International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 15s, 2025
https://www.theaspd.com/ijes.php

The Impact Of Natural Dyeing On Enhancing Physical Properties Of Cellulosic Fabrics Across Textile Structures

Reham Mostafa Mohammad[1,2*] Hanaa K. Elseady[1,2], Sabah A. Elkasab[3], Adel Roshdy Abd-Almoaty[1,2]

[1*]Department of Art Education, College of Education, King Faisal University; Al-Ahsa 31982, Saudi Arabia.
*Orcid: https://orcid.org/0000-0002-0210-0641 Email: rmahmed@kfu.edu.sa.
[2]Department of Fashion, The Higher Institute of Applied Arts, 6th October City, Egypt.
[3]Department of Spinning, Weaving and Knitting, Faculty of Applied Arts, Helwan University, Egypt.

Abstract
The study aimed to investigate the impact of fabric structure on fabric dye uptake rate and natural dyeing effect on physical properties of fabrics.
Different blended linen/cotton structures (Plain 1/1, Twill 1/3, Twill 2/2, and Atlas 4) were used to examine the dyeing process variables, absorbance average, air permeability, elongation, and tensile strength. Noting the general weakness of the resulting color on most cellulosic compositions dyed with natural dyes, the effect of using (Solidogen) as a cationic agent was used to initially treat cellulosic textile fabrics to increase their dyeability. The difference in color strength between the untreated and treated fabrics was investigated through a variables study of cationization process. After reaching the best treatment conditions, color strength was measured and recorded. A noticeable increment was observed from K/S (1.00) up to (11.52) by an increasing ratio of (91.32) %.
According to the fabric structure, the Plain achieved the highest color strength (11.52) whereas Atlas recorded the lowest (9.60). A slight decrease in the colorfastness properties and air permeability of dyed fabrics was observed. While an increase in tensile strength of Plain, Twill 1/3, Atlas 4, and Twill 2/2 was noticed respectively, there was an increase in elongation values for all the used textile structures.

1. INTRODUCTION

Natural dyeing has gained significant attention due to increasing concerns on environmental sustainability and adverse impacts on ecosystems of synthetic dyes. Despite being less polluting than other sectors, the weaving and spinning industry significantly contributes to environmental pollution. The dyeing process involves chemicals and industrial dyes, the major pollution sources (Chequer et al., 2013).

Natural dyes were the first thing man used in dyeing, but their demand decreased due to the scientific research conducted by the English chemist Perkin (Mellor & Cardwell, 1963). In 1856 AD, he accidentally discovered a way to prepare dyes chemically in the laboratory, and this was the beginning of the scientific revolution in the manufacture of synthetic dyes, which in turn led to an increase in pollution, which made the world return to calling for natural dyes to protect the environment and reduce its pollutant (Abel, 2012).

Despite the environmental benefits, there are a few limitations to natural dyes in the context of color fastness, range of achievable shades, and dye uptake. These limitations are limited specifically to cellulosic fabrics like linen and cotton resulting in low affinity for natural dyes (Repon et al., 2024). This demands innovative approaches like cationic treatments to improve the performance of nature dyes and enhance dyeability (Haji & Naebe, 2020).

Fabric properties like air porosity and permeability play a significant role in examining the effectiveness of dyeing processes. CLATON defined fabric's air permeability as the air in cm^2 that passes per second through 100 cm^2 of the fabric surface area (Kulichenko, 2005). SKINKLE & BOOTH defined the porosity of fabrics as the ratio of the air void in the fabric to the total volume of the fabric, and it can be expressed as a percentage. SKINKLE also confirmed that the smaller the air voids are and the greater their number is, the less permeable and warmer the fabric is (Epps & Leonas, 2000; Skinkle, 1949). The permeability of fabric is affected by the cross-sectional area of each hole, the number of holes within the square unit of measurement of the fabric and depth of each hole (Johansen, 1941).

This study aimed to study the probability impact of using different fabric structures (Plain 1/1. Twill 1/3, Twill 2/2, and Atlas 4) towards the dyeing process, absorbance average, and the dependent result in air permeability and tensile strength. The environment and human health suffer from many pollutants that cause negative results, thereon global orientation was called back to return to nature. Therefore, the natural blended cotton/linen and natural dye derived from vegetable sources; Cassia fistula fruits were used in this search. This research examined how pre-treatment method and different textile structures influence color strength, dye update, fastness properties, and their role on fabric physical properties. The study determined the impact of cationic treatment on the interplay between color strength, tensile strength, air permeability, elongation, and fabric composition using the natural dye from cucumber tree (Cassia fistula). It seeks to provide an approach for enhancing natural dyes' performance on cellulosic fabrics and minimizing environmental harm as one of the sustainable solutions.

1.1. Factors Affecting the Air Permeability of Fabrics

1.1.1. Coverage Factor

The coverage factor affects all properties related to air spaces in the fabric (Begum & Milašius, 2022). Researchers have agreed that the fabric's permeability rate decreases due to increasing the warp, weft, or coverage factors. Permeability is affected by the number of weft and warp threads per unit area, the number of these threads, and the number of twists. The importance of air permeability increases in the case of summer fabrics made of synthetic fibers that do not absorb sweat, such as nylon and dacron, as they must be designed with relatively high permeability that enables the transmission of sweat through wide pores (Bera & Chakraborty, 2022).
As for the case of filaments that absorb sweat, such as cotton and linen, it is possible to design fabrics made of them with low permeability, i.e., with densely threaded fabric composition suitable for efficient use in summer. In the case of using nylon threads with continuous filaments in the production of shirt fabrics, they are woven in a knitting method, which has the characteristics of providing wide gaps that allow the body to ventilate and get rid of sweat (Deopura & Padaki, 2015; Lawrence, 2015).
Non-woven fabrics originate from the bond or felt process between yarn fibers while traditional fabrics include weaving or knitting methods for yarn multiplications. Weaving creates fabric through the perpendicular and crossing paths of warp and weft yarns which run straight across the material. Woven fabrics are made when a weft strand interlaces with warp threads which run along the fabric's length using a loom. The selvedge of fabric obtains its name when wefts are double-backed to establish a non-fraying border (Kumar & Hu, 2018).
The three fundamental weaving structures include Plain, Twill, and Atlas (Satin) weave. A Plain weave produces strong durable fabric yet a Twill weave creates a fabric that drapes well and feels rough to the touch while an Atlas weave features complex thread arrangements that yield a smooth reflective fabric surface. Knitting methods form yarns into loops that are generally released between successive loops until a secure loop structure forms. The softness along with stretchability makes weft knitted fabric an appealing choice but warp knitted fabric provides stretch quality alongside anti-ladder resistance. Non-woven fabrics use either an applied bonding agent between fibers or utilize thermoplastic features that fuse together by themselves. Wool felt represents an expensive non-woven fabric that uses animal hair for the creation of handicrafts as well as hats and slippers (Begum & Milašius, 2022).
Wool is used for winter clothes and cotton for summer clothes, and both can absorb body moisture and transfer it to the outside atmosphere (Maduna & Patnaik, 2020). This depicts that the fabric can be designed with any degree of air permeability without interfering with the body's comfort, as it is easy for moisture and heat to transfer from the body to the outside atmosphere through the spaces between the filaments. Suppose the fabric design is not open enough and the permeability is not high. In that case, the body's moisture cannot transfer through the pores of the fabric to the outside atmosphere, which results in the body's discomfort when using clothes made from these fibers (Ullah et al., 2022).

