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Using Pectin to Enhance the Dyeability Performance and Antimicrobial Activity Using Different Dyes on Modified Proteinic and Synthetic Fabrics

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Abstract: The study sought to identify the primary problems arising during the dyeing of proteinic and synthetic fabrics (wool, polyester, and acrylic fabrics). Pretreatment has a stronger influence on the dyeing qualities of materials as well as the environment. The main goal of this study is to modify proteinic and synthetic fabrics (wool, polyester, and acrylic) by using biopolymer (pectin) to enhance their coloring with synthetic and natural dyes and its antimicrobial properties. The treatment was carried out by applying a pectin solution to the fiber, followed by dyeing with synthetic and natural dyes. The efficacy was then evaluated in terms of shade depth by evaluating the K/S value and colorfastness attributes of pectin-treated dyed cloth samples. Pectin-treated textiles were found to have a greater depth of shade than untreated dyed samples. In terms of colorfastness, the dyed samples with and without pectin pretreatment had nearly identical dry rubbing fastness. Pectin-treated textiles, on the other hand, had lower wet rubbing and washing fastness ratings, especially for materials with greater pectin concentrations.

Keywords: pectin; biopolymers; anionic modification; textile dyeing.

1. Introduction

The chemical and physical state of the dye and the material, environmental conditions, the source and intensity of lighting, as well as additional dyeing bath additives, all affect dyeability and light fastness. Several modifications may be made to the fabric's physical and chemical properties to provide it with better properties than untreated fabric [1-3]. An anionic modification via using bio-polyanion (pectin) was used. One of the surface modifications used to increase the color strength of changed-colored textiles is the use of pectin [4]. This biopolymer can modify textile fiber surfaces due to the pectin's abundance of carboxylic groups [5,6].

Pectin is a natural polysaccharide derived from higher plants that consist mostly of a backbone of (14)-linked -D-galacturonic acid (GalA) units that have been partially methyl esterified or acetylated. Furthermore, this linear chain might be broken up by (12)-linked -L-rhamnopyranosyl units with neutral sugar side chains, primarily arabinans. [7-9].

Pectin is classified into two types based on the esterification degree of the carboxylic acid groups: elevated methoxyl pectin (HMP, esterification degree greater than 50 percent)and low methoxyl pectin (LMP, esterification degree less than 50%). (LMP, esterification degrees lower than 50%). [10-12] These polysaccharides, which also are widely dispersed in plant cell walls, have several uses in food (as a gelling agent, emulsifier, and stabilizer) and pharmaceutical (as anti-tumor, antioxidant, anti-diabetic, and anti-cancer) [13,14]. Numerous firms began making pectin because of the huge amounts of fruit left over after the juice and wine industries, particularly apple or citrus pulps[15].

Dyestuff is a colored organic substance that is used to color various substrates. Textile is one of the many materials that may be dyed using dyes. Dyes are divided into two categories: Natural and synthetic dyes. Natural dyes are becoming more and more popular since they are non-toxic and environmentally beneficial. Bio-colorants obtained from natural sources are renewable and sustainable bio-resources but have Poor brightness and fastness properties: Color pay-off from natural dyes tends to fade quickly. More so, quality may not be as consistent as what synthetic dyes can deliver [16-22].

Peppermint has a rich sweetish odor, a warm, pungent flavor, and a refreshing aftertaste. Fresh leaves are used in cooking, while dried blossoms flavor chocolates, pastries, beverages, salads, and other dishes. Its essential oil is frequently used to flavor meals. The plant is a hybrid of water mint (Mentha aquatica) and spearmint (Mentha spicata), and it is widely produced throughout Europe, Asia, and North America. Peppermint grows well on soil that has a high water retention capacity. All commercial mints are seedless and reproduce via underground stolons (runners or rootstock) produced by existing plants [23].

