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Preparation of Absorbent Medical Cotton from Non-spinnable Egyptian Cotton Fibers

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Abstract

A PROCESS has been investigated to make absorbent cotton from short staple Egyptian cotton non-spinnable fibers resulting from spinning waste using conventional chemical preparation compared with the enzymatic processes. The physical, chemical and mechanical properties were measured and compared to Egyptian standards (2160/ 2014).

The efficiency of the bio-scoured and bio-bleached cotton fibers was compared with that of the conventionally chemically treated fibers. Prepared absorbent cotton could find its application in biomedicine as surgical cotton. It was revealed that the water absorbing characters of the bio-scoured and bio-bleached samples were considerably higher. Also, the mechanical properties of the cotton fibers were found to be higher for the sample treated using enzymes than the sample treated conventionally with chemicals.

Keywords: Absorbent Cotton, Bio-Scouring, Bio-Bleaching, Eco-friendly, Egyptian standards.

Introduction

Cotton fibers are hydrophobic in nature due to pectin, wax and other impurities present on the surface of the fiber, to convert them into hydrophilic the fibers were scoured and bleached (1). Absorbent cotton should be hydrophilic fibers in character and free of impurities. So, scouring process using sodium hydroxide helps to remove the hydrophobic substances such as wax and pectin on the surface of cotton fiber by chemical scouring pretreatment. Also, hydrogen peroxide used to remove the color substrate and whiten the cotton fiber through oxidation process known as bleaching (2)

Figure 1 showed the common cotton fiber structure and the distribution of cellulose and other non-cellulosic substances in the fiber layers. Cuticle The outer layer of cotton fiber is a thin film of the waxy layer covers the primary wall, creating grooves on the cotton surface. Then primary wall comprises non-cellulosic materials and amorphous cellulose in which the fibrils are arranged in a crisscross pattern. Due to non-structured orientation of cellulose and non-cellulosic materials, the primary wall surface is unorganized and open. This gives flexibility to the primary wall, which is required during cell growth. The major components that are responsible for the interactions in the primary wall are cellulose, hemicelluloses, pectins, proteins and ions. While in the secondary wall only crystalline cellulose is present in a highly organized compact structure with cellulose fibrils laying parallel to one another. (3)

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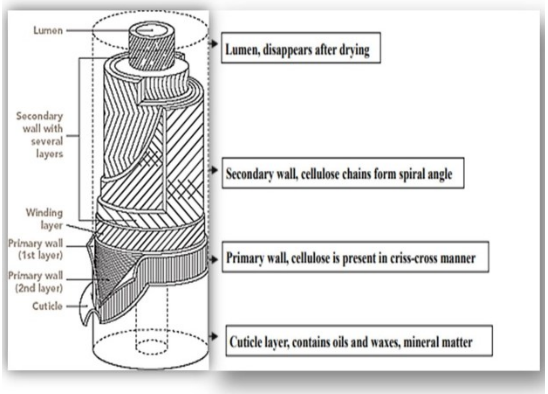

Figure 1. Cotton fiber structure and the distribution of cellulose and other non-cellulosic substances in the various fiber layers

Enzymes are biocatalysts could be used in textile industry. As they are environmentally friendly than other substances, enzymatic treatments are becoming more and more popular in the textile sector. Based on numerous textile processing applications, biotechnology has expanded and enzymes have been developed. Enzymes are used in all textile chemical processing steps to adopt green technology and meet the demands of the fourth industrial revolution. (4,5)

Fats, waxes, pectins, and proteins found in raw cotton fibers impart a hydrophobic nature and prevent dyeing from working properly. Usually, boiling aqueous sodium hydroxide is used for alkaline scouring to remove these non-cellulosic contaminants. Enzymes can be utilized to enhance cotton's wettability and fabric quality as a more environmentally friendly alternative. Although scouring boosts the cellulose content of the fiber above 99%. Numerous negative effects of using different chemicals and high temperatures include the production of toxic gases and fumes, corrosive effects, large energy consumption, cellulose depolymerization, decreased fiber strength, and ecosystem degradation. (6-8)

