S values of the dyed fabrics (No formic acid treatment) | | | |
| | | | Modal | | Cotton | |
| | | | Woven | Knitted | Woven | Knitted |
| 1 | Annatto | Orange | 11.72 | 10.96 | 11.12 | 10.75 |
| 2 | Onion | Orange Red | 11.77 | 10.98 | 11.10 | 10.76 |
| 3 | Pomogranate | Brown | 11.82 | 11.02 | 11.15 | 10.80 |
| 4 | Indigo | Blue | 11.92 | 11.11 | 11.29 | 11.04 |
| 5 | Myrobalan | Green | 11.88 | 11.04 | 11.25 | 10.83 |
| 6 | Bar berry | Yellow | 11.85 | 10.98 | 11.14 | 10.72 |
| 7 | Reactive Dye | Red | 12.12 | 12.84 | 12.95 | 12.62 |
| 8 | Sulphur Dye | Black | 11.71 | 11.48 | 11.36 | 11.07 |

### 3.5 Fastness properties of dyed modal and cotton (woven and knitted) fabrics

The fastness properties (wash, light and rubbing) of natural and synthetic (indigo, kum kum, bar berry, reactive dye (M), reactive dye (H) and sulphur) dyes applied on formic acid treated (4% owm) modal and cotton fabrics (woven and knitted) are given in Table 5. From this table, it is evident that the overall fastness properties of formic acid treated and dyed modal and cotton (woven and knitted) fabrics are correspondingly more than that of the untreated one. The wash fastness of the formic acid treated modal fabrics is good as compared with other fatnesses like light and rubbing fastness properties. The reason for the good wash fastness may be due to the good reaction between the reactive groups of the dyes and that of the reactive site of the polymers in the fabric materials. Modal and cotton fabrics contain the reactive group –OH which is present throughout the polymeric chain [6, 10]. These reactive groups are responsible for the good dyeing and wash fastness in the dyed fabrics. It is obvious that the light fastness and rubbing fastness properties are moderate to poor only due to their behaviour towards these applications.

**Table 5.** Fastness properties of modal and cotton (woven and knitted) fabrics

| S. No. | Dyes | Fastnesses of the (formic acid treated) dyed fabrics | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Modal | | | | | | | | Cotton | | | | | | | |
| | | Woven | | | | Knitted | | | | Woven | | | | Knitted | | | |
| | | W | L | R | | W | L | R | | W | L | R | | W | L | R | |
| | | | | Wet | Dry | | | Wet | Dry | | | Wet | Dry | | | Wet | Dry |
| 1 | Annatto | 3-4 | 5 | 2-3 | 4 | 3-4 | 4-5 | 2-3 | 3-4 | 3-4 | 4-5 | 2-3 | 3-4 | 3 | 4 | 2-3 | 3-4 |
| 2 | Onion | 4 | 5 | 2-3 | 4 | 3-4 | 4-5 | 2-3 | 3-4 | 3-4 | 5 | 2-3 | 3-4 | 3-4 | 4 | 2 | 3 |
| 3 | Pomogranate | 3-4 | 5 | 2-3 | 3-4 | 3 | 4-5 | 2-3 | 3-4 | 3 | 5 | 2-3 | 3-4 | 3 | 4-5 | 2-3 | 3 |
| 4 | Indigo | 4-5 | 5-6 | 3 | 3-4 | 4 | 5 | 2-3 | 3 | 4 | 5-6 | 2-3 | 3-4 | 4 | 5 | 2 | 3 |
| 5 | Myrobalan | 3-4 | 5-6 | 2-3 | 3-4 | 3-4 | 5 | 2-3 | 3-4 | 3-4 | 5 | 2-3 | 3-4 | 3-4 | 5 | 2 | 3-4 |
| 6 | Bar berry | 3-4 | 4-5 | 2-3 | 4 | 3 | 4-5 | 2-3 | 4 | 3 | 4-5 | 2-3 | 3-4 | 3-4 | 4 | 2-3 | 4 |
| 7 | Reactive Dye | 4-5 | 6 | 3 | 4 | 4-5 | 5-6 | 2-3 | 4 | 4-5 | 6 | 3 | 3-4 | 4 | 5-6 | 2-3 | 4 |
| 8 | Sulphur Dye | 4-5 | 6 | 2-3 | 3-4 | 4 | 5-6 | 2-3 | 3 | 4 | 5-6 | 2-3 | 3 | 4 | 5 | 2 | 3 |
| S. No. | Dyes | Fastnesses of the dyed fabrics (No formic acid treatment) | | | | | | | | | | | | | | | |
| | | Modal | | | | | | | | Cotton | | | | | | | |
| | | Woven | | | | Knitted | | | | Woven | | | | Knitted | | | |
| | | W | L | R | | W | L | R | | W | L | R | | W | L | R | |
| | | | | Wet | Dry | | | Wet | Dry | | | Wet | Dry | | | Wet | Dry |
| 1 | Annatto | 3 | 4-5 | 2-3 | 3-4 | 3-4 | 4 | 2-3 | 3-4 | 3 | 4-5 | 2-3 | 3-4 | 3 | 4 | 2-3 | 3 |
| 2 | Onion | 3-4 | 4-5 | 2-3 | 4 | 3-4 | 4 | 2-3 | 3-4 | 3 | 4-5 | 2-3 | 3 | 3-4 | 4 | 2 | 3 |
| 3 | Pomogranate | 3 | 4-5 | 2 | 3-4 | 3 | 4 | 2 | 3 | 3 | 4-5 | 2 | 3-4 | 3 | 4-5 | 2-3 | 3 |
| 4 | Indigo | 4 | 5 | 3 | 3 | 3-4 | 4-5 | 2-3 | 3 | 4 | 5-6 | 2-3 | 3-4 | 4 | 4-5 | 2 | 3 |
| 5 | Myrobalan | 3-4 | 5 | 2 | 3-4 | 3 | 5 | 2-3 | 3 | 3-4 | 4-5 | 2-3 | 3 | 3-4 | 4-5 | 2 | 3-4 |
| 6 | Bar berry | 3 | 4 | 2-3 | 4 | 3 | 4 | 2 | 3-4 | 3 | 4 | 2 | 3-4 | 3-4 | 4 | 2-3 | 3-4 |
| 7 | Reactive Dye | 3-4 | 4 | 2 | 3-4 | 3 | 4-5 | 2 | 3 | 3 | 4-5 | 2-3 | 3 | 3 | 4 | 2 | 3 |
| 8 | Sulphur Dye | 4 | 5 | 2 | 3 | 3-4 | 5 | 2-3 | 3 | 3-4 | 5 | 2 | 3 | 3-4 | 4-5 | 2 | 3 |