Polyester fiber is naturally hydrophobic due to the lack of hydrophilic groups in its structure. Surface modifications are necessary to make the fabric surface hydrophilic enough for effective moisture management performance to make polyester fiber garments pleasant for consumers. Its hydrophobicity results in poor performance in terms of effective moisture management performance, anti-static characteristics, and so on. The insertion of new functional groups by chemical modification processes is one method for changing the physical and chemical properties of the fiber. By selecting the appropriate experimental circumstances, limiting the chemical alteration to the fiber's surface should be feasible while keeping the inner structure unaltered [24].

The raw material of wool fabric contains carboxyl and amine groups, which allows it to be dyed with acidic dyes, while polyacrylic fabric contains nitrile and carboxyl groups, which facilitates its dyeing with basic dyes.

The present work aims to increase functional groups onto fabric surfaces to assess the fastness and dyeability of synthetic and natural dye without the aid of mordants by pretreatment of wool, polyester, and polyacrylic fabric with pectin. The relative unlevelness index (RUI), color strength (K/S), dye fixation, dyeing parameters, and fastness characteristics were assessed. Antimicrobial properties, as well as physical and mechanical properties, were evaluated. Dyeing conditions were employed to improve the dyeing process's efficiency and antibacterial impact.

2. Materials and Methods

2.1. Material.

Polyester fabric (100%; 160 g/m^2), acrylic fabric (100%; 210 g/m2), and wool (100%; 310 g/m2) fabrics were purchased from Misr El-Mahala Co. Egypt.

Methylene blue (C.I. basic blue 9) as a basic dye, Acid blue 193 as an acid dye, and C.I. Disperse Blue 183 as dispersed dye were kindly supplied by Dystar Co., Egypt. Natural dye was extracted from mint leaves collected from Egypt's local market.

The natural gel was extracted from the citrus peel (Orange and pomegranate peels collected from the local market) to use as an eco-friendly polymer for the pretreatment step.

Hostapal CV, an anionic textile auxiliary based on alkyl aryl polyglycol ether, was used as a detergent. Sodium bicarbonate, sodium bicarbonate, sodium hydroxide, citric acid (CA), sodium hypophosphite (SHP), acetic acid, dispersing agent, ethyl alcohol, and urea used were laboratory-grade chemicals and used without further purification.

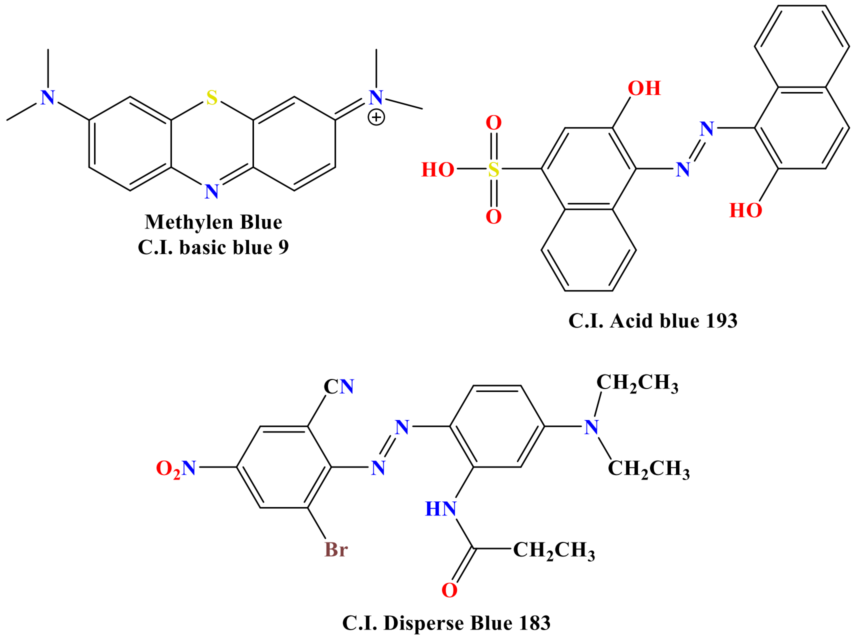

Figure 1. Chemical structure of used dyes.

