NC STATE College of Textiles
JTATM Journal of Textile and Apparel, Technology and Management

Volume 10, Issue 1, 2016

Study of Chemical Treated Cotton Fabric for functional Finishes using Chitosan

J. Jeyakodi Moses[1], and V.K. Venkataraman[2]
[1]Department of Applied Science, PSG College of Technology
[2]Department of Chemistry, PSG Polytechnic College
India

ABSTRACT

Cotton fabrics were treated with sodium hydroxide, morpholine and cellulase enzyme. These treated cotton fabrics were applied by chitosan followed by dyeing with some selected dyes such as annatto, onion, pomegranate, indigo, myrobalan, bar berry (natural dyes); and reactive and Sulphur dyes (synthetic) respectively. These treated samples were tested for different functional properties such as, wicking, water vapor & air permeability, K/S value, fastness properties, antimicrobial property, and SEM analysis. Results show that chitosan treatment imparts functional properties on cotton fabrics. Among all the treated fabrics, sodium hydroxide treated cotton fabric revealed higher values.

Keywords: Cotton fabric, chitosan, air permeability, k/s value, antimicrobial property, SEM

Introduction

Among all the cellulose polymeric variety, cotton is considered as one of the important textile fibers, suitable for various applications such as sportswear, functional wear, leisure wear, inner wear and other garments. Since cotton is non-allergic it doesn't irritate sensitive skin and preferred when worn close to the skin[1]. Cotton has a high absorbency[2] rate and holds up to 27 times its own weight in water. Cotton can be dyed with many natural colors extracted from natural sources and synthetic dyes such as direct dye, reactive dye, Sulphur dye, vat dye, etc[3]. Vegetable source of natural dyes are renewable[4]. Pigments extracted from the roots of vegetable sources are mostly used for red dyes[5]. The organic cultivation of dye plants for the certified natural textile industry is as emerging and promising sector of organic farming[6]. Henna or Egyptian privet is the source of an ancient and very important yellow dye[7], which continues to be as commonly used all over the world today as it is in the ancient times[8].

Recent market survey shows that the apparel consumers all over the world are demanding functionality in the product[9-11]. With this perspective the current work make use of ecofriendly chemicals for imparting anti-microbial property[12]. Chitosan is found to be the new range of chemicals used in imparting antimicrobial property[13-15] on cotton textiles. The antimicrobial activity of chitosan is influenced by a number of factors that include the type of chitosan, the degree of deacetylation, molecular weight and other physicochemical properties. The process of deacetylation involves in the removal of acetyl groups from the molecules of chitin leaving behind a compound with a high degree of chemically reactive amino group[16-18].

This research work focuses on the treatment of cotton (woven and knitted) fabrics with sodium hydroxide, morpholine, and cellulase enzyme followed by the application of chitosan in order to improve its behavior followed by dyeing with natural and synthetic dyes. These fabrics were then assessed for wicking, water vapor & air permeability, K/S values, fastness properties, antimicrobial properties, and SEM analysis.

Materials and Methods

Materials

The materials used in this study were as follows;

Textile Fabrics:

Cotton (woven and knitted) fabrics with following specifications were used in this study.

Woven Fabric					Knitted fabric		
Ends / Inch	Picks / Inch	GSM	Yarn Count (Ne)		Yarn count (Ne)	GSM	Loop length (mm)
			Warp	Weft			
84	94	146.1	27.1	26.1	27.5	136.9	2.6

Dyes, chemicals and auxiliaries:

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 (reactive red HB – C.I. No. Red 24), and Sulphur dye (Sulphur black – C.I. No. Sulphur Black 1)] used were in the commercial grade. Chitosan, with 81 % deacetylation and molecular weight of 65 kilo Dalton was procured from Central Marine Fisheries Research Institute, Cochin-682018 (India). The other chemicals mentioned elsewhere for this study were in AR grade.

Methods

Pretreatment on cotton (woven and knitted) fabrics

The cotton fabrics (woven and knitted) were pretreated (scouring and bleaching) as per the established technique[19, 20].

Sodium hydroxide treatment on cotton (woven and knitted) fabrics

The cotton fabrics (woven and knitted) were treated with sodium hydroxide of the concentration 15% (owm) for one hour at 85ºC.

Morpholine treatment on cotton (woven and knitted) fabrics

The cotton fabrics (woven and knitted) were treated with aqueous solution of morpholine 40% for one hour at 40ºC.

Cellulase enzyme treatment on cotton (woven and knitted) fabrics

The cotton fabrics (woven and knitted) were treated with Cellulase enzyme of the concentration 4.0% (owm) for one hour at 70ºC.

Physical properties of cotton (woven and knitted) fabrics

The cotton fabrics (woven and knitted) were treated with aqueous solution of sodium hydroxide, morpholine, and cellulase enzyme. The physical properties (tensile strength, stiffness, crease recovery angle and drape coefficient of woven cotton fabric; and bursting strength and mean drape coefficient of knitted cotton fabric) of treated and untreated cotton fabrics were tested as per the established techniques[1, 19, 20].