W – Wash Fastness L – Light Fastness R – Rubbing Fastness

### 3.6 Water vapour permeability of modal and cotton fabrics

The data of water vapour permeability of formic acid treated (4% owm) modal and cotton (woven and knitted) fabrics dyed with annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye and sulphur dyes are given in Table 6. The ASTM E 96 test is used for measuring the water vapour permeability which is the speed or rate at which the water vapor moves through a fabric. The water vapor transport properties of textile materials are of considerable importance in determining the comfort properties of clothing systems [49]. Water vapor transport through porous textiles may occur due to both diffusion (driven by vapor concentration differences) and convection (driven by gas pressure differences).

From the Table 6, it is clearly seen that the formic acid (4% owm) treated modal and cotton (woven and knitted) fabrics dyed with annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye and sulphur dyes give high values of water vapour permeability compared with the corresponding no formic acid treatment materials. The water vapour permeability is due to the property of a material which permits the passage of water vapour through it, and the time rate of water vapour transmission through a unit area of flat materials of unit thickness induced by a unit vapor pressure difference between two specific surfaces under specified temperature and humidity conditions, due to this the value is more in the woven materials than those of the knitted one [41, 43]. The reactive dyed modal and cotton fabrics show the high water vapour permeability value followed by bar berry, myrobalan, annatto, onion, pomogranate, indigo, and sulphur dyed textiles; this is due to the different attracting behaviors of the dyes that also influenced in the results of permeability [6, 49].

### 3.7 Air permeability of modal and cotton fabrics

The values of air permeability of formic acid (4% owm) treated modal and cotton (woven and knitted) fabrics dyed with annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye and sulphur dyes are given in the Table 7. Air permeability is the rate of air flow passing perpendicularly through a known area under a prescribed air pressure differential between the two surfaces of a material. Air permeability test gives the rate of airflow through a material under a differential pressure between the two faces of a fabric. It is expressed as the quantity of air in cubic centimeter passing per second through a square centimeter of the fabric.

It is seen from the Table 7 that the formic acid treated modal and cotton (woven and knitted) fabrics dyed with annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye and sulphur dyes give excellent air permeability behaviour. However, the treated and dyed plain woven fabric gives high air permeability values than those of the corresponding knitted fabrics. The reactive dyed modal and cotton fabrics show the high air permeability values followed by bar berry, myrobalan, annatto, onion, pomogranate, indigo, and sulphur dyed fabrics (woven and knitted).