1.1.2. Textile Structure

Researchers have proven that double and integrated fabrics that contain many interlocking per square unit area have less air permeability than fabrics of similar weight. They have also proven that the most air-permeable textile structures are Atlas (Satin), Twill, Twill, and Plain (Bivainytė & Mikučionienė, 2011; Dejene & Gudayu, 2024; Gungor Turkmen et al., 2024).

1.1.3. Twist Coefficient
There is a direct relationship between the twist coefficient and the rate of air permeability of fabrics (Atalie et al., 2018; Bivainytė & Mikučionienė, 2011).

2. MATERIALS

2.1. Textile Dye
In this research, a natural dye extracted from a plant source, the fruit of the Cassia fistula tree was used.
Common name: Golden tree.
Scientific Classification:
Kingdom: Vegetarianism.
The Faction: Legumes (Leguminosae).
Scientific name: Cassia fistula
English name: Golden Shower Tree, Golden Chain
Cassia fistula is a perennial tree plant. The tree reaches a height of about 30 feet, and the length of the leaf reaches about 1 foot. It is pinnate in shape, composed of many leaflets, and the plant has dense flowers of a beautiful yellow color with a pleasant smell. The plant's fruit is a large pod that resembles the carob fruit, except that it is longer, reaches about two feet.

Description of the Fruit (the Part Used) in Dyeing
A long cylindrical pod, green in color that turns to dark brown or black when ripe, is hard and woody, and contains many seeds.

Chemical Contents of the Fruit Pulp
The pulp of the Cassia fistula fruit contains a high percentage of sugar and some complex ketone compounds (Bahorun et al., 2005). The plant extract also contains 1.5% anthraquinone, phytoleic acid, emodin, chrysophanic acid, beta-sitosterol, etc. (Bahorun et al., 2005). Every 100 g of dry fruit contains about 827 mg of calcium, one of the highest percentages in the fruit. The fruit also contains potassium, iron, and manganese, and their percentages are high. There is also aspartic acid 16.6%, glutamic acid 19.5%, and lysine 6.6%.

Color-Causing Compounds in Cassia fistula
The heart of the fruit also contains a yellow coloring substance that turns red when an alkali is added due to the presence of anthraquinone derivatives, which consist of phytolic acid and anthraquinone acid.

2.2. Fabrics
Prepared blended linen/cotton fabrics were used, (linen warp, 28/2 m), (cotton weft, 20/2 m) with 22 threads/cm for the warp, 17 weft/cm and a weight of 120 g/m2 using the following simple textile structures: (Plain 1/1 - Twill 2/2 -Twill 1/3 - Atlas 4).

2.3. Chemicals and Auxiliary Materials
- Cationic agent (Solidogen FRZ Hoechst AG) to increase the dyeuptake on the fabric.
- Sodium carbonate Na_2Co_3 used to adjust the pH of the dyeing solution.
- Acetic acid CH_3COOH used to adjust the pH of the dyeing solution.
- Sodium chloride salt NaCl.
- Non-ionic soap Hostapal CV-ET (Hoechst).

3. PRACTICAL EXPERIMENTS

3.1 A natural plant dye extraction: The used dye solution was extracted from (the fruits of the Cassia fistula tree, including its seeds) was used, as the fruits were dried in the air for 24 hours, then crushed in the laboratory, then boiled for 1 hour, then filtered with cotton gauze so that the extract concentration became 10%.

3.2. Study of the Effect of the Difference in the Fabric Composition on the Color Strength

Equal weights of the different fabric compositions used in this research (Plain 1/1 - Twill 2/2 - Twill 1/3 - Atlas 4) were dyed under the same dyeing conditions using the Cassia fistula fruit extract dye to compare the color strength of the resulting color on each of them.

3.3. Study of the Fabrics Cationization Conditions

The cationizing variables were studied to determine the optimum conditions for cationization process. (Atlas 4) weave as a random selection of used weave structures was used in the cationizing optimization. All cationized samples were dyed with fixed dyeing conditions, then the color strength of the treated samples was recorded to discover the optimum cationization conditions for the best dyeuptake resulting on the dyed samples.

3.3.1. Study of Cationic Agent Concentration

The treatment was carried out with various concentrations of the cationic agent under the same conditions at a temperature of 70˚C at a pH of (6) for 30 minutes, then the samples were dyed under constant conditions using the extract of the Cassia fistula dye at a concentration of 50% of the solution (10%) at a pH of (7). The dyeing of the samples continued for 30 minutes at boiling temperature.
The various concentrations used for the cationic agent are: (0, 5, 10, 15, 20) % relative to the weight of the fabric.

3.3.2. Study of pH Medium of Cationization Process

The pH medium of cationization process were examined using pH variables at (3, 4, 5, 6, 7, 8). Optimum cationizin agent concentration was used.

3.3.3. Study of Cationization Process Temperature

The best cationization process pH was adjusted in the presence of the temperature variable; (room temperature, 40, 60, 80, 100)˚C. to determine the best processing temperature to get the highest color strength in the post-dyeing process.

3.3.4. Study of Cationization Process Time

Using the best conditions for the previous temp. variables, the time variable was tested to determine the appropriate duration for processing. The following periods were studied: (15, 30, 45, 60, 75) minutes.

3.4. Study of Fabric Dyeing Conditions

Using the best conditions for the previous cationizing variables, dyeing process factors were tested to determine the appropriate conditions for achieving the highest dye uptake.

3.4.1. Dye Concentration

The dyeing process was applied at boiling temp. for 1 hour using different dye concentration variables; (25, 50, 75, 100) % of a dye solution (10%).

3.4.2. Adjusting the Dyeing pH Medium

Using a fixed dye concentration, the pH medium variable was studied at (4, 5, 6, 7, 8, 9).

3.4.3. Studying the Effect of Adding Sodium Chloride Salt Conc. for the dyeing process

By controlling dyeing pH at a constant optimum pH, variables of sodium chloride concentrations were studied; (0, 10, 20, 30, 40) g/L.

3.4.4. Dyeing Process Time

Dyeing at variable time durations (15, 30, 45, 60, 75) was tested through constant optimum dyeing conditions to determine the suitable dyeing time for maximum dye absorbance.

3.4.5. Dyeing Process Temperature

The temperatures were chosen to determine the best temperature that can increase the K/S value were ranged between: (room temperature, 40, 60, 80, 100)˚C.

3.4.6. Fabric Washing

After the pretreatment of fabrics by cationizing agent followed by the optimum dyeing process, washing process was carried out to remove any excess dye using 2 g/L of soap at a temperature of 60˚C for 15 minutes.

4. TESTS AND MEASUREMENTS

4.1 Measuring the Color Strength K/S

The color strength of all dyed samples was measured using a Reflectance Measurements ICS-TEXICON Computerized Spectrophotometer, Model M 520220 (produced by ICS-TEXICON Limited Co., England) (Sule, 2002). The color strength is calculated using the equation: Kubelka–Mun: K/S = (1 - R)2 / 2 RK is the dye absorption coefficient, S is the dye diffusion coefficient, and R is the reflection coefficient of the dyed materials (Chowdhury et al., 2024; Sule, 2002).

4.2. Color Fastness Tests

Several tests were conducted according to the AATCC system; test No. (68-1993) for washing, rubbing, perspiration, and test (16A-1971) for color fastness to light. These tests were conducted on the cationized and dyed fabric compositions at constant optimum treatment conditions.