Wicking behavior of cotton (woven and knitted) fabrics

The wicking height of the cotton fabric was determined[21, 22]. Fabric samples measuring 10 cm x 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[23, 24].

Water vapor permeability of cotton (woven and knitted) fabrics

Water vapor permeability (WVP) is the speed or rate at which moisture vapor moves through a fabric. The ASTME 96 moisture vapor test (open cup test) was used for measuring the WVP rate of the cotton fabric[25].

Air Permeability of cotton (woven and knitted) fabrics

ASTM – D737 method was used for measuring the air permeability of cotton fabric. This test gave the rate of airflow through a material under a differential pressure between the two faces of a cotton fabric[26].

Chitosan application on treated cotton (woven and knitted) fabrics

Chitosan was dissolved with 2% acetic acid solution and were filtered before application. The solution was taken in a bath with material to liquor ratio of 1:100. The samples were entered into the chitosan bath and the pH was maintained at 5.0±0.2 with acetic acid solution. The chitosan bath temperature was raised to 95°C and kept at this temperature for 30 minutes. After application the bath was cooled to 30°C; the samples were taken out and washed with warm water, rinsed with cold water and dried[27].

Dyeing of cotton (woven and knitted) fabrics

The dyeability of cotton fabrics (woven and knitted) was investigated using natural and synthetic dyes. Dyeing was carried out 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[20, 28].

K/S analysis of the dyed cotton (woven and knitted) fabrics

Colorimetric data of natural and synthetic dyed cotton fabrics were determined by AATCC 135-1985 (2003) technique using a Datacolor SF 600 plus spectrophotometer interfaced to a PC[29].

Color fastness analysis of the cotton (woven and knitted) fabrics

The natural and synthetic dyed samples were washed[29] under condition IIIA of AATCC Test Method 124-2001 (2003) to determine the color change effect of dyed fabrics. Light fastness tests[30] were carried out according to AATCC Test Method 16 E-1998 (2003). AATCC standardized crock meter was used to determine the rubbing fastness[31] of natural dyed fabrics under wet and dry condition to assess the color change and staining property AATCC 61-1996 (2003).

Antimicrobial assessment of the cotton (woven and knitted) fabrics

The antibacterial activity on the natural dyed (annatto, onion, pomegranate, indigo, myrobalan and bar berry) and synthetic dyed (reactive dye and Sulphur dye) cotton (woven and knitted) fabrics was assessed[32, 33] qualitatively according to the AATCC test method 147-2004 by the parallel streak method.

SEM Study on dyed and finished cotton (woven and knitted) fabrics

Scanning electron microscope studies were carried out on dyed and finished woven and knitted cotton fabrics from 30kV scanning electron microscope JEOL (Japan) Model JSM-6360[33, 34].

Results and Discussion

Physical properties of cotton (woven and knitted) fabrics

The physical properties such as tensile strength, stiffness, crease recovery angle and drape coefficient of woven cotton fabric; and bursting strength and mean drape coefficient of knitted cotton fabric are shown in Table 1. The tensile strength of woven cotton fabrics marginally decreased when treated with sodium hydroxide, morpholine and cellulase enzyme. The decrease of tensile strength is more for morpholine treated cotton fabric followed by enzyme treated and alkali treated woven cotton fabric. The same trend is followed both in warp and weft directions. The overall average decrease in tensile strength between treated (alkali, morpholine and cellulase) and untreated woven cotton fabric is less than 5%. The stiffness of sodium hydroxide treated woven cotton fabric is quite less (av. 0.98) compared to morpholine treated (av. 1.04), cellulase treated (av. 1.06) and untreated (av. 1.07) woven cotton fabrics. The crease recovery angle of sodium hydroxide treated woven cotton fabric is very good (av. 119) compared to morpholine treated (av. 116), cellulase treated (av. 114) and untreated (av. 113) woven cotton fabrics. The sodium hydroxide treated woven cotton fabric shows good mean drape coefficient (82.26%) followed by morpholine treated (81.86%), cellulase treated (80.94%) and untreated (80.65%) woven cotton fabrics. There is very close difference in the mean height at burst (mm) for bursting strength of knitted cotton fabrics. The differences of mean height at burst among treated (alkali, morpholine and cellulase) and untreated knitted cotton fabrics is less than 5% only. The mean drape coefficient of sodium hydroxide treated knitted cotton fabric is more (67.54%) when compared with morpholine treated (66.78%), cellulase treated (65.44%) and untreated (63.96%) knitted cotton fabrics.