2.2. Methods.

2.2.1. Pretreatment of fabrics.

Raw materials (wool, polyester, and polyacrylic fabrics) are immersed in a solution containing 10 g/L citric acid and 5 g/L sodium hypophosphite at 40°C for 10 minutes, then squeezed at 80 % wet pickup and then dried in the oven at 100°C for 3 minutes.

2.2.2. Treatment of fabrics with pectin**.**

Untreated and pre-treated fabrics were immersed in a solution containing different pectin concentrations (1, 2, 3, and 4 %) at 40°C for 10 minutes, then squeeze the treated fabrics at 80 % wet pickup, after that, the fabrics were dried in the oven at 100°C for 3 minutes.

2.2.3. Extraction of natural dye.

To eliminate dust and particle debris, the naturally fresh leaves of mint leaves were carefully washed and cleaned with tap water. Mint leaves were left to die at room temperature overnight, and then it was cut into little pieces. For aqueous extraction, 125 g of mint leaves were immersed in 1000 ml of distilled water and heated to 100°C for 60 minutes before vacuum filtering with filter paper. The extraction was then kept at 4°C, and the filtrate was utilized without additional filtration.

2.2.4. Dyeing method.

2.2.4.1. Traditional dyeing procedure for wool fabrics with an Acid dye.

Dissolve the dye with a small amount of hot water; thereafter, add the appropriate volume of water based on the liquor ratio. Begin dying at around 40°C and stir thoroughly while raising the temperature to 90°C in 15 minutes, after which continue dyeing at this temperature for 120 minutes. During the dyeing process, three equal quantities of salt are introduced. When the dyeing process is finished, the fabric should be removed, rinsed, washed, rinsed, and dried. During the dyeing process, the quantity of the dye bath should be kept constant by periodic tiny additions of hot water.

2.2.4.2. Traditional dyeing procedure for polyester fabrics with dispersed dye.

Begin the dyeing process at room temperature by putting the polyester sample and the predicted volume of wetting agent and water and stirring for 5 minutes. Next, add the dispersion agent, carrier, and acetic acid at room temperature and mix for 5 minutes. Then, for 5 minutes, add the dispersed dye and stir. Throughout the next 20 minutes, steadily raise the temperature to 95°C. Continue the dyeing at 95°C for another 60 minutes. After dyeing, the fabric is removed and placed in a reduction clearing bath containing caustic soda (NaOH) and sodium hydrosulfite for 15 minutes at 80°C. Cold water is used to rinse the sample. Finally, the fabric is immersed in a soaping wash containing non-ionic detergent for 15 minutes at 50°C.

2.2.4.3. Traditional dyeing procedure for polyacrylic fabrics with a basic dye.

The dye heats in boiling water till thoroughly dissolved, then making a dye bath with a retarder and sodium acetate as a buffer because it's a good idea to adjust the dyeing rate by dying at pH 5. A retarder is required for level dyeing. Afterward, put the fabric in a blank dye solution containing the retarder at 40°C for 10-15 minutes. Bring the water to a boil, then gradually increase the temperature for about an hour for the dying process to complete. Carefully cool the dye bath to 50-60°C once the dying is complete.

2.2.4.4. Dyeing procedure for treated fabrics with different dyes.

Untreated and pre-treated fabrics were dyed in solutions containing 0.5 g/L of basic, acid, disperse, or natural dyes at temperatures (50, 70, 80, and 90°C) for (30, 45, and 60) minutes, then dried dyed samples were put in the oven at 100oC for 3 minutes. Finally, the fabric is immersed in a soaping wash containing non-ionic detergent for 15 minutes at 50°C.