4.3. Tensile Strength and Elongation Test

Using an electronic strength and elongation tester, the four fabric compositions were tested before and after proceeding with cationization and dyeing processes according to the American specification ASTM/D No. 1682/1924.

4.4. Air Permeability Test

Air permeability was tested on fabrics before and after cationizing and dyeing using (Elester) device according to the English specification (BS) No. 2925/1958.

5. RESULTS AND DISCUSSION

5.1. Effect of the Difference in Textile Compositions on the rate of Color Strength of blended linen/cotton fabrics

The untreated four textile compositions were dyed under the same conditions using 30% Cassia fistula extract (10%) at pH (7) when boiling for 60 minutes. The strength of the resulting color was measured on each textile composition and recorded in Figure 1.

From the figure, we find that the descending order of the dyed textile compositions in terms of the rate of dyeuptake is as follows: (Plain 1/1 - Twill 2/2 - Twill 1/3 - Atlas 4).

This result may be referring to the smoother the fabric surface is, the less its ability to absorb liquids, and the smoothness of the surface is graded according to the elongation of the fibers, where Atlas 4 has the longest dyeing time and the lowest color strength, followed by (Twill 1/3 - Twill 2/2 - Plain 1/1), which means that there is an inverse relationship between the length of the dyeing period and the resulting color strength. Whereas the highest color strength was achieved on Plain composition (7.7), it was considered a low reading against the usual color strengths recorded using synthetic dyes on cellulosic fabrics. This general weakness in the achieved color may refers to the low affinity of cellulosic fabrics for most natural dyes.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 15s, 2025
https://www.theaspd.com/ijes.php

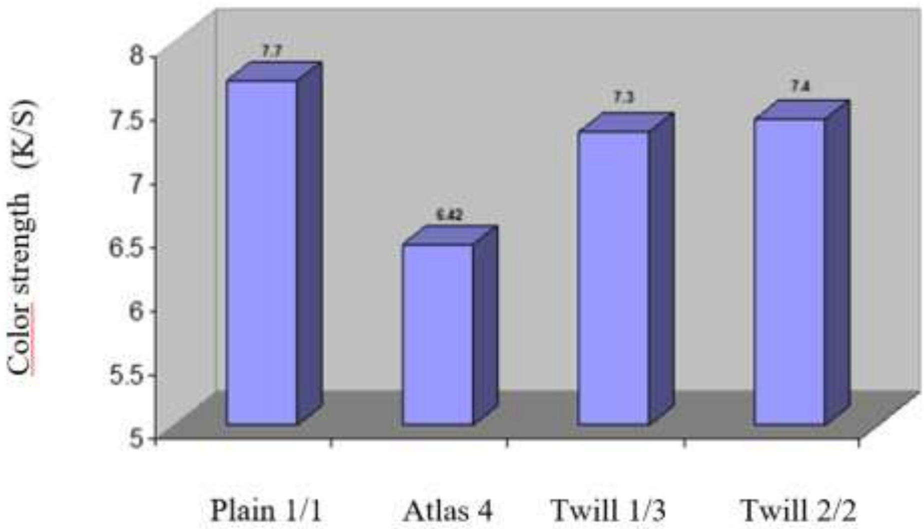


Figure 1: The Effect of the Difference in Textile Composition on the Rate of Color Strength of Blended Linen/Cotton Fabrics

Cassia fistula extract contains m any colored phenolic compounds that can give high color strength during cellulosic fabric dyeing. Improving the cellulosic fabric absorbancy is expected to increase its dyeability for natural dyes. This has led to studying variables of the cationization process as one of the pre-treatment methods of enhancing cellulosic fabric dye uptake and color strengths.

5.1.1. Concentration of Cationic Agent

Studying the concentration of Solidogen FRZ as a Cationic agent, to help achieve a higher dye uptake resulting in a higher color strength. Atlas 4 has almost minimum result in dye uptake, so it was used in studying the effect of the cationization process to enhance the resulting color strength. After measuring the color strength, it was shown in Figure 2 that the highest rate of color strength was achieved (8.48) using (5%) of the cationic material, an increase of about 41% compared to the untreated fabric.

A sharp decrease in color strength was recorded by cationic agent increase formed inversely proportional.

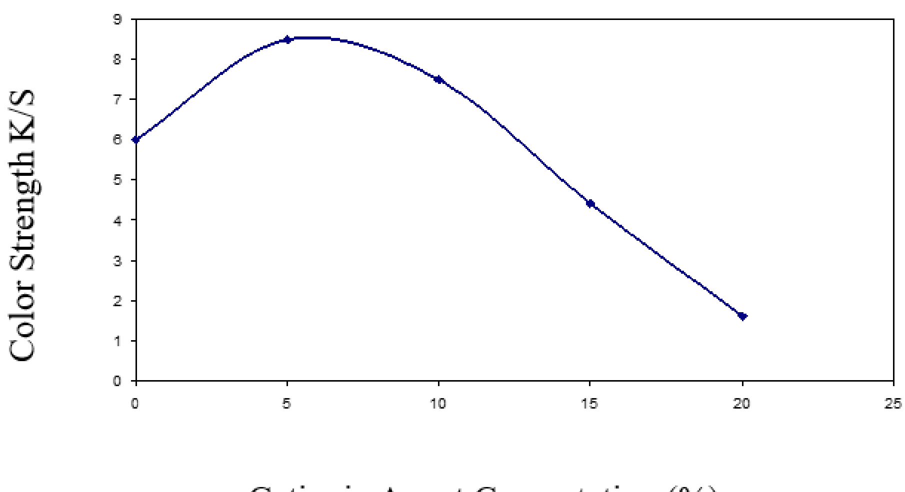


Figure 2: Effect of Solidogen (FRZ) Cationic Agent Concentration on Color Strength of blended linen/cotton Fabrics

Based on the above, due to the poor affinity of cotton and its blends to dyeing with natural dyes, cationic material (FRZ Solidogen) is used. It increases the affinity to natural dyes as it creates dye adsorption sites. On the surface of the cellulose material, as it is known that cellulose ionizes in the aqueous medium and gives negative charges, and at the same time, natural dyes, especially those containing hydroxyl and carboxyl groups, also ionize to deliver negative ions, which causes them to repel the cellulose material. Then comes the cationic material, which in most cases depends on the formation of the ammonium salt, whether quaternary, trivalent, or divalent, which has a positive charge that interacts with cellulose through an ionic bond that links the fabric and the dye. The more positively charged sites on the cellulose, the greater attraction between the fabric and the dye molecules, which increases the dye's stability to improve the color strength and the fastness properties. Whereas adding FRZ Solidogen up to 5% enhances cellulosic fabric dyeability, higher ratios will desorbe the dye particles into the surrounding aqueous media resulting in lower color strengths of dyed fabrics. It can be referred to changing neutral media which binds the fabric with the dye, to positively charged sited Adjusting the pH for Cationization Treatment A study of the appropriate hydrogen medium for the cationizing treatment process of blended linen /cotton showed that the neutral medium is the best for this treatment, as the color strength continued to increase gradually with the decrease in the acidity of the treatment medium, reaching the maximum color strength, which came (K/S = 9.30) at pH (7). Upon entering alkalinity, the color strength began to fade significantly, as was reached (7.30) at pH (8), as shown in Table 1 and Figure 3.