Several types of chemicals are used as bleaching agents, and their selection depends upon the material of fabrics as well as their intended use. Hydrogen peroxide is the most useful bleaching agent for cotton fibers and cotton blends (9,10) as the chlorine containing bleach compounds such as sodium hypochlorite and sodium chlorite have been withdrawn for the market and their usage was gradually limited because of its disadvantages, bleaching with peroxide has many advantages when using in cotton bleaching compared to hypochlorite bleaching (11,12)

On the other hand, promising results have been reported by glucose oxidase enzyme that converts glucose to hydrogen peroxide and gluconic acid used for bleaching that was revealed In our previous study where we using glucose oxidase and as increasing the enzyme concentration the whiteness of cotton fibers was improved to be close to those cotton fibers treated with conventional H_2O_2 bleaching processes and Whiteness obtained was acceptable when compared with conventional method (13) . In another study we imply that oxygen bleaches such as sodium Percarbonate (SPC) and sodium perborate (SPB) can replace the hydrogen peroxide. Moreover, oxygen bleaches are considered as good alternatives for other bleaches because of their economic and environmental impact as they are more stable and can be stored in a solid form. Besides, they can be active at lower temperatures. Hydrogen peroxide is the most famous bleaching agent used in industry but it could be produced by enzymatic system using glucose oxidase. (13,14)

Cotton as a natural fiber is mostly used to make yarn, fabrics and garments. However, cotton waste that cannot be spun because its fibers are less than 20 mm long is typically unsuitable for spinning or weaving. Such short staple cotton could find alternative applications in the field of medical purposes such as dressings, bandages, and cosmetic purposes, etc. The demand for absorbent cotton is proportional to population, expansion of public health services, and increased income level. Absorbent Cotton Demand (Global) is growing 10% per year, Absorbent/Surgical Cotton Demand in Egypt also growing and reaching more than a million kg per year. (15)

With all of that reasons, here in this study an attempt was made to use enzymes in preparation of cotton waste fibers and convert this un-spinnable short staple cotton into absorbent cotton in an eco-friendly and economical product.

Materials and Methods

Cotton fiber

Short staple cotton fibers were collected from un-spinnable waste cotton from spinning department at the Cotton Research Institute,

Enzyme

- The commercial enzyme alkaline pectinase was used

- Glucose oxidase enzyme was supplied by Novozymes Company and used for bio-bleaching.

Chemicals

All chemicals used in these processes were of analytical Grade: Sodium hydroxide; NaOH, sodium chloride; NaCl, sodium carbonate; Na2CO3, hydrogen peroxide; H2O2, sodium silicate; Na2SiO3, magnesium chloride; MgCl2 6H2O, D (+) glucose, HCl buffer, and non-ionic wetting agent; Triton X – 100

Preparatory process

Cotton fibers were cleaned and opened through trash separator to remove trash in the fiber, using Micro dust Trash Analyzer instrument (MDTA3).

Scouring

a) Chemical conventional scouring

Conventional alkaline scouring was carried out under conditions typically used in textile factories. The raw cotton fibers was scoured using aqueous sodium hydroxide (3 g/ L) and nonionic wetting agent (Triton X 1 g/ L) at 90 ◦C for 30 min. at liquor ratio of 1:20. In addition, the cotton samples were washed with water and then neutralized with acetic acid (3 g/ L) at 55 ◦C for 10 min

b) Bio- scouring

Bio-scouring was carried out in a glass beaker, 5gm samples of raw cotton waste fibers was treated with pectinase enzyme concentrations (5 g/ L) at a liquor ratio of 1:20 and in the presence of 1 g /L nonionic wetting agent. Treatment with pectinase was carried out at pH 8.5 at 55 ◦C for 30 min. After incubation with the Pectinase treatment followed by boiling at 90 ◦C for 10 min. after this, samples were rinsed with tap water at room temperature and air-dried. (6)

Bleaching

c) Conventional Bleaching.