Table 1. Physical properties of cotton (woven and knitted) fabrics

S. No.	Treatments	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	Untreated cotton	362	317	1.08	1.06	112	114	80.65	7.3	629.1	12.1	63.96
2	Sodium hydroxide treated cotton	358	316	0.99	0.98	118	120	82.26	7.6	635.4	11.7	67.54
3	Morpholine treated cotton	355	315	1.05	1.03	116	117	81.86	7.4	630.6	12.0	66.78
4	Cellulase enzyme treated cotton	356	315	1.07	1.05	114	115	80.94	7.3	630.2	11.9	65.44

Wp → Warp Wt → Weft

Wicking of the dyed chitosan applied cotton (woven and knitted) fabrics

The data of wicking behavior of cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye and Sulphur dyes are given in Table 2. From Table 2, it is clear that the wicking behavior of all the samples is good, however woven fabrics show some edge over the knitted fabrics. The wicking behavior of sodium hydroxide treated cotton fabric is significantly high compared with those of untreated cotton fabric. Among the treated cotton fabrics the sodium hydroxide treatment influences more on the wicking behavior followed by morpholine treatment and cellulase treatment. The differences in the wicking behavior of the dyed (annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye, and Sulphur dye) cotton fabric is only marginal. However, the reactive dyed cotton fabric shows the high wicking value when compared with the other dyed cotton fabrics. All the data are comparable and similar between the woven and knitted dyed cotton fabrics.

Table 2. Wicking of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Wicking (cm) of dyed cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	9	15	15	13	8	15	12	11
2	Onion	9	16	15	14	8	15	13	12
3	Pomegranate	9	17	15	14	8	13	13	12
4	Indigo	8	16	14	13	6	13	12	11
5	Myrobalan	9	16	15	13	8	15	13	12
6	Bar berry	9	20	17	15	8	17	15	13
7	Reactive Dye	9	18	17	15	9	15	15	12
8	Sulphur Dye	7	15	13	12	6	12	11	10

1. Untreated cotton 2. Sodium hydroxide treated cotton
3. Morpholine treated cotton 4. Cellulase enzyme treated cotton

Water vapor permeability of the dyed chitosan applied cotton (woven and knitted) fabrics

The data of water vapor permeability of cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye and Sulphur dyes are given in Table 3. The ASTME 96 test is used for measuring the w ater vapor permeability which is the speed or rate at which the water vapor moves through a fabric. The rate of water vapor that passes through the fabric was determined by reduction in the height of water in the cup. Water was poured into cups up to 6 cm from base level. The cups were marked for every 0.5 mm. The fabric samples were placed tightly on top of the cups where the water, the air above the water, and the room environment were at the same temperature and pressure. After 48 hours the level of water decreased in the cups and the reduction in height of water was noted down. The moisture vapor transfer rate is the difference between the initial height of water and the actual height of water in the cups. The water vapor transport properties of textile materials are of considerable importance in determining the comfort properties of clothing systems. 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 3, it is clearly seen that the cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye and Sulphur dyes give good values of water vapor permeability. However, the treated and dyed plain woven fabric gives high values than those of the corresponding knitted fabrics. The water vapor permeability is due to the property of a material which permits the passage of water vapor through it, and the time rate of water vapor 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. The reactive dyed cotton fabric shows the high water vapor permeability value followed by bar berry, myrobalan, annatto, onion, pomegranate, indigo, and Sulphur dyed textiles.

Table 3. Water vapor permeability of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Water Vapor permeability (g/m^2/day) of dyed cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	2038	2074	2063	2054	2030	2068	2057	2048
2	Onion	2030	2070	2060	2050	2025	2065	2053	2040
3	Pomegranate	2028	2068	2057	2048	2025	2060	2050	2042
4	Indigo	2024	2066	2054	2043	2018	2060	2047	2037
5	Myrobalan	2042	2080	2068	2060	2037	2073	2060	2053
6	Bar berry	2050	2087	2076	2066	2045	2082	2070	2061
7	Reactive Dye	2054	2092	2080	2072	2050	2085	2074	2066
8	Sulphur Dye	2020	2063	2050	2040	2015	2056	2044	2035

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Air Permeability of the dyed chitosan applied cotton (woven and knitted) fabrics

The values of air permeability of cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye and Sulphur dyes are given in the Table 4. 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 is an important factor in the performance of textile materials such as gas filters, fabrics for air bags, clothing, mosquito netting, parachutes, sails, tent age and vacuum cleaners. Air permeability also can be used to provide an indication of the breathability of weather resistant and rain proof fabrics, or of coated fabrics in general, and to detect changes during the manufacturing process. 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 4 that the cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye and Sulphur dyes give excellent air permeability behavior. However, the treated and dyed plain woven fabric gives high air permeability values than those of the corresponding knitted fabrics. The reactive dyed cotton fabrics shows the high air permeability values followed by bar berry, myrobalan, annatto, onion, pomegranate, indigo, and Sulphur dyed fabrics (woven and knitted).