Table 1: Rate of Increase on Color Strength of Blended Linen/Ccotton Fabrics by Adjusting Hydrogen Media of Cationization Process

Rate of increase (%)	Color Strength (K/S)	pH
----	7.13	3
7.01	7.63	4
12.20	8.00	5
18.93	8.48	6
30.43	9.30	7
2.38	7.30	8

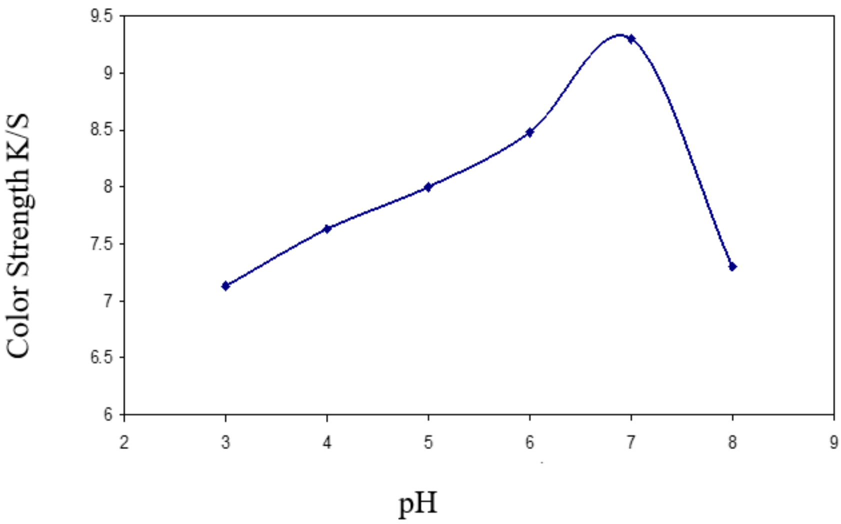


Figure 3: Effect of pH of Cationization process on Color Strength of Blended Linen/Cotton Fabrics

This color decreasing may be refers to the ionization of the cationic material and the separation of a negative ion from it, which in turn combines with the aqueous hydrogen, forming an acidic radical that causes an increase in the acidity of the medium, which causes a change from the neutral medium suitable for achieving the best color absorption to an acidic medium that is not suitable for good absorption.

5.1.2. Controlling the Treatment Time during the Cationization Treatment

30 minutes is the ideal time to complete the cationic treatment process and get the highest color strength (11.52) with Solidogen, as seen in Figure 4. As the treatment duration increases or decreases from 30 minutes, the color strength decreases, and the color decrease rate increases with the increase in the treatment duration until the decrease reaches (25.91%) when the treatment continues for 75 minutes.

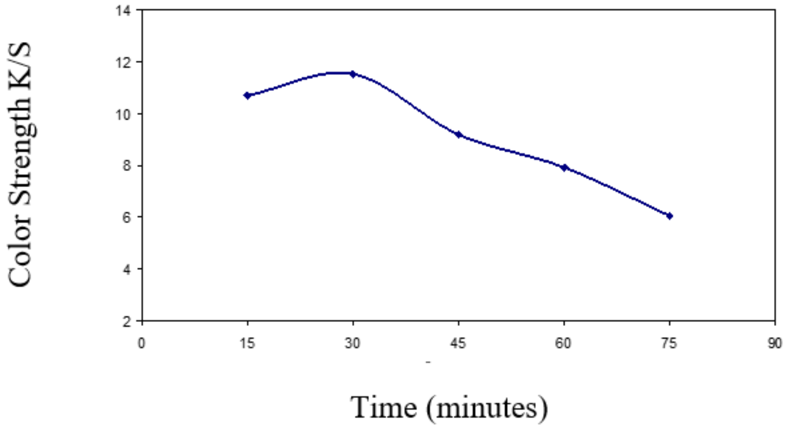


Figure 4: Effect of Cationization Process Time on Color Strength of Blended Linen/Cotton Fabrics

The cationic agent (Solidogen) may be negatively affected by the increase in the treatment period under the influence of the used temperature of 70 °C, as it is likely to be exposed to decomposition, which limits the chance of the formation of the cationic salt, which increases the absorption rate.

5.1.3. Controlling the Treatment Temperature of Cationization Treatment

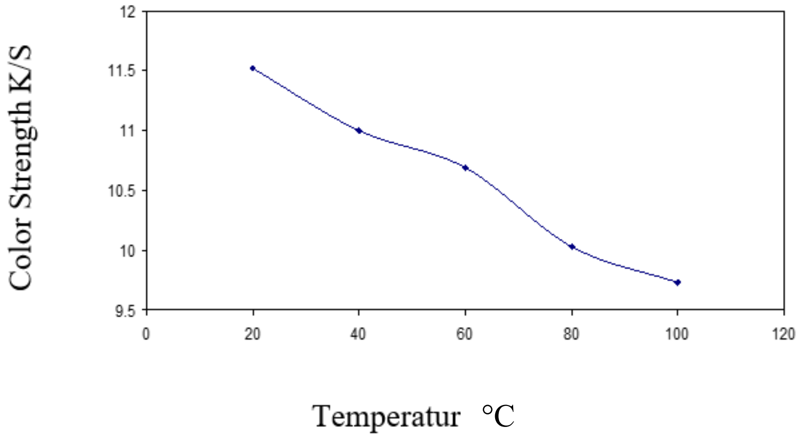


Figure 5: Effect of Cationic Process Temperature on Color Strength of Blended Linen/Cotton Fabrics

By studying the cationic treatment temperature, it was observed that the steady increase in temperature is accompanied by a steady decrease in the color strength, which indicates that raising the temperature is not compatible with the nature of the cationic compound, which may lead to its decomposition and hydrolysis. Accordingly, room temperature is the recommended optimum temperature for cationic treatment with Solidogen, as it achieves the maximum color strength, with a value of (11.52), as shown in Figure 5. At the same time, we find that the decrease in color strength increases significantly with increasing temperature, as the rate of decline reaches (15.54%) at the boiling temperature.

5.2Studying the Ideal Conditions for the Dyeing Process

The dyeing process was carried out for different textile structures after treating them with cationic material under the optimum conditions, which are:

- **Treatment textile concentration by cationizing agent:** 5% Solidogen (by weight of material).
- **pH:** 7.
- **Processing time:** 30 minutes.
- **Temperature:** At room temperature 20 °C.

After the end of the treatment period, the study of the ideal dyeing conditions began by studying all variables, which included:

5.2.1 Studying the Effect of Dye Concentration on the Color Strength of Cationized Blended Linen/Cotton Fabrics

From Table 2 and Figure 6, it is clear that there is a limited increase in the strength of the color with the increase in the dye concentration. This limited increase is not proportional to the amount of dye consumed, which makes it preferable to be satisfied with a 50% concentration of the dye, as can achieve a suitable color strength of (11.52).