2.3. Testing and analysis.

2.3.1. Determination of Carboxyl content.

Carboxyl content of the treated fabrics according to the ASTM Standard Test Method (D1926 - 00) [25]. In brief: A 250 ml stoppered conical flask containing 0.25 g of the material was weighed, to which 40 mL of 0.1 N NaOH was then added. With sporadic shaking, the conical flasks were left overnight. Then, use phenolphthalein as an indicator to titrate the filtrate against HCl (0.05 N).Carboxyl content percent was calculated according to the following equation:

$$\text{Carboxyl contents \%} = \frac{(V_B - V_S) \times M_{HCl}}{W_t} \times 100$$

where Vb is the volume of HCl consumed by the blank experiment, Vs is the volume of HCl consumed by the sample, MHCl = Molarity of HCl, and W is the weight of the sample.

2.3.2. Measurement of color properties**.**

A Data color (Data color International 500 reflectance spectrophotometer) was used to determine the color of the textile materials. The Kubelka–Munk equation was used to calculate the color strength (K/S):

$$K/S = \frac{(1 - R)^2}{2R}$$

where R denotes reflectance, K denotes absorption coefficient, and S denotes scattering coefficient [17,26,27].

2.3.3. RUI value.

The Relative Unlevelness Index was used to calculate the levelness of colored materials (RUI). RUI was calculated by measuring reflectance at ten randomly selected places on each sample in the visible wavelength region (390–700 nm) at 10 nm intervals. The RUI takes into account reflectance measured over the visible spectrum, with a correction mechanism that takes into account human visual sensitivity.

$$S_\lambda = \frac{\sqrt{\sum_{i=1}^{m} \times (R_i - R_m)^2}}{n-1} \qquad RUI = \sum_{\lambda=390}^{700} \times \left(\frac{S_\lambda}{R_s}\right) \times V_\lambda$$

where S_λ is the standard deviation of reflectance measured at a specific wavelength, and n is the number of measurements at each wavelength. R_m is the relative unlevelness index [RUI], where V is the photopic relative luminous efficiency function, and n is the number of wavelengths for which reflectance values are averaged [30]. R_i is the reflectance value of the measurement number (i) for each wavelength [31,32].

2.3.4. Color fastness properties**.**

The washing fastness properties of colored samples were assessed using the standard ISO 105-C01:2006 test technique [33]. Launderings were done in the Launder-O-Meter (Atlas Electric Co., USA) at 30°C with soap [34-36]. The washed specimens were graded on a visual grey scale.

This method is intended to determine the quantity of color transferred by rubbing from the surface of a colored textile material to another surface. The test is performed using the

AATCC crock meter following AATCC Test Method 8-2016 [37]. Wet and dry rubbing fastness tests were performed. The test specimens were evaluated using a visual greyscale, and the rubbing fastness rating was graded on a five-point scale (as above) [38]. Acidic and alkaline perspiration was carried out according to the test method of AATCC 15-2013 and ISO 105-EO4 (2013) [39,40]. The five fastness ratings could be described as follows: 5 = excellent; 4 = good; 3 = fair; 2 = bad, and 1 = extremely poor.

The color fastness measurements to light were determined according to the AATCC Test Method 16-2014 [26,41].

2.3.5. Antibacterial properties.

According to the AATCC test method 100-1993, the antibacterial characteristics were quantitatively assessed against gram-negative bacteria, *Escherichia coli*, and gram-positive bacteria, *Staphylococcus aureus* [42]. The decrease in bacterial populations was computed using the following equation:

Reduction rate (%) = (A-B)/A×100

where: A = the number of bacterial colonies recovered from untreated fabrics and B = the number of bacterial colonies recovered from treated fabrics.

2.3.6. Mechanical properties of the treated fabric.

Tensile strength and elongation must be measured at 25°C and 65 percent relative moisture using an FMCW 500 tensile strength machine (Veb Thuringer Industrie Werk Rauenstein 11/2612 Germany) following the ASTM research system D1682-59T. [43] The crease recovery angle (CRA) was measured using the AATCC test procedure 66 – 2014. [44] The fabric roughness was determined using the surface roughness instrument SE 1700 following ASTM test system D 7127–13 [45]. The stiffness or rigidity of printed cloth was tested using cantilever equipment following ASTM test D 1388-14e1 [46,47].