The scoured cotton fibers were chemically bleached using 1.5 g/l sodium hydroxide, 0.4 g/l sodium silicate, 0.2 g/l sodium carbonate, 0.2 g/l magnesium sulphate, and 25 ml/l 35% hydrogen peroxide. The liquor ratio was 1:50 at boiling for 90 minutes. The samples were finally washed with hot water followed by cold water.

d) Bio-bleaching

The bio-scoured cotton fibers were bleached with liquor ratio of 1:20 using Glucose oxidase enzyme, with enzyme concentrations (1 g/l), and D-glucose (10 g/l) at neutral pH 7 and 40 OC for 60 minutes. Afterward the pH was changed to alkaline 10 and the temperature was raised to 85^{o}C. The fibers were then rinsed, and the enzyme solution discarded. (13)

Testing and Analysis

All testing samples was carried out in laboratories where standard atmospheric conditions at 65 ± 2% relative humidity and 21 ± 2°C temperature was maintained. All experiments were performed in triplicate.

Mechanical properties: Tensile strength and elongation percentage

Cotton bundle tensile strength and elongation were determined on the Stelometer Strength – Elongation tester according to ASTM standards D: 1445-1990, at the fiber testing Lab., Cotton Research Institute.

Whiteness index

The whiteness index was measured using the double beam spectrophotometer. The measurement was done in accordance to ASTM E313-96 using CIE color system coordinates.

Fiber length UHM, fiber Strength and Elongation

Automatic measurement of mechanical fiber properties such as fiber length distribution, fiber bundle force and elongation at short stable fibers for absolute measurement of tenacity by automatic determination of sample mass, UHM, Elongation (%), strength (g/tex) according to (ASTM D-5034) using CCS-FIBROTEST-Station

Fiber Micronaire value

Micronaire Station equipped with Micronaire tester according to ASTM D3813- ASTM D1448. (D-1448-59)-ISO 2403:2021 ISO 10306, 14th Edition, September 24, 2019.

Cotton fiber Chemical composition

Chemical analysis used to determine the fiber Chemical composition, such as; moisture, sugar, wax, ash and cellulose content of the cotton waste fibers were measured according to ASTM- D2495-07(2019), ISO 18068(2014), ASTM D2495-07(2019) and ASTM D629–99, respectively.

Statistical analysis

The WinPepi statistical software package was used to compare conventional and bio processes of cotton fibers. Student-t test based on a two-tailed test was used to compare two groups. P values less than 0.05 were considered significant.

Results and Discussion

Table 1 illustrated the Chemical composition of the raw cotton sample we used which is waste Short staple cotton fibers collected from un-spinnable waste cotton from a spinning system. Nearly 90% of the cotton fibers are cellulose, It has about 8% moisture regain and Waxes which are esters of complex monohydric alcohol with fatty acid less than 1% of cotton fiber weight.

Cotton fibers have sugars as a product of the natural growing process. These 'plant sugars' when broken down to individual carbohydrates contain primarily the monosacchrides glucose and fructose, the disaccharides sucrose and trehalose, and small amounts of other monosacchardies and oligosaccharides.(18) The reducing sugar content in raw Egyptian cotton sample was 0.16 percent on the fiber based on the lint weight.

Table 1. Chemical composition of cotton

Constituent	Cellulose	Wax	Sugar	Moisture	Ash	Other Substances
Percentage in cotton fibers	89.5%	0.74%	0.16%	7.8	0.95%	0. 85%

Table 2 and Figure 2 determined the properties of Egyptian cotton unspinable fibers chemically treated with sodium hydroxide in scouring process and compared with enzymatically treated cotton fibers.

Data determined that the fiber strength values of cotton fibers were in the range of 27.8-28.6 (g/tex) in the cotton raw fibers and values of chemically scoured using sodium hydroxide were in range 23.2 -24.8 (g/tex) while bio-scoured using pectinase enzyme were in range 24.5-25.8 (g/tex). However, the difference didn’t reach statistical significance.

Similarly, the difference of fiber elongation % weren’t statistically significant between the chemically scoured and bio-scoured samples.

On the other hand, uniformity index was highly statistically significant (P value <0.0001)

Regarding the UHM and micronaire values the differences were non-significant.