Table 2: Effect of Dye Concentration on Color Strength of Cationized Blended Linen/Cotton Fabrics

Rate of increase (%)	Color strength K/S	Dye concentration (%)
----	11.40	25
1.05	11.52	50
1.23	11.54	75
2.19	11.65	100

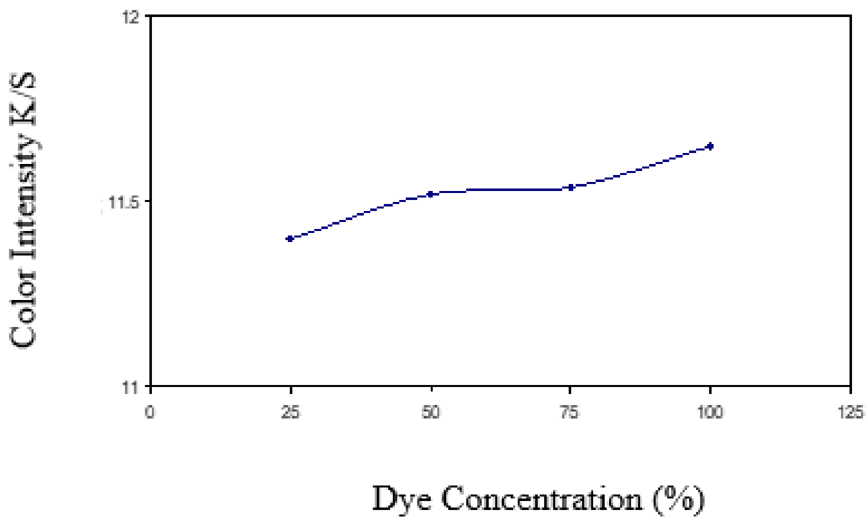


Figure 6: Effect of Dye Concentration on Color Strength of Cationized Blended Linen/Cotton Fabrics

The brown color is the color hue resulting from dyeing with Cassia fistula extract, measured at wavelength (λ = 355). This color may result from many color compounds in the plant and their interaction with the cellulosic fabric under dyeing conditions.

Anthraquinone, the primary colorant found in the mature pods of Cassia fistula, can play a key role in conferring the fabric's distinctive reddish-brown coloration.

5.2.2 Adjusting the pH for the Dyeing Process of Cationized Blended Linen/Cotton Fabrics

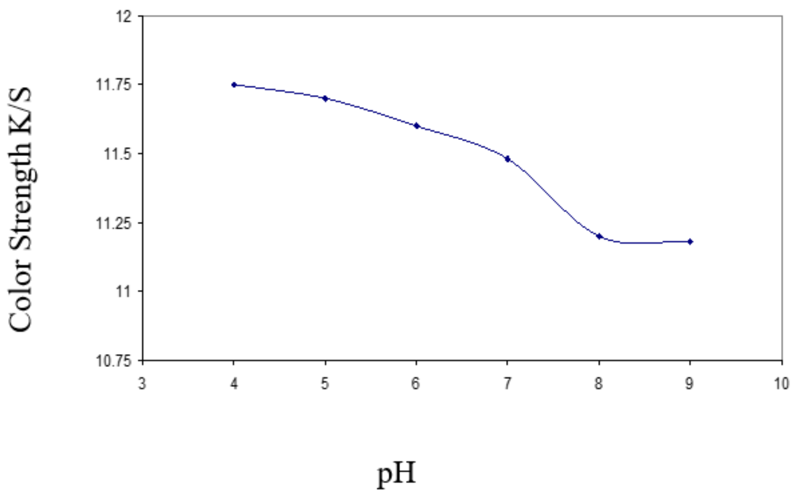


Figure 7: Effect of pH on Color Strength of Cationized Blended Linen/Cotton Fabrics

The physicochemical properties of the dyeing process, such as equilibrium, degree of exhaustion, and dyeing rate, depend mainly on the pH medium. It was noted from Figure 7 that as the pH decreases to pH = 4, the color increases until it reaches 11.75. This may be attributed to the increase in the presence of positive charges that limit the repulsion of the anionic natural dye with the negatively ionized cellulose material in the water, which in turn causes the formation of bonds between the dye and the fabric, thus increasing the strength of the color. The color behavior was reversed and began to gradually decrease with the increase in the alkalinity of the medium, reaching (11.18) at pH = 9 at a rate of decrease of 4.85%, which is due to the creation of additional negatively charged sites on the fabric, which increases its repulsion with the dye.
The rate of color decrease from acidic to alkaline medium is not significant, and this may be because some of the color compounds contained in the extract can react with cellulose in an acidic medium. In contrast, others respond in an alkaline medium. Therefore, both media may be suitable for dyeing in terms of the rate of color increase. But, to protect the cellulosic's durability, resorting to a neutral medium is preferable.

5.2.3 Studying the Effect of Salt on the Color Strength of Cationized Blended Linen/Cotton Fabrics

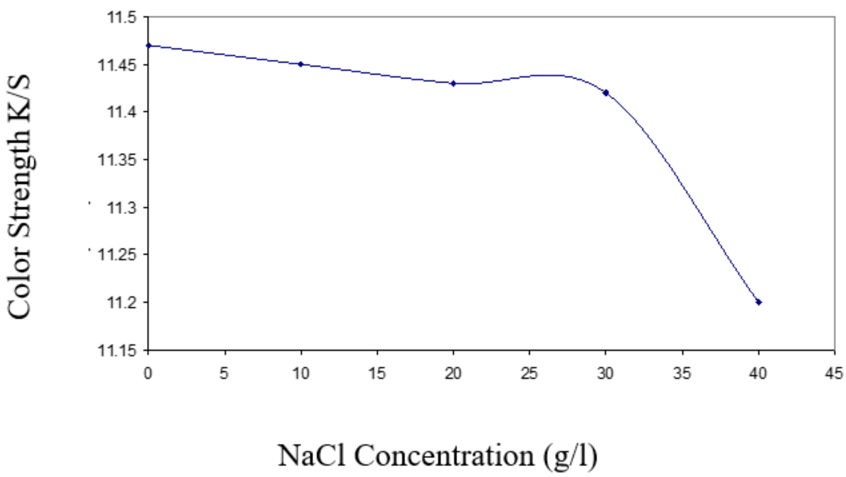


Figure 8: Effect of Sodium Chloride Concentration on Color Strength of Cationized Blended Linen/Cotton Fabrics

Since the cellulose fabric contains hydroxyl and carboxyl groups, it carries a negative charge when ionized. The Cassia fistula dye also contains some carboxyl and phenolic groups, which makes it ionize with a negative charge, which creates electrical repulsion forces between the material and the dye, which stands as an obstacle between the adsorption of the dye molecules on the surface of the material, which requires the addition of positive charges either from pH controller or from sodium ions resulting from the salt addition. Ionization of the added salt molecules at appropriate concentrations allows the formation of a positive sodium charges layer between the fabric and the dye that increases the adsorption of the dye inside the material, especially in an acidic medium. This is the general expectation from this kind of treatment in these conditions but, in this case, with the cationization pre-treatment of the fabric, it is likely that the positive ammonium cations have performed the function of the positive sodium ions and replaced them, which enables to dispense with adding salt. A limited gradual decrease of 0.17% in color strengths of dyed fabrics was noticed by gradually adding NaCl up to 30 g/l and then a jumping decrease to 1.93% was achieved. This result can be referred to as a gradual increase of salt companies by a gradual increasing of positive sodium charges which may lead to closing all negative sites in the aqueous media reaching a saturation state resulting in the precipitation of dye molecules and desorption of color out of fabrics causing weaken color strengths on the fabrics.