The analysis of SEM images of formic acid treated and dyed and untreated & undyed modal and cotton fabrics are given in the representative Figures 1, 2 & 3. Figure 1 reveals about the micrographs of formic acid treated and dyed modal fabrics. Figure 2 reveals about the micrographs of formic acid treated and dyed cotton fabrics. These figures show clearly about the effect of formic acid in the corresponding materials and the subsequent dyeing. There is a clear difference between the no formic treated & dyed; and formic acid treated & dyed (indigo) modal fabrics (woven and knitted). Similar trend is also seen for the cotton fabrics. These micrographs reveal about the enhancement of dyeing after formic acid treatment on modal and cotton fabrics respectively compared with those of the untreated & undyed one (figure 3).

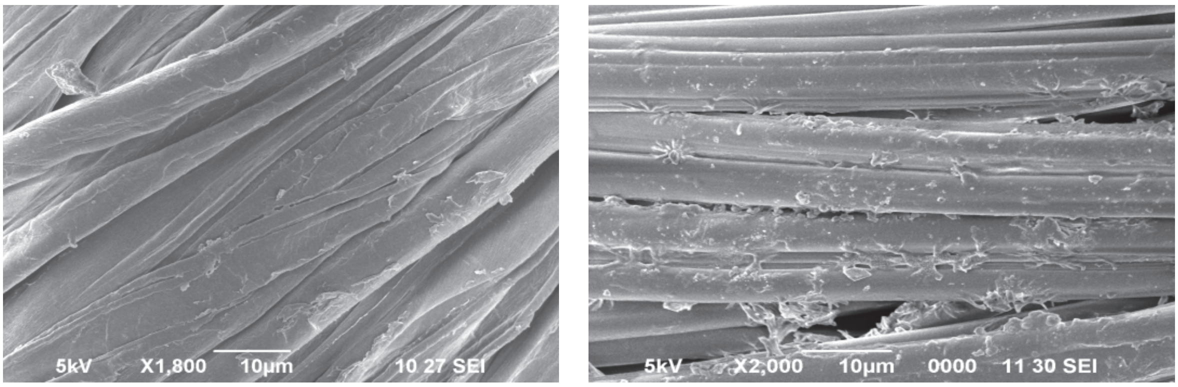
**Table 6.** Water vapour permeability of modal and cotton fabrics

| S. No. | Dyes | Water vapour permeability (g/m2/day) of formic acid treated & dyed fabrics | | | |
|---|---|---|---|---|---|
| | | Modal | | Cotton | |
| | | Woven | Knitted | Woven | Knitted |
| 1 | Annatto | 2073 | 2062 | 2067 | 2056 |
| 2 | Onion | 2069 | 2058 | 2064 | 2052 |
| 3 | Pomogranate | 2067 | 2056 | 2060 | 2049 |
| 4 | Indigo | 2065 | 2053 | 2058 | 2046 |
| 5 | Myrobalan | 2079 | 2067 | 2072 | 2060 |
| 6 | Bar berry | 2086 | 2075 | 2080 | 2069 |
| 7 | Reactive Dye | 2091 | 2080 | 2084 | 2073 |
| 8 | Sulphur Dye | 2062 | 2050 | 2055 | 2043 |
| **S. No.** | **Dyes** | **Water vapour permeability (g/m2/day) (No formic acid treatment)** | | | |
| | | **Modal** | | **Cotton** | |
| | | **Woven** | **Knitted** | **Woven** | **Knitted** |
| 1 | Annatto | 2024 | 2012 | 2014 | 2006 |
| 2 | Onion | 2018 | 2010 | 2010 | 2005 |
| 3 | Pomogranate | 2016 | 2010 | 2010 | 2004 |
| 4 | Indigo | 2014 | 2004 | 2007 | 2001 |
| 5 | Myrobalan | 2018 | 2016 | 2017 | 2009 |
| 6 | Bar berry | 2038 | 2025 | 2028 | 2018 |
| 7 | Reactive Dye | 2048 | 2040 | 2040 | 2031 |
| 8 | Sulphur Dye | 2013 | 2011 | 2009 | 2009 |