Table 4. Air permeability of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Air Permeability (l/min) of dyed cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	115	123	119	116	111	120	116	113
2	Onion	113	122	118	115	111	119	115	112
3	Pomegranate	112	121	117	114	109	118	114	111
4	Indigo	1109	120	116	113	107	117	113	110
5	Myrobalan	116	129	123	119	113	125	120	116
6	Bar berry	117	131	124	120	115	127	121	117
7	Reactive Dye	119	133	126	122	116	130	123	119
8	Sulphur Dye	108	123	117	113	106	119	114	110

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

K/S values of the dyed chitosan applied cotton (woven and knitted) fabrics

The K/S values of the dyes such as annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye (H), and Sulphur dye applied on cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) applied with chitosan are given in Table 5. From this table it is observed that woven cotton fabric shows overall high K/S values than the knitted cotton fabric. The K/S value of chitosan applied sodium hydroxide treated cotton fabric is maximum when compared with morpholine treated, cellulase treated and untreated cotton fabrics. The higher K/S value on the chitosan applied sodium hydroxide treated cotton fabric is influenced by the higher swelling action of sodium hydroxide followed by morpholine treatment and cellulase treatment. Among the dyes applied on the cotton fabric (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) there is only a marginal differences in the K/S values; however reactive dye shows the maximum K/S values. Even though the woven cotton fabric and knitted cotton fabric posses only a small differences in the K/S values for the dyes (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) applied on the chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated); there is a uniform trend maintained in these values and the values of woven fabric give an edge over the knitted fabric.

Table 5. K/S values of dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Colors obtained	K/S values of the dyed chitosan applied cotton fabrics							
			Woven				Knitted			
			1	2	3	4	1	2	3	4
1	Annatto	Orange	13.57	15.00	14.12	13.85	13.18	14.78	13.81	13.68
2	Onion	Orange Red	13.55	15.52	14.20	14.21	13.28	14.77	13.98	13.89
3	Pomegranate	Brown	13.50	15.44	14.55	14.36	13.17	14.80	13.88	13.76
4	Indigo	Blue	14.20	15.63	15.26	15.33	13.93	15.99	14.49	14.21
5	Myrobalan	Green	13.42	15.50	14.64	14.47	13.63	14.69	14.78	13.87
6	Bar berry	Yellow	13.63	15.55	14.66	14.46	13.71	14.90	14.36	13.99
7	Reactive Dye	Red	14.85	16.15	15.96	15.98	14.67	15.46	15.29	15.06
8	Sulphur Dye	Black	14.62	15.62	15.37	15.36	14.41	15.29	14.68	14.40

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Washing fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

The washing fastness of the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) woven and knitted chitosan applied cotton fabrics are given in Table 6. It is evident from this table that there is no significant differences in the wash fastness of the woven and knitted chitosan applied cotton fabric (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dyes. However, the sodium hydroxide treated and dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) chitosan applied cotton fabric (woven and knitted) shows improved wash fastness compared to the corresponding morpholine treated, cellulase treated and untreated cotton fabrics. Among the dyes (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) applied on chitosan given cotton fabric (woven and knitted) (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) the reactive dyed one gives higher wash fastness over that of the other dyed ones (annatto, onion, pomegranate, indigo, myrobalan, bar berry, and Sulphur dye). Even though the trend is followed similarly both in woven fabrics and knitted fabrics, the woven fabrics show marginal increase over the knitted dyed fabrics.

Table 6. Washing fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Washing fastness of the dyed chitosan applied cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	3-4	4	3-4	3-4	3	3-4	3	3
2	Onion	3	4	3-4	4	2-3	3-4	3-4	3
3	Pomegranate	3-4	4	4	3-4	3-4	4	4	3-4
4	Indigo	3-4	4-5	4	4	3-4	4	4	4
5	Myrobalan	3-4	4	4	4	3	3-4	3-4	3-4
6	Bar berry	4	4	3-4	3-4	3	4	3-4	4
7	Reactive Dye	3-4	5	4-5	4	3-4	4-5	4	4
8	Sulphur Dye	3-4	4-5	4	4	3-4	4	4	4

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Light fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

The light fastness of the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) woven and knitted chitosan applied cotton fabrics are given in Table 7. From this table, it is seen that the overall light fastness of the woven and knitted chitosan applied cotton fabric (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye is good (average 5). The sodium hydroxide treated chitosan applied cotton fabric (woven and knitted) dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye shows higher light fastness values than the morpholine treated, cellulase treated and untreated cotton fabrics. The high light fastness of the dyed chitosan applied cotton fabric is influenced by sodium hydroxide treatment for more swelling thereby more dyeing reaction in cotton fabric (woven and knitted) followed by morpholine treatment, cellulase treatment and no treatment. The reactive dye gives more light fastness value (average 5 – 6) when compared with all the other applied dyes (average 5) on chitosan applied cotton fabric (woven and knitted). Similarly there is a uniform trend between woven fabric and knitted fabric for light fastness values on the treated (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) and dyed chitosan applied cotton fabric, however the woven fabric has an edge over the corresponding knitted fabric.