Table 2. Physical and Mechanical Properties of chemically and enzymatic scoured cotton fibers

		Raw	Scoured		P. value#
			chemical	Enzymatic	
Fiber strength (g/tex)		28.6	24.8	25.81	**0.148**
		27.8	23.25	24.53	
		28.5	24.49	25.5	
	Mean	28.3	24.16	25.28	**non significant**
	S.D.	0.44	0.85	0.67	
Fiber elongation %		6.7	6.1	5.9	**0.074**
		6.1	6.0	5.3	
		6.3	5.9	5.4	
	Mean	6.37	6.00	5.53	**non significant**
	S.D.	0.31	0.10	0.32	
Unif. Index		84.2	64.1	73.1	**<0.0001***
		83.4	64.9	71.9	
		83.9	64.2	73	
	Mean	83.83	64.40	72.67	**highly significant**
	S.D.	0.40	0.44	0.67	
UHM		20.9	18.6	20.6	**0.029***
		20.6	18.9	19.3	
		20.7	18.5	20.6	
	Mean	20.73	18.67	20.17	**highly significant**
	S.D.	0.12	0.21	0.43	
Micronaire		3.5	3.2	3.4	**0.189**
		3.1	3	3.1	
		3.2	3.1	3.3	
	Mean	3.27	3.10	3.27	**non significant**
	S.D.	0.21	0.10	0.15	

#P value were due to the comparison of chemical and enzymatic scoured fibers

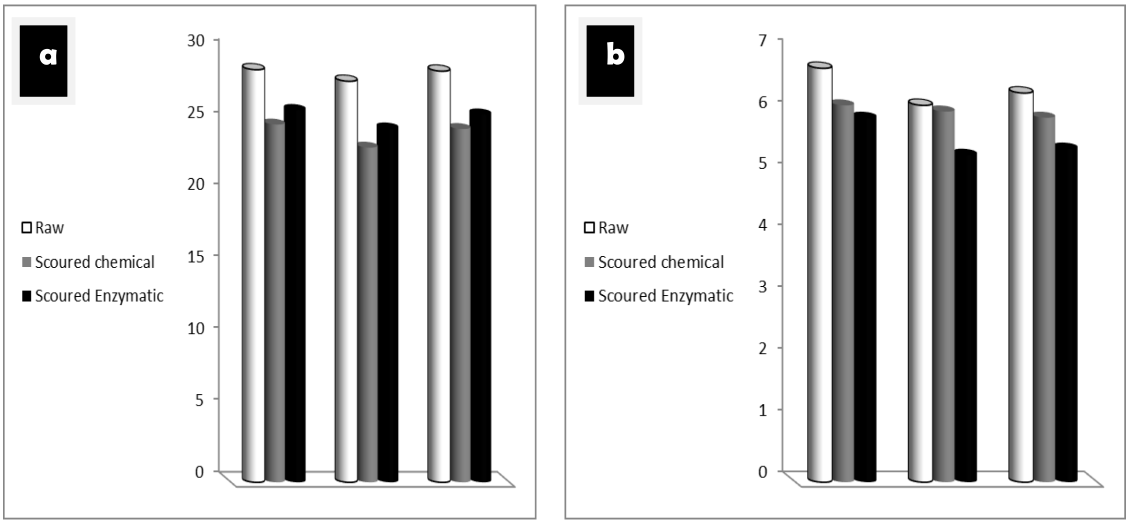

Figure 2. Mechanical Properties of chemically and enzymatic Scoured cotton fibers; a) Fiber strength (g/tex) and b) Fiber elongation %

Table 3 and Figure3 determined the properties of Egyptian cotton unspinnable fibers chemically treated with hydrogen peroxide in bleaching process and compared with enzymatically treated cotton fibers. Regarding the data in table 3 and figure 3 the bleaching process affected the mechanical properties whether was chemically or enzymatically treated. that can be explained as the cellulose chains were broken due to the breaking of the hydrogen bonds in addition to increasing the amount of amorphous cellulose .so increasing the fiber elongation and decreasing the fiber strength (16) .

There was a significant difference between the chemical and enzymatically bleaching concerning fiber strength. Elongation, uniformity and UHM, however, micronaire values weren’t statistically different.