3. Results and Discussion

3.1. Effect of pectin concentration.

Raw materials (wool, polyacrylic, and polyester) were treated with different concentrations of pectin (1, 2, 3, and 4%). To add functional groups on the surface of the material to improve the dyeing properties, and then dye the treated materials with (Acid, Basic, Disperse, and natural dyes).

From Table 1, Table 2, and Table 3, it can be noticed that all treated (wool, acrylic, polyester) materials had greater color strength, dye fixation, and RUI values than untreated fabrics. Color strength increases while increasing the pectin concentration; we can conclude that the ideal treatment concentration is 3%, as the results improve slightly after this concentration. Pectin has a carboxyl group (COOH) as a functional group; when textiles are treated with it, the negative charge on the fabric's surface increases.

The amount of carboxyl groups attached to the treated fabrics were counted by looking at the carboxyl content of both blank and pectin-treated textiles. The more carboxyl groups coated on the surface of different textiles, the more anionic charge will be present on the surface due to the presence of pectin since pectin has (COOH) as its functional group (COO-).

Table 1. Carboxyl content and color performance of dyed wool fabric with different dyes in the presence and absence of citric acid as a crosslinker.

Fabric	Pectin (%)	Cross linker	Carboxyl content %	Basic dye				Disperse dye				Acid dye				Natural dye			
				K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI	
						value	rating			value	rating			value	rating			value	rating
Wool	0	with	3.32	3.01	21.38	0.445	Good	6.34	77.89	0.331	Good	11.22	95.49	0.481	Good	6.86	60.55	0.419	Good
		without	3.12	2.88	54.34	0.675	Poor	4.93	91.98	0.611	Poor	4.79	83.45	0.498	Poor	4.20	76.83	0.594	Poor
	1	with	5.15	3.15	20.62	0.431	Good	7.41	88.74	0.409	Good	12.55	84.00	0.483	Good	7.70	59.91	0.441	Good
		without	5.07	3.10	23.14	0.531	Poor	5.34	93.60	0.532	Poor	11.81	92.05	0.469	Good	6.75	63.44	0.511	Poor
	2	with	6.33	3.29	19.96	0.418	Good	8.47	77.89	0.488	Good	13.87	76.55	0.485	Good	8.54	59.40	0.464	Good
		without	6.26	3.31	15.43	0.388	Good	5.74	95.03	0.453	Good	18.83	94.53	0.440	Good	9.29	58.81	0.427	Good
	3	with	7.29	8.58	37.62	0.478	Good	9.65	79.88	0.457	Good	25.38	90.03	0.198	Excellent	14.54	69.13	0.378	Good
		without	7.23	4.50	33.71	0.370	Good	9.50	96.64	0.405	Good	27.14	75.62	0.199	Excellent	13.71	69.65	0.325	Good
	4	with	8.12	8.75	37.62	0.448	Good	9.84	79.88	0.473	Good	25.89	90.03	0.342	Good	14.83	69.13	0.421	Good
		without	8.07	4.59	33.71	0.379	Good	9.69	96.64	0.429	Good	27.68	75.62	0.319	Good	13.99	69.65	0.376	Good

Treatment condition: Pectin (1, 2, 3, and 4 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4, dyeing time: 30 min, dyeing temperature: 70°C, drying at 100°C for 3 min, curing at 140°C for 3 min.

RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.

Table 2. Carboxyl content and color performance of dyed acrylic fabric with different dyes in the presence and absence of citric acid as a crosslinker.