Table 7. Light fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Light fastness of the dyed chitosan applied cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	4	5	5	4-5	4	5	4	4
2	Onion	4	5-6	5	5	3-4	5	4	4
3	Pomegranate	4-5	5	5-6	4	4	4-5	4-5	4-5
4	Indigo	4-5	6	5-6	5-6	4	5-6	5	4-5
5	Myrobalan	4	5-6	5	4-5	3-4	5	5	5
6	Bar berry	3-4	5	4-5	4-5	4	5	4-5	4
7	Reactive Dye	4-5	6	6	5-6	4	5-6	5-6	5
8	Sulphur Dye	5	6	5-6	5-6	4	5-6	5	5

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Rubbing fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

The rubbing fastness both in wet and dry state of the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) woven and knitted chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) are given in Table 8. Table 8 shows that the rubbing fastness in dry state is extremely good than that of wet state. The reactive dyes show marginal high value of rubbing fastness than other dyes (annatto, onion, pomegranate, indigo, myrobalan, bar berry, and Sulphur dye) applied on woven and knitted chitosan applied cotton fabrics in the dry state whereas in the corresponding wet state, as expected the rubbing fastness is in the poor form. The sodium hydroxide treated chitosan applied cotton fabrics (woven and knitted) dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye show increased rubbing fastness values compared with those from cellulase and untreated fabrics. The sodium hydroxide treatment increases the swelling in cotton fabrics thereby correspondingly increases the penetration of dyes also, hence the increased rubbing fastness value is obtained. The average rubbing fastness values for the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) woven chitosan applied cotton fabric (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) has an edge over the corresponding knitted fabric.

Table 8. Rubbing fastness of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Rubbing fastness of the dyed chitosan applied cotton fabrics															
		woven								Knitted							
		1		2		3		4		1		2		3		4	
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1	Annatto	2	2	2-3	4	2-3	3-4	2-3	3	2	2	2-3	3-4	2-3	3-4	2	3
2	Onion	2	2-3	2-3	4	2-3	3-4	2	3	2	2-3	2-3	3-4	2	3	2	3
3	Pomegranate	2	2-3	3	4	2-3	3-4	2-3	3-4	1-2	2-3	2-3	3-4	2-3	3	2	3
4	Indigo	2	3	3	3-4	2-3	3-4	2-3	3	1-2	2-3	2-3	3-4	2	3	2	3
5	Myrobalan	2	2	3	4	2-3	3-4	2	3	1-2	2	2-3	3-4	2	3-4	2	3
6	Barbery	2	2-3	2-3	4	2-3	3-4	2-3	3-4	2	2-3	2-3	4	2-3	4	2-3	4
7	Reactive Dye	2	3	3	4	3	3-4	3	3-4	2	2-3	2-3	4	2-3	4	2-3	4
8	Sulphur Dye	2	2-3	2-3	3-4	2-3	3	2	3	1-2	2-3	2-3	3	2	3	2	3

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Stain resistance of the dyed chitosan applied cotton (woven and knitted) fabrics

The stain resistance of the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) woven and knitted chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) are given in Table 9. From this table, it is seen that the stain resistance of synthetic dyes (reactive dye (H) and Sulphur dye) is more compared to those of natural dyes (annatto, onion, pomegranate, indigo, myrobalan, and bar berry) applied on both woven and knitted chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated). Similarly, natural dyes also give good stain resistance on woven and knitted chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) comparably with synthetic dyes. In general, the stain resistance of all these dyes (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) dyed on woven and knitted chitosan applied cotton fabrics is good (average 4). The sodium hydroxide treated chitosan applied cotton fabrics (woven and knitted) show high stain resistance values than morpholine treated, cellulase treated and untreated dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye) fabrics. The woven fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) give marginal increase in stain resistance values over the corresponding knitted fabrics dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dyes.

Table 9. Stain resistance of the dyed chitosan applied cotton (woven and knitted) fabrics

S. No.	Dyes	Stain resistance of the dyed chitosan applied cotton fabrics							
		Woven				Knitted			
		1	2	3	4	1	2	3	4
1	Annatto	3	4-5	4	3-4	2-3	3-4	3-4	3
2	Onion	2-3	4	3	3	2-3	4	3	3
3	Pomegranate	3	4-5	3-4	3-4	2-3	4	3	3
4	Indigo	3	4-5	4	4	3	4	3-4	3
5	Myrobalan	3-4	5	4	4	3	4	3-4	3-4
6	Bar berry	3	4	4	3-4	3	3-4	3-4	3
7	Reactive Dye	3-4	5	4	4	3-4	4	4	4
8	Sulphur Dye	3-4	4-5	4	4	3	4	3-4	3-4

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

Antibacterial assessment of the dyed chitosan applied cotton (woven and knitted) fabrics

The antimicrobial assessment of the dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye, and Sulphur dye) woven and knitted chitosan applied cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) is given in Table 10. All these dyed samples showed a higher zone of inhibition against Staphylococcus aureus when compared to Escherichia coli. In general, the sodium hydroxide treated chitosan applied cotton fabric (woven and knitted) shows a higher zone of inhibition (both by Staphylococcus aureus and Escherichia coli) followed by morpholine treated, cellulase treated and untreated cotton fabrics (woven and knitted) when dyed with annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye (H), and Sulphur dye. The reactive dye shows maximum inhibition followed by Sulphur dye in synthetic dye category whereas indigo gives maximum inhibition followed by other natural dyes when dyed on chitosan applied cotton fabrics (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) as exhibited by staphylococcus aureus and escherichia coli.