5.2.4 **Studying the Effect of Dyeing Process Time on the Color Strength of Cationized Blended Linen/Cotton Fabrics**

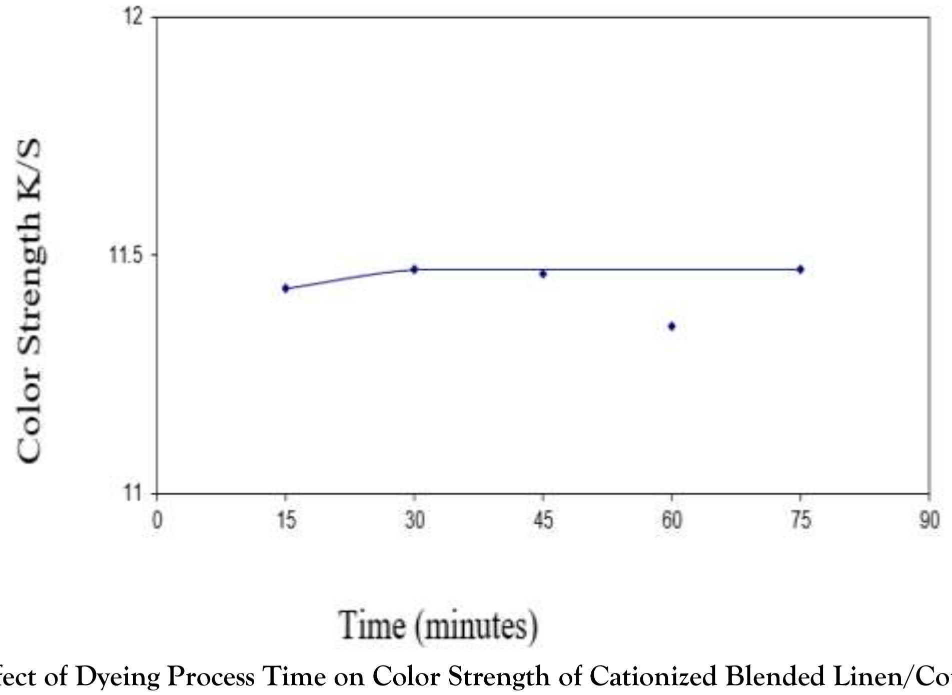


Figure 9: Effect of Dyeing Process Time on Color Strength of Cationized Blended Linen/Cotton Fabrics

The time of dyeing determines substantially how the fabric will behave and absorb the dye. 15 to 75 minutes experiments showed that dye absorption is constant, suggesting fabric saturation happens early. This supports the effect of the cationic treatment prior to dyeing, which promotes the uptake of the dye through increased ionic attraction between positively charged fabric and dye.

After equilibrium is established between internal and external ions, additional extension of dyeing time does not enhance dye uptake. This trend follows the linear pattern in Figure 9.

5.2.5 Studying the Effect of Dyeing Process Temp. on the Color Strength of Cationized Blended Linen/Cotton Fabrics

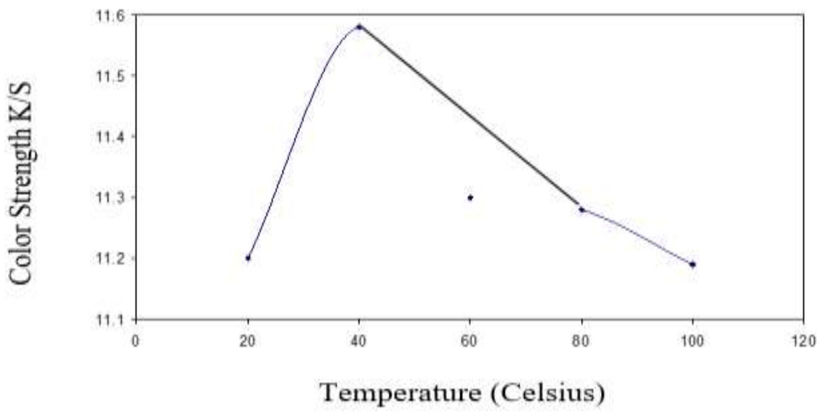


Figure 10: Effect of Temperature on the Dyeing Process of Cationized Blended Linen/Cotton Fabrics

°C

From Figure 10, it is clear that the highest color value will be achieved at 40 ° C, as this slight increase in temperature helps to increase the solubility of dye molecules in water and thus their ionization, which contribute of color homogeneity due to the regularity of diffusion. In contrast, with the gradual raise of temperature more than 40°C, a gradual decrease in the resulting color value resulted, according to fast excitement of dye molecules. Dyeing between 60-80 ° C showed a state of equilibrium which may pointed to reach a saturated dyed fabrics, equality of charges surrounding the fabric and in the inner of the fabric. By elevating dyeing temp. from 80 ° C up to boiling, The fabric recorded a slight decrease of color strengths that is attributed to a reversal movement of molecules toward exiting the fabric's pores in what is known as desorption.
Thus, by studying the conditions of the dyeing process, it was found that the best conditions for completing the dyeing process are:

- **Dye concentration:** 50% (W.O.F).
- **pH**: 4.
- **Dyeing time:** 15 minutes.
- **Dyeing temperature:** 40 ° m.

6 TESTS AND MEASUREMENTS

6.1Color Fastness Tests

Colorfastness tests were performed on the four dyed textile structures to determine cassia fistula dyeing fastness on fabrics and whether the results were different according to textile structure.
Also, optimized cationization and dyeing processes were applied on Atlas fabrics, then be measured to determine if there was any difference according to the increase of absorbency and color strength.

Table 3: Evaluation of Color Fastness Properties across Different Blended Linen/Cotton Structures

Lightfastness /8	Rubbing		Washability		Sweat Resistance				Used fabric Structure
			Staining	Alteration	Acidic Sweat		Alkaline Sweat		
	Dry	Wet			Staining	Alteration	Staining	Alteration	
5-6	4-5	3-4	4	4	4	4	4	4	Plain 1/1
5	4-5	3-4	4	4	3	4	4	4	Twill 1/3
5-6	4-5	3-4	4	4	4	4	4	4	Twill 2/2
5-6	4-5	3-4	4	4	4	4	4	4	Atlas 4
4-5	4-5	3	4	4	3-4	4	4	4	Atlas 4*

*** Treated by cationizing Agent and dyed under ideal conditions.**

Table 3 shows that the Cassia fistula extract achieves good dyeing stability compared to the generally poor stability of most natural dyes. This may be due to the presence of minerals that play a major role in dye stability, such as potassium, magnesium, and iron. When comparing the stability degrees of fabric with Atlas 4 textile structure treated under the best treatment and dyeing conditions with its counterparts of other different textile structures dyed without treatment, it is noted that the stability degrees are very similar. There may be a slight decrease in the light fastnesss, wet rubbing, and staining which may be related to non-fixative excess dye particles on the outer surface of the fabrics. Depending on these results, Post-mordanting process is highly recommended.

6.2Tensile, Elongation, and Air Permeability Tests

Table 4: Results of the Tests (Before and After Cationization & Dyeing) for Blended Linen/Cotton Fabrics.

Air Permeability	Weft Elongation	Warp Elongation	Weft Tensile Strength	Warp Tensile Strength	Dyeing effect	Fabric structure
litre/min/cm2	%	%	K.G.M	K.G.M		
7.6	15.6	17.9	45.7	43.3	Before dyeing	Plain 1/1
6.57	17.9	20.2	50.7	45	After dyeing	
7.9	17	16.2	42.7	33	Before dyeing	Atlas 4
7.54	19.5	21.5	40	43.3	After dyeing	
7.88	16.5	17	40.3	38	Before dyeing	Twill 1/3
7.52	17	18.5	47.7	38.3	After dyeing	
7.7	19	15.5	36.7	31.7	Before dyeing	Twill 2/2
7.36	17.5	16.5	34	36.3	After dyeing	

6.2.1 The effect of Cationization and Dyeing Processes on the Tensile Strength of Warp & Weft threads for Different Fabric structures.