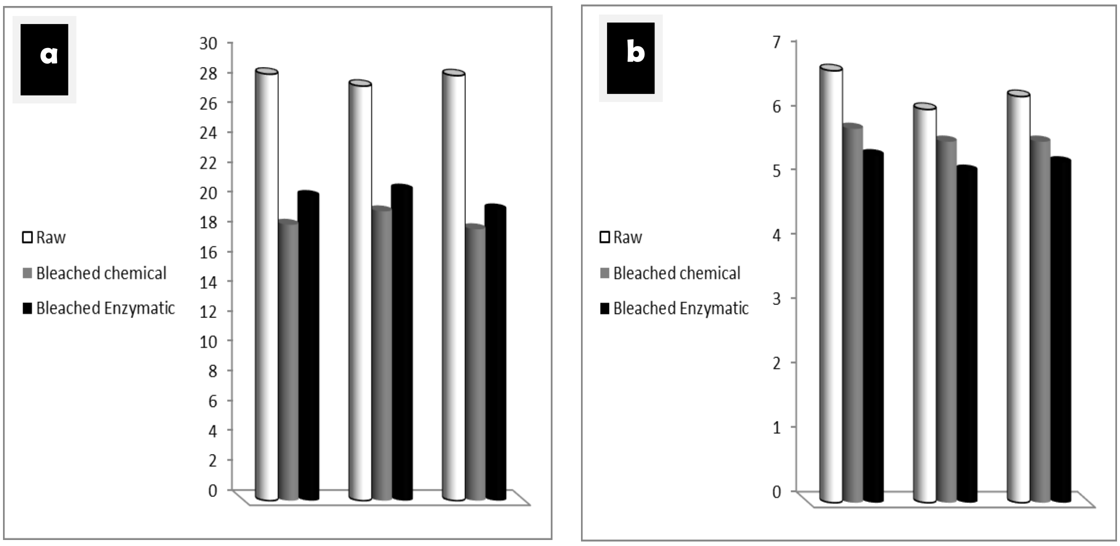

Figure 3. Mechanical Properties of chemically and enzymatic bleached cotton fibers; a) Fiber strength (g/tex) and b) Fiber elongation %

Table 3. Physical and Mechanical Properties of chemically and enzymatic bleached cotton fibers

		Raw	Bleached		P. value#
			chemical	Enzymatic	
Fiber strength (g/tex)		28.6	18.5	20.43	**0.042 ***
		27.8	19.4	20.86	
		28.5	18.2	19.53	
	Mean	28.30	18.70	20.27	
	S.D.	0.44	0.62	0.68	**significant**
Fiber elongation %		6.7	5.8	5.39	**0.015 ***
		6.1	5.6	5.15	
		6.3	5.6	5.28	
	Mean	6.37	5.67	5.27	
	S.D.	0.31	0.12	0.12	**significant**
Unif. Index		84.2	66.5	77.5	**<0.0001***
		83.4	66.4	76.8	
		83.9	66.1	77.3	
	Mean	83.83	66.33	77.20	**highly significant**
	S.D.	0.40	0.21	0.36	
UHM		20.9	16.9	18.3	**0.005***
		20.6	17.3	18.3	
		20.7	16.4	18.5	
	Mean	20.73	16.87	18.37	
	S.D.	0.12	0.26	0.067	**highly significant**
Micronaire		3.5	3	3.3	**0.540**
		3.1	3.1	3	
		3.2	3.1	3.1	
	Mean	3.27	3.07	3.13	**non significant**
	S.D.	0.21	0.06	0.15	

#P value were due to the comparison of chemical and enzymatic bleached fibers

The absorbent cotton prepared by either conventional chemical method or by eco-friendly enzymatic process, it is required to confirm to certain standards and qualities, such as laid down by **Egyptian Standards (2160/ 2014)**
Some of these qualities should be in the absorbent cotton:

Sinking time (absorbency) should be less than 10 seconds.

- Sinking time (absorbency) in chemically processed is 7 seconds.
- Sinking time (absorbency) in enzymatically processed is 8 seconds.