Fabric	Pectin (%)	Cross linker	Carboxyl content %	Basic dye				Disperse dye				Acid dye				Natural dye			
				K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI	
						value	rating			Value	rating			value	rating			value	rating
Acrylic	0	with	2.11	5.56	63.18	0.450	Good	0.89	74.79	0.407	Good	0.75	64.10	0.430	Good	2.40	64.52	0.429	Good
		without	1.87	6.17	71.49	0.529	Poor	0.54	46.96	0.485	Good	0.52	55.91	0.400	Good	2.41	67.51	0.471	Good
	1	with	3.64	4.09	26.79	0.447	Good	7.72	89.66	0.425	Good	0.89	42.75	0.449	Good	4.23	48.92	0.440	Good
		without	3.39	5.00	31.36	0.471	Good	7.96	86.47	0.458	Good	1.40	71.54	0.445	Good	4.79	52.97	0.458	Good
	2	with	4.74	2.62	12.06	0.443	Good	14.54	90.76	0.443	Good	1.02	34.34	0.467	Good	6.06	44.65	0.451	Good
		without	4.26	3.83	16.47	0.414	Good	15.38	89.11	0.431	Good	2.27	76.43	0.489	Good	7.16	49.39	0.445	Good
	3	with	5.49	6.38	25.75	0.298	Good	17.69	96.30	0.409	Good	2.59	86.62	0.410	Good	8.89	57.78	0.372	Good
		without	4.93	6.55	25.15	0.191	Excellent	18.21	91.92	0.408	Good	2.42	81.76	0.481	Good	9.06	55.69	0.360	Good
	4	with	6.11	6.51	25.75	0.371	Good	18.04	96.30	0.426	Good	2.64	86.62	0.439	Good	9.06	57.78	0.412	Good
		without	5.51	6.68	25.15	0.302	Good	18.57	91.92	0.420	Good	2.47	81.76	0.485	Good	9.24	55.69	0.402	Good

Treatment condition: Pectin (1, 2, 3, and 4 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4, dyeing time: 30 min, dyeing temperature: 70°C, drying at 100°C for 3 min, curing at 140°C for 3 min.

RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.

Table 3. Carboxyl content and color performance of dyed polyester fabric with different dyes in the presence and absence of citric acid as a crosslinker.

Fabric	Pectin (%)	Cross linker	Carboxyl content %	Basic dye				Disperse dye				Acid dye				Natural dye			
				K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI		K/S	Dye fixation	RUI	
						value	rating			value	rating			value	rating			value	rating
polyester	0	with	0.21	2.40	60.91	0.412	Good	10.33	62.70	0.470	Good	1.58	62.70	0.411	Good	4.77	84.52	0.431	Good
		without	0.20	1.54	42.66	0.318	Good	10.79	33.04	0.489	Good	0.76	33.04	0.353	Good	4.36	77.73	0.387	Good
	1	with	0.41	2.13	43.15	0.447	Good	10.83	92.13	0.470	Good	1.86	54.64	0.448	Good	4.94	73.77	0.455	Good
		without	0.61	2.20	54.86	0.374	Good	11.44	98.88	0.473	Good	1.19	31.85	0.402	Good	4.94	76.81	0.416	Good
	2	with	1.02	1.85	31.30	0.482	Good	11.32	98.72	0.470	Good	2.13	49.88	0.485	Good	5.10	65.92	0.479	Good
		without	1.63	2.86	64.85	0.430	Good	12.09	99.02	0.457	Good	1.61	31.32	0.451	Good	5.52	76.10	0.446	Good
	3	with	2.65	1.89	20.42	0.446	Good	15.57	88.97	0.199	Excellent	2.11	31.59	0.417	Good	6.80	57.29	0.354	Good
		without	2.14	2.92	23.97	0.384	Good	14.63	99.32	0.190	Excellent	1.96	27.80	0.409	Good	6.89	57.99	0.328	Good
	4	with	2.39	3.22	34.17	0.464	Good	15.88	88.97	0.334	Good	2.15	31.59	0.451	Good	7.08	62.35	0.417	Good
		without	2.26	3.99	32.14	0.407	Good	14.92	99.32	0.324	Good	2.00	27.80	0.430	Good	6.97	60.39	0.387	Good

Treatment condition: Pectin (1, 2, 3, and 4 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4, dyeing time: 30 min, dyeing temperature: 70°C, drying at 100°C for 3 min, curing at 140°C for 3 min.

RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.