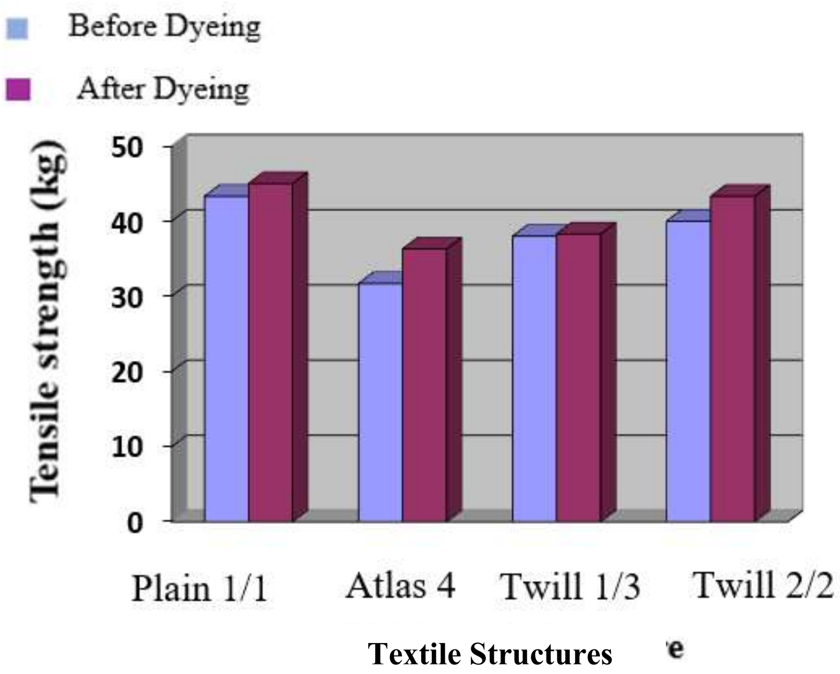


Figure 11: Effect of Cationization & Dyeing process with Natural Cassia Fistula Extract on Warp Tensile Strength for Different Structures of Blended Linen/Cotton Fabrics.

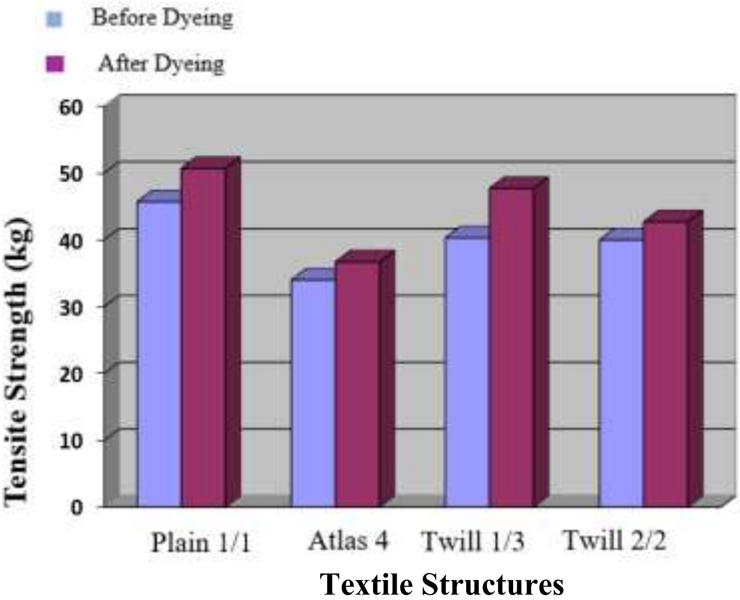
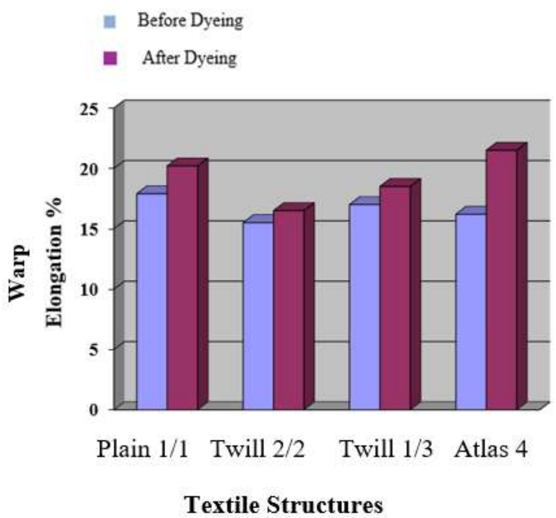


Figure 12: Effect of Cationization & Dyeing process with Natural Cassia Fistula Extract on Weft Tensile Strength for Different Structures of Blended Linen/Cotton Fabrics.

Table 4 and Figure 11, 12 show that there is a significant enhancement in tensile strengths of warp & weft threads of all different structures after cationization and dyeing with Cassia Fistula natural dye. It may be caused by cohesion increasing, cross-sections closing of the threads as a result of fibers swelling resulting from dye absorption, which is mainly reflected in the tensile strength.Whereas Atlas 4 was recorded the highest tensile strength regarding warp threads, the plain weave structure achieved the highest regarding weft.
While Atlas 4 achieved the lowest value for weft tensile strength, Twill 1/3 was the lowest regarding warp.
Although many studies indicate the possibility of a decrease in tensile strength as a result of some treatments, such as the cationic treatment used in the research, the results confirm the opposite, and this may be because the cation is linked to cellulose through carbon atom number 6 in the methyl hydroxyl group of cellulose. CH2-OH, without breaking any internal H- bond in cellulose, keeps it strong without causing weakness.

6.2.2 The effect of Cationization and Dyeing Processes on the Elongation of Warp & Weft threads for Different Fabric structures.



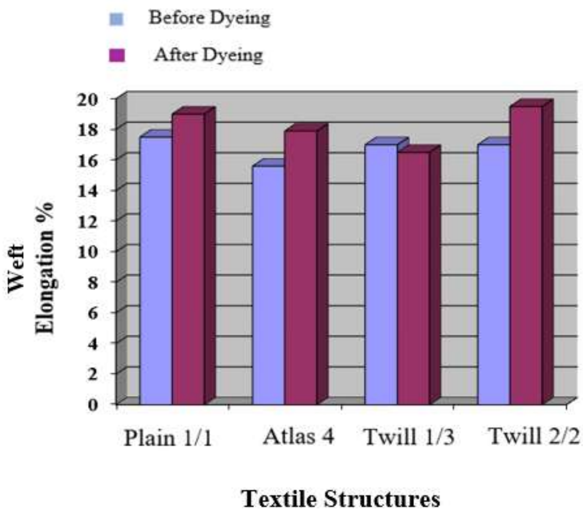


Figure 13: Effect of Cationization & Dyeing Process with Natural Cassia Fistula Extract on Warp/Weft Elongation for Different Structures of Blended Linen/Cotton Fabrics.

The elongation values of the different textile structures were given in Table 4 and Figure 13 before and after cationization and dyeing. According to the statistical analysis, there is a significant increase in warpwise and weftwise to get the maximum rate of increasing with Atlas 4 weave structure (32.7%), (14.70%) respectively, while noticeable decrease in elongation was observed with Twill 2/2 was recorded 7.98%.
The results revealed that cationization and dyeing processes improved the elongation characteristics of the fabric.