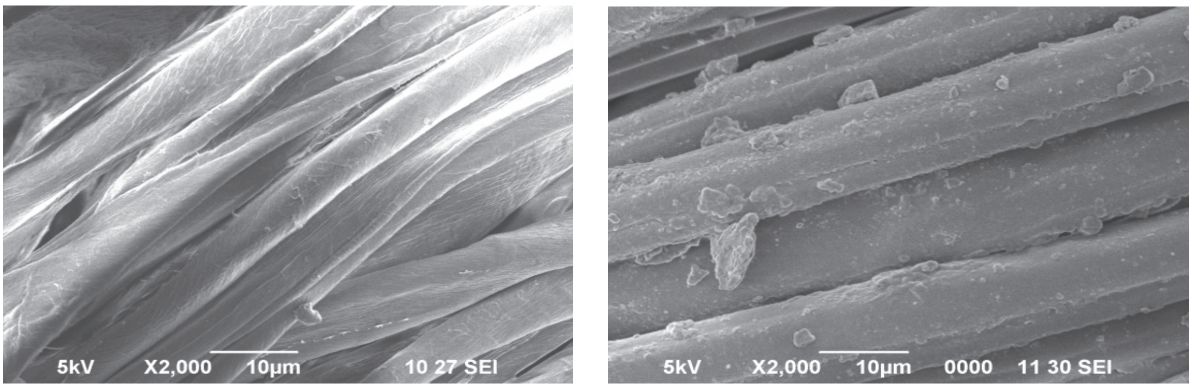
**Table 7.** Air permeability of modal and cotton fabrics

| S. No. | Dyes | Air permeability (l/min) of formic acid treated & dyed fabrics | | | |
|---|---|---|---|---|---|
| | | Modal | | Cotton | |
| | | Woven | Knitted | Woven | Knitted |
| 1 | Annatto | 123 | 119 | 120 | 116 |
| 2 | Onion | 122 | 118 | 119 | 115 |
| 3 | Pomogranate | 121 | 117 | 118 | 114 |
| 4 | Indigo | 120 | 116 | 117 | 113 |
| 5 | Myrobalan | 129 | 123 | 125 | 120 |
| 6 | Bar berry | 131 | 124 | 127 | 121 |
| 7 | Reactive Dye | 133 | 126 | 130 | 123 |
| 8 | Sulphur Dye | 123 | 117 | 119 | 114 |
| **S. No.** | **Dyes** | **Air permeability (l/min) (No formic acid treatment)** | | | |
| | | **Modal** | | **Cotton** | |
| | | **Woven** | **Knitted** | **Woven** | Knitted |
| 1 | Annatto | 106 | 100 | 101 | 98 |
| 2 | Onion | 103 | 101 | 102 | 97 |
| 3 | Pomogranate | 102 | 99 | 100 | 96 |
| 4 | Indigo | 101 | 98 | 99 | 95 |
| 5 | Myrobalan | 110 | 102 | 105 | 99 |
| 6 | Bar berry | 111 | 103 | 106 | 100 |
| 7 | Reactive Dye | 114 | 109 | 109 | 103 |
| 8 | Sulphur Dye | 105 | 99 | 101 | 96 |