Table 10. Antibacterial assessment of the dyed chitosan applied cotton fabrics

S. No.	Dyes	Antibacterial activity of the natural and synthetic dyed chitosan applied cotton fabrics															
		Woven Fabric								Knitted Fabric							
		1		2		3		4		1		2		3		4	
		SA	EC	SA	EC	SA	EC	SA	EC	SA	EC	SA	EC	SA	EC	SA	EC
1	Annatto	26	25	36	34	31	29	29	28	24	22	37	31	30	29	28	26
2	Onion	27	26	36	33	31	30	29	29	25	23	35	31	30	28	27	26
3	Pomegranate	27	25	37	34	32	30	30	28	25	22	36	31	31	29	29	27
4	Indigo	31	29	40	38	36	33	35	32	29	26	38	37	33	32	30	30
5	Myrobalan	27	26	36	34	32	31	30	29	25	24	35	32	31	30	28	27
6	Bar berry	29	28	38	35	34	32	32	31	26	24	36	33	32	31	29	27
7	Reactive Dye	37	35	48	46	43	40	41	38	34	32	46	43	42	38	39	33
8	Sulphur Dye	33	31	42	41	39	37	37	34	31	29	41	40	38	35	35	31

SA → Staphylococcus aureus EC → Escherichia coli

1. Untreated cotton
2. Sodium hydroxide treated cotton
3. Morpholine treated cotton
4. Cellulase enzyme treated cotton

SEM analysis of chitosan applied cotton fabric

The analysis of SEM images of dyed chitosan applied cotton fabrics (woven and knitted) have been discussed under this section. The SEM image of chitosan is given in the following Figure 1. The dye was selected to dye some of the sample fabric based on the suitable performance. Accordingly, chitosan applied woven and knitted cotton fabrics were dyed with barberry dye and their respective SEM images were analyzed.

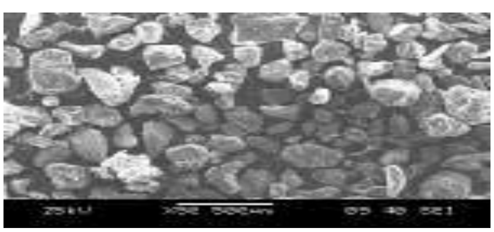

Figure 1. SEM micrograph of intact *chitosan before application on cotton fabric*

SEM analysis of chitosan applied woven cotton fabric

The SEM images of untreated / undyed, and dyed chitosan applied woven cotton fabrics are given in the Figures 2a, 2b, 2c, 2d, and 2e respectively. As the samples were treated with different chemicals and subsequently chitosan applied and dyed, it is evident from the Figures 2b, 2c, 2d and 2e respectively that there are some clear differences in the respective images. Accordingly, Figure 2b shows the SEM image of untreated chitosan applied and dyed woven cotton fabric. Figures 2c, 2d and 2e clearly give the differences in the corresponding SEM images about the influences of the respective chemical treatments and chitosan application on woven cotton fabric. Hence, the chitosan applied and dyed sodium hydroxide treated cotton fabric (Figure 2c) gives good appearance in the SEM image followed by morpholine treated (Figure 2d) and enzyme treated (Figure 2e) respectively.

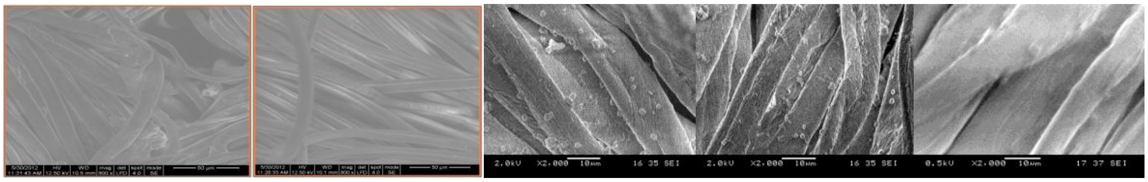

Figure 2. SEM micrograph of a) undyed / untreated, b) untreated / dyed, c) sodium hydroxide treated / dyed chitosan applied, d) morpholine treated / dyed chitosan applied, and e) enzyme treated, / dyed chitosan applied woven cotton fabrics

SEM analysis of chitosan applied knitted cotton fabric

The SEM images of dyed chitosan applied knitted cotton fabrics are given in the Figures 3a, 3b, 3c, and 3d respectively. Figure 3 is the SEM image of untreated / undyed knitted cotton fabric. As the samples were treated with different chemicals (sodium hydroxide, morpholine and enzyme) and subsequently chitosan applied and dyed, it is evident from the Figures 3a, 3b, 3c, and 3d respectively, that there are some clear differences in the respective images. Accordingly, Figure 3a shows the SEM image of untreated chitosan applied and dyed knitted cotton fabric. Figures 3b, 3c, and 3d clearly give the differences in the corresponding SEM images about the influences of the respective chemical treatments and chitosan application on knitted cotton fabrics. Hence, the chitosan applied and dyed sodium hydroxide treated cotton fabric (Figure 3b) gives good appearance in the SEM image followed by morpholine treated (Figure 3c) and enzyme treated (Figure 3d) respectively.