6.2.3 The effect of Cationization and Dyeing Processes on the Air Permeability of Different Fabric structures.

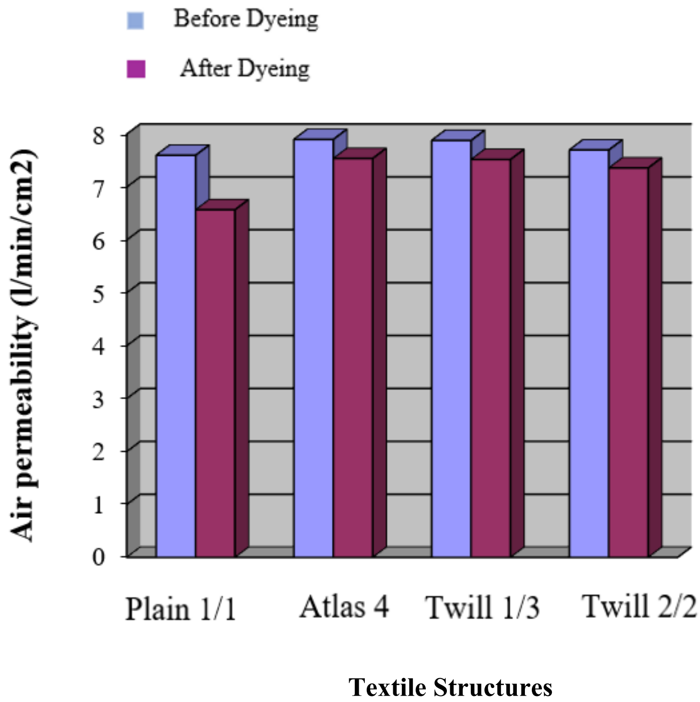


Figure 14: Effect of Cationization & Ddyeing Process with Natural Cassia Fistula Extract on the Air Permeability of Different Blended Linen/Cotton Fabric.

Table 4 and Figure 14 show that after cationization and dyeing process, all the fabrics structures have less air permeability with semi similar ratios. The most air-permeable fabric was Plain 1/1.
This is due to the absorption of the natural dye by the textile fibers within the interstitial spaces, which in turn swell, causing an increase in the thickness of the thread and a decrease in the area of the holes in the textile structure, and consequently a reduction in the air spaces and a decrease in the rate of air permeability.

However, we note that Atlas 4 still has the best fabric structure in terms of air permeability, even after dyeing. Perhaps this is what gives an advantage to the Atlas fabric structure, especially with linen, as it provides the fabric with a softness that reduces the roughness of linen and, at the same time, increases air permeability, taking into account the high capacity to absorb water, as its moisture acquisition rate reaches high ratios, thus increasing the elements of feeling comfortable.

7 CONCLUSION

Cellulosic fabrics treated by cationization enhance cellulose dye uptake, reduce dye consumption, and minimize environmental pollution. Compared with the control fabric, the dyed blended linen/cotton fabric shows a tensile strength improvement, an elongation percentage increment, and no negative impact except a slight reduction in air permeability. Atlas 4 fabric structure has the highest porosity before and after the dyeing process. The dye obtained from Cassia fistula extract has a very satisfactory fastness on blended linen/cotton fabrics.

REFERENCES

1. Abel, A. (2012). The history of dyes and pigments: From natural dyes to high performance pigments. In Colour design (pp. 557-587). Elsevier.
2. Atalie, D., Tesema, A. F., & Rotich, G. K. (2018). Effect of weft yarn twist level on thermal comfort of 100 percent cotton woven fabrics. Research Journal of Textile and Apparel, 22(3), 180-194.
3. Bahorun, T., Neergheen, V. S., & Aruoma, O. I. (2005). Phytochemical constituents of Cassia fistula. African journal of Biotechnology, 4(13).
4. Begum, M. S., & Milašius, R. (2022). Factors of weave estimation and the effect of weave structure on fabric properties: A review. Fibers, 10(9), 74.
5. Bera, M., & Chakraborty, S. (2022). Knitted active wears. In Advanced Knitting Technology (pp. 255-305). Elsevier.
6. Bivainytė, A., & Mikučionienė, D. (2011). Investigation on the air and water vapour permeability of double-layered weft knitted fabrics. Fibres and textiles in Eastern Europe., 19(3), 69-73.
7. Chequer, F. D., de Oliveira, G. A. R., Ferraz, E. A., Cardoso, J. C., Zanoni, M., & de Oliveira, D. P. (2013). Textile dyes: dyeing process and environmental impact. Eco-friendly textile dyeing and finishing, 6(6), 151-176.
8. Chowdhury, M. J., Uddin, M. T., Biswas, M. I., Lyzu, C., Parveen, S., Eti, S. A., & Razzaq, M. A. (2024). Leather dye from Trema orientalis (L.) and its antibacterial effects. Industrial Crops and Products, 210, 118159.
9. Dejene, B. K., & Gudayu, A. D. (2024). Exploring the potential of 3D woven and knitted spacer fabrics in technical textiles: A critical review. Journal of Industrial Textiles, 54, 15280837241253614.
10. Deopura, B., & Padaki, N. (2015). Synthetic textile fibres: polyamide, polyester and aramid fibres. In Textiles and fashion (pp. 97-114). Elsevier.
11. Epps, H. H., & Leonas, K. K. (2000). Pore size and air permeability of four nonwoven fabrics. International Nonwovens Journal(2), 1558925000OS-1558900215.
12. Gungor Turkmen, B., Celik, P., Sehit, H., & Bedez Ute, T. (2024). The effects of hollow yarn and fabric structure on permeability and moisture management properties of woven fabrics. The Journal of The Textile Institute, 115(4), 527-534.
13. Haji, A., & Naebe, M. (2020). Cleaner dyeing of textiles using plasma treatment and natural dyes: A review. Journal of cleaner production, 265, 121866.
14. Johansen, D. A. (1941). Textile Testing Physical, Chemical and Microscopical. John H. Skinkle. Pp. x+ 272.(London: and Co., Ltd., 1940.) 158. net. Nature, 147.
15. Kulichenko, A. (2005). Theoretical analysis, calculation, and prediction of the air permeability of textiles. Fibre Chemistry, 37(5), 371-380.
16. Kumar, B., & Hu, J. (2018). Woven fabric structures and properties. In Engineering of high-performance textiles (pp. 133-151). Elsevier.
17. Lawrence, C. (2015). Fibre to yarn: filament yarn spinning. In Textiles and fashion (pp. 213-253). Elsevier.
18. Maduna, L., & Patnaik, A. (2020). Heat, moisture and air transport through clothing textiles. Textile Progress, 52(3), 129-166.
19. Mellor, C. M., & Cardwell, D. S. (1963). Dyes and dyeing 1775–1860. The British Journal for the History of Science, 1(3), 265-279.
20. Repon, M. R., Islam, T., Paul, T. K., Jurkonienė, S., Haji, A., Shukhratov, S., & Toki, G. F. I. (2024). Natural dyes in textile printing: parameters, methods, and performance. Environmental Science and Pollution Research, 31(35), 47552-47583.
21. Skinkle, J. H. (1949). Textile testing: physical, chemical and microscopical. (No Title).
22. Sule, A. (2002). Computer colour analysis: textile applications. New Age International.
23. Ullah, H. M. K., Lejeune, J., Cayla, A., Monceaux, M., Campagne, C., & Devaux, É. (2022). A review of noteworthy/major innovations in wearable clothing for thermal and moisture management from material to fabric structure. Textile Research Journal, 92(17-18), 3351-3386.