### 3.8 SEM analysis of modal and cotton fabrics

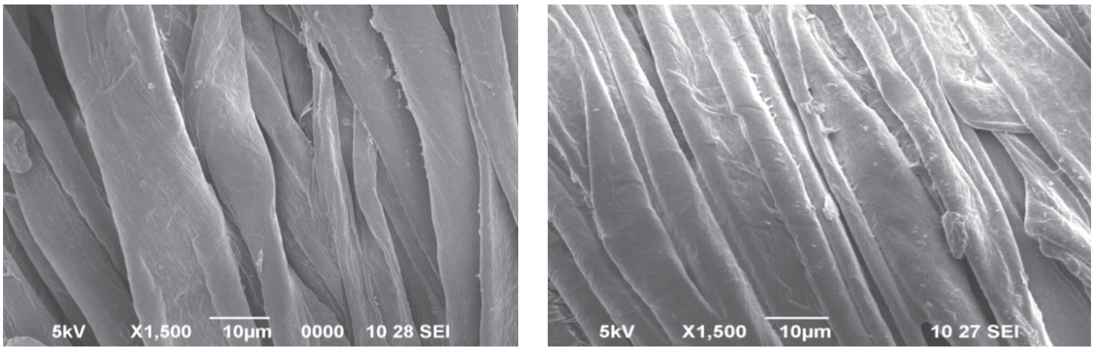



**1-a)** No formic acid treated & Indigo dyed **1-b)** Formic acid treated & Indigo dyed
woven modal fabrics

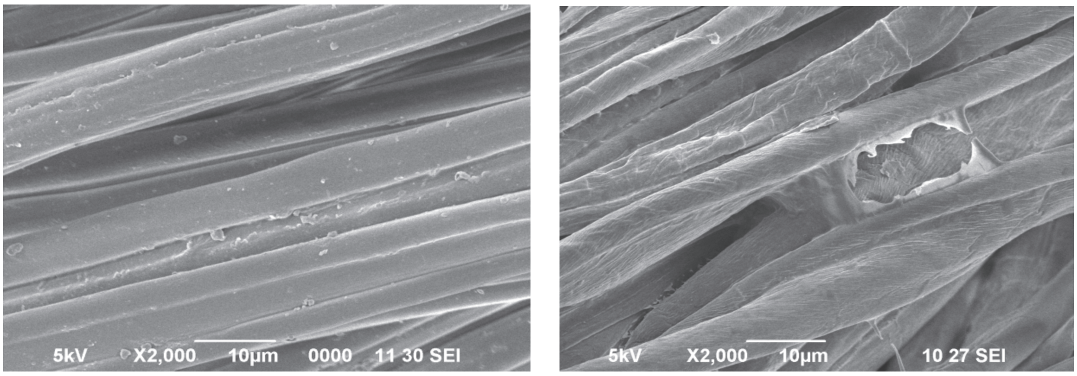



**1-c)** No formic acid treated & Indigo dyed **1-d)** Formic acid treated & Indigo dyed
Knitted modal fabrics

**Fig. 1.** Formic acid treated and indigo dyed modal fabrics.




**2-a)** No formic acid treated & Indigo dyed **2-b)** Formic acid treated & Indigo dyed
woven cotton fabrics




**2-c)** No formic acid treated & Indigo dyed **2-d)** Formic acid treated & Indigo dyed
Knitted cotton fabrics

**Fig. 2.** Formic acid treated and indigo dyed cotton fabrics.

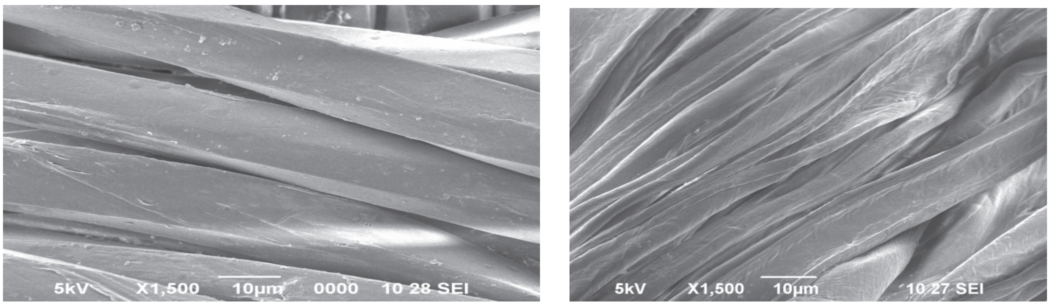



**Fig. 3.** Untreated & undyed modal and cotton woven fabrics.

## 4. Conclusion

The tensile strength of modal fabric both in warp and weft direction and crease recovery angle are very good in comparison with cotton fabric. Whereas the stiffness [warp & weft] and mean drape co-efficient are less in modal fabric over that of cotton fabric. In the case of knitted fabric, cotton shows greater values than that shown by modal fabric for bursting strength and mean drape coefficient respectively. The modal fabric after treatment with formic acid (98%) at the concentration of 4% (owm) for 30 minutes at room temperature gives considerable changes in the physical properties under the favorable limit suitable for the application. The absorbency is improved in the modal fabric (woven and knitted) after treatment with formic acid (98%) at the concentration of 4% (owm) for 30 minutes at room temperature similar to that of cotton fabric. The modal fabric after treatment with formic acid (98%) at the concentration of 4% (owm) for 30 minutes at room temperature shows improved wicking compared with the untreated one.

The K/S values of the dyes such as annatto, onion, pomogranate, indigo, myrobalan, barberry, reactive dye, and sulphur dye applied on formic acid treated modal (woven and knitted) fabrics are good compared with that of no formic acid treated one, similar to the trend of cotton fabrics. The fastness properties (wash, light, & rubbing) of the formic acid treated and dyed (annatto, onion, pomogranate, indigo, myrobalan, bar berry, reactive dye and sulphur dye) woven and knitted modal fabrics are comparatively good over that of no formic acid treated one, as that of cotton fabrics. In general, the overall fastness properties are more in formic acid treated fabrics. The formic acid treated woven and knitted modal fabrics as well as cotton fabrics give good values of water vapour permeability and air permeability in accordance with the wicking behaviour. The SEM micrographs of the formic acid treated & dyed modal and cotton fabrics seem to be better than that of no formic acid treated one.

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