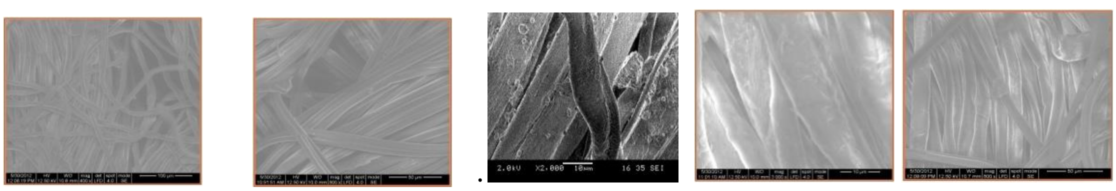

Figure 3. SEM micrograph of a) undyed / untreated, b) untreated / dyed, c) sodium hydroxide treated / dyed chitosan applied, d) morpholine treated / dyed chitosan applied, and e) enzyme treated / dyed and chitosan applied knitted cotton fabric

Conclusion

The physical properties (tensile strength, stiffness, crease recovery angle and drape coefficient of woven cotton fabric; and bursting strength and mean drape coefficient of knitted cotton fabric) of the cotton fabrics treated with sodium hydroxide, morpholine and cellulase enzyme are not much reduced compared with the corresponding untreated cotton fabric and they are within the tolerance limit. The wicking value is very good in both the type of fabrics, however the woven fabrics show more wicking behavior compared to the knitted cotton fabric. The woven and knitted cotton fabrics also give good values of water vapor permeability and air permeability.

Chitosan treatment on cotton improves the functional properties. The K/S values of the dyes such as annatto, onion, pomegranate, indigo, myrobalan, barberry, reactive dye, and Sulphur dye dyed on chitosan applied cotton (woven and knitted) fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) are good. The sodium hydroxide treated chitosan applied cotton fabrics show maximum color data followed by morpholine treated and cellulase enzyme treated cotton fabrics.

The fastness properties (wash, light, rubbing and stain resistance) of the chitosan applied and dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye and Sulphur dye) woven and knitted cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) are good. In general, the overall fastness properties are more in sodium hydroxide treated chitosan applied cotton fabrics followed by morpholine treated and cellulase enzyme treated cotton fabrics.

The antimicrobial character of the chitosan applied and dyed (annatto, onion, pomegranate, indigo, myrobalan, bar berry, reactive dye, and Sulphur dye) woven and knitted cotton fabrics (sodium hydroxide treated, morpholine treated, cellulase treated and untreated) is good. All these chitosan applied and dyed samples showed a higher zone of inhibition against Staphylococcus aureus when compared to Escherichia coli. In general, the sodium hydroxide treated chitosan applied cotton fabric (woven and knitted) shows a higher zone of inhibition (both by Staphylococcus aureus and Escherichia coli) followed by morpholine treated, cellulase enzyme treated cotton fabrics. SEM micrographs reveal that the dyed chitosan applied sodium hydroxide treated cotton fabric gives good appearance followed by morpholine treated and enzyme treated respectively.

Acknowledgements

The authors wish to thank the Management and the Principal, PSG College of Technology, Coimbatore for given the permission and providing the necessary infrastructure. Thanks are also due to The Head, Department of Applied Science for the kind help in department laboratory supports.

References

1. Lewin, M., (2007). Handbook of Fibre Chemistry, 3rd edition, CRC Press, Baco Raton, USA, pp.331-382.
2. Meenaxi Tiwari, Archana Singh, Alka Ali, (2009). Resist printing on cotton fabric with vat dye using different resisting agents, *Asian Dyer*, pp. 32-35.
3. Thakare, A.M., Manoj Das, Brijesh Misra, April (2006), New Approaches in Dyeing of Cotton, *Asian Dyer*, pp. 35-36.
4. Janhom, S., Watanesk, R., Watanesk, S., Griffiths, P., Arquero, A., Naksata, W., March (2006), Comparative Study of Lac Dye Adsorption on Cotton Fibre Surface Modified by Synthetic and Natural Polymers, *Dyes and Pigments*, 71, pp.188-193.
5. NCIB Pubmed (2002), www.ncbi.nih.gov.
6. Anna Hartl, Christian.R.Vogl, (2003), The potential use of organically grown dye plants in Organic Textile Industry, *Journal of sustainable Agriculture*, vol. 23(2), pp.17.
7. El-Shishtawy, R.M., Nassar, S.H., (2002), Cationic Pretreatment of Cotton Fabric for Anionic Dye and Pigment Printing with Better Fastness Properties, *Colour Technol*, 118(3), pp.115.
8. Christie, R.M., Hill, J.M., Rosair, G., February (2006), The crystal structure of CI Pigment Yellow 97, A superior performance Hansa Yellow Pigment, *Dyes and Pigments*, 71, pp.194-198.
9. Mehmet Orhan, Dilek Kut, Cem Gunesoglu, March (2007), Use of triclosan as antibacterial agent in textiles, *Indian Journal of Fibre & Textile Research*, 32, pp. 114-118.
10. Menezes, E., (2002), Antimicrobial Finishing for Speciality Textiles, *Internaitonal Dyer*, 187 (12), pp. 13 – 16.
11. Purwar, R., Joshi, M., (2004), Recent Development in Antimicrobial Finishing of Textiles – A Review, *AATCC Review*, 4 (3), pp.22 – 25.
12. An Yuan Gao, Robin Cranston, (2008), Recent Advances in Antimicrobial Treatment of Textiles , *Text Res J*, 78(1) , pp.60 – 72.