Water Holding Capacity should be more than 23 (g/g)

- Water Holding Capacity in chemically processed was 30(g/g)
- Water Holding Capacity in enzymatically processed was 30(g/g)

Whiteness Index (CIE method) should be around 80

- Whiteness Index in chemically processed was 80
- Whiteness Index in enzymatically processed was 75

Fibers should show suitable strength and elongation under tension

- Fiber strength and elongation were (18 g/tex ,5.6%) in chemically processed.
- Fiber strength and elongation were (19 g/tex ,5.2%) in enzymatically processed.

Micronaire value should be more than 3

- Micronaire value in this study is 3.1 in chemically processed.
- Micronaire value in this study is 3.0 in enzymatically processed.

Fiber length shouldn't be less than 10 mm

- Fiber length value in this study is 19.5 mm in chemically processed.
- Fiber length value in this study is 20 mm in enzymatically processed.

Sulphated Ash content should not be more than 0.4%.

- Sulphated Ash content in this study is 0.30% in chemically processed.
- Sulphated Ash content in this study is 0.28% in enzymatically processed.

Moisture content should be nearly 8%.

- Moisture content in this study is 8% in chemically processed.
- Moisture content in this study is 8% in enzymatically processed.

Acidic and Alkaline properties should be Neutral

- Acidic properties of either chemically or enzymatically prepared samples in this study was Neutral
- Alkaline properties of either chemically or enzymatically prepared samples in this study was Neutral

Water soluble substances should be less than 0.5%

- There wasn't Water soluble substances in either chemically or enzymatically processed fibers

Ether soluble substances should be less than 0.5%

- Ether soluble substances in chemically processed were 0.18(%)
- Ether soluble substances in enzymatically processed were 0.21(%)

Conclusions

In addition to being environmentally friendly, enzymatic treatments such as ; Bio-souring can be improved the cotton fiber characteristics by removing the non-cellulosic impurities as equal to alkali scouring without causing big loss of weight or tensile strength. Also, bio-bleaching was whitening the fibers without damaging the cotton fibers characteristics. Additionally, enzymatic treatment eliminates the severe pollution issues and excessive energy usage that are related to traditional chemical treatments.

The absorbent cotton prepared by either conventional chemical method or by eco-friendly enzymatic process, it is required to confirm to certain standards and qualities, such as laid down by Egyptian Standards (2160/ 2014)

Conflicts of interest:

"There are no conflicts to declare".

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تحضير القطن الطبي الماص من شعيرات القطن المصري الغير قابل للغزل

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يهدف البحث الي استخدام عوادم شعيرات القطن المصري الغير قابلة للغزل والناتجة من مرحلة التسريح في نظام الغزل الحلقي وتوظيفها للأستخدام في المجال الطبي كقطن طبي عالي الامتصاص وذلك بواسطة المعالجات سواء بالطرق الكيميائية التقليدية أو باستخدام الطريقة الحيوية "الإنزيمات" وذلك في مراحل الغلي والتبييض.
وتم إجراء مقارنة بين الخواص الفيزيائية، الميكانيكية والكيميائية للاقطان المعالجة بالطريقة التقليدية وبالطريقة الحيوية ومطابقتها للمواصفة القياسية المصرية "٢١٦٠/٢٠١٤".
وقد لوحظ زيادة نسبة امتصاص القطن المعالج سواء بالطريقة الكيميائية او الحيوية بنسب عالية جدا الا انه في الطريقة الكيميائية كانت درجة البياض عالية مقارنة بتلك المعالجة بالانزيمات ومع ذلك تفوقت الانزيمات في الحفاظ علي الالياف وخواصها الميكانيكة والمتانة بالاضافة الي كونها طريقة صديقة للبيئة.
ونظرا لزيادة الاحتياج للاقطان الطبية عالية الامتصاص والذي يزيد الطلب عليها بمعدل ١٠% سنويا في كل دول العالم كما يزداد الطلب عليها في مصر ليصل الي حوالي مليون كجم سنويا.
ويعد اعادة استخدام عوادم الالياف وتوظيفها في انتاج منتج ذو قيمة اقتصادية عالية هو من اهم اهداف هذه الدراسة وتوصياتها.