13. Anjali Karolia, Snehal Mendopara, (2007), Imparting antimicrobial and Fragrance finish on cotton using chitosan with silicon softener, *Indian J, Fibre Text Res,* 32, pp.99.
14. Md.S.Rahman, Chauhan, D.V., Tiwari, S.K., (2005), Formalydehyde free Wrinkle recovery and antimicrobial finish using chitosan, *ATIRA communications on Text,* 39, pp.47.
15. Deepti Guptha, Komal Saini, April (2008), Low molecular weight chitosan derivatives for antimicrobial treatment of cotton, *Asian dyer*, pp. 58 – 63.
16. Mairal, A.K., Vaidya, A.J., August (2008), Formaldehyde free finishing of cotton using cationic chitosan, *Asian dyer*, pp. 44 – 47.
17. Pradip Kumar Dutta, Joydeep Dutta, Tripathi, V.S., (2004), Chitin and chitosan: Chemistry, properties and applications, *Indian J.Sci & Ind, Res.* 63 pp. 20 – 29.
18. Lidija Fras zemljic, Sinnona Strnad, Ol ivera Sauperl, (2009), Characterization of Amino Groups for Cotton Fibers coated with Chitosan, *Text Res. J,* 79(3), pp.219 – 225.
19. Shukla, S.R., (2000), Advances in Preparatory Process in Cotton, NCUTE-Programme Series, Chemical Preparatory Process in Textiles, IIT, Delhi.
20. Trotman, E.R., (1984), Dyeing and Chemical Technology of Textile Fibers, 6th edition, Edward Arnold, London.
21. Tyagi, G.K., Krishna, G., Bhattacharya, S., Kumar, P., (2009), Comfort aspects of finished polyester-cotton and polyester-viscose ring and MJS yarn fabrics, *Indian J of Fiber & Textile Research,* 34, pp. 137-143.
22. Swarna Natarajan, Jeyakodi Moses, J., (2012), Surface Modification of Polyester Fabric using Polyvinyl Alcohol in Alkaline Medium, *Indian Journal of Fiber & Textile Research.* 37, pp. 287-291.
23. Kissa, E., (1996), Wetting & Wicking, *Textile Research Journal.* 66(10), pp. 660-668.
24. AATCC Test Method 197; 2011, (2011), *Vertical Wicking of Textiles*, Technical Manual of the AATCC, Research Triangle Park, USA.
25. ASTM – E96, (2000), Standard Test Methods for Water Vapor Transmission of Materials.
26. ASTM – D737, (2012), Standard Test Methods for Air Permeability of Textile Fabrics.
27. Ammayappan, L., Jeyakodi Moses, J., (2008), Study of Antimicrobial activity of Aloevera, chitosan, and curcumin on cotton, wool, and rabbit hair, Fibers and Polymers, 10(2), pp.161–166.
28. Mohanty, B.C., Chandramauti, K.V., Naik, H.D., (1987), Natural Dyeing Process of India, Published by Calico Museum of Textiles, India.
29. AATCC Test Method 135-1985: (2003), Colour measurement of textiles: Instrumental Technical manual of the AATCC, Research Triangle Path, USA.
30. AATCC Test Method 16-1998: (2003), Colour fastness to light, Technical Manual of the AATCC, Research Triangle Park, USA.
31. AATCC Test Method 61-1996: 'Colour fastness to laundering: Home and communication- accelerated, Technical manual of the AATCC', Research. Triangle Park, U.S.A, 2003.
32. AATCC Test Method 147-2004, 'Antibacterial Activity Assessment of Textile Materials–Parallel Streak Method: Technical Manual of the AATCC', Research Triangle Park, USA, 2004.
33. M. Gouda and A. Hebeish 'Preparation and Evaluation of CuO/Chitosan Nanocomposite for Antibacterial Finishing Cotton Fabric', Journal of Industrial Textiles, 39 (3), pp. 203 – 213, 2010.
34. Hearle. J.W.S., Sparrow, J.T., Cross, P.M., (1972), Use of the Scanning Electron Microscope Pergamon Press, Oxford, U.K..