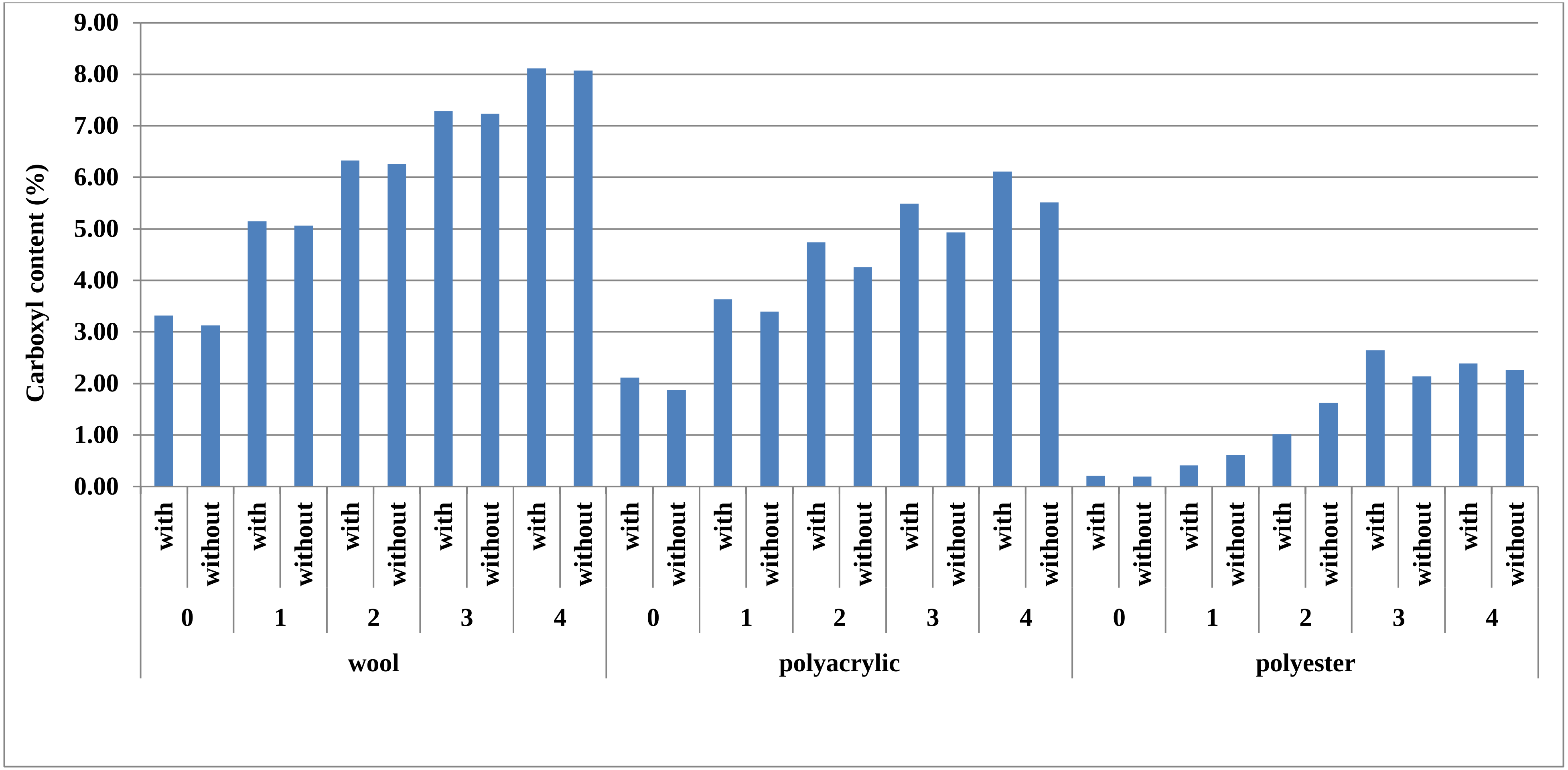

Figure 2. Effect of pectin concentration on the carboxyl content (%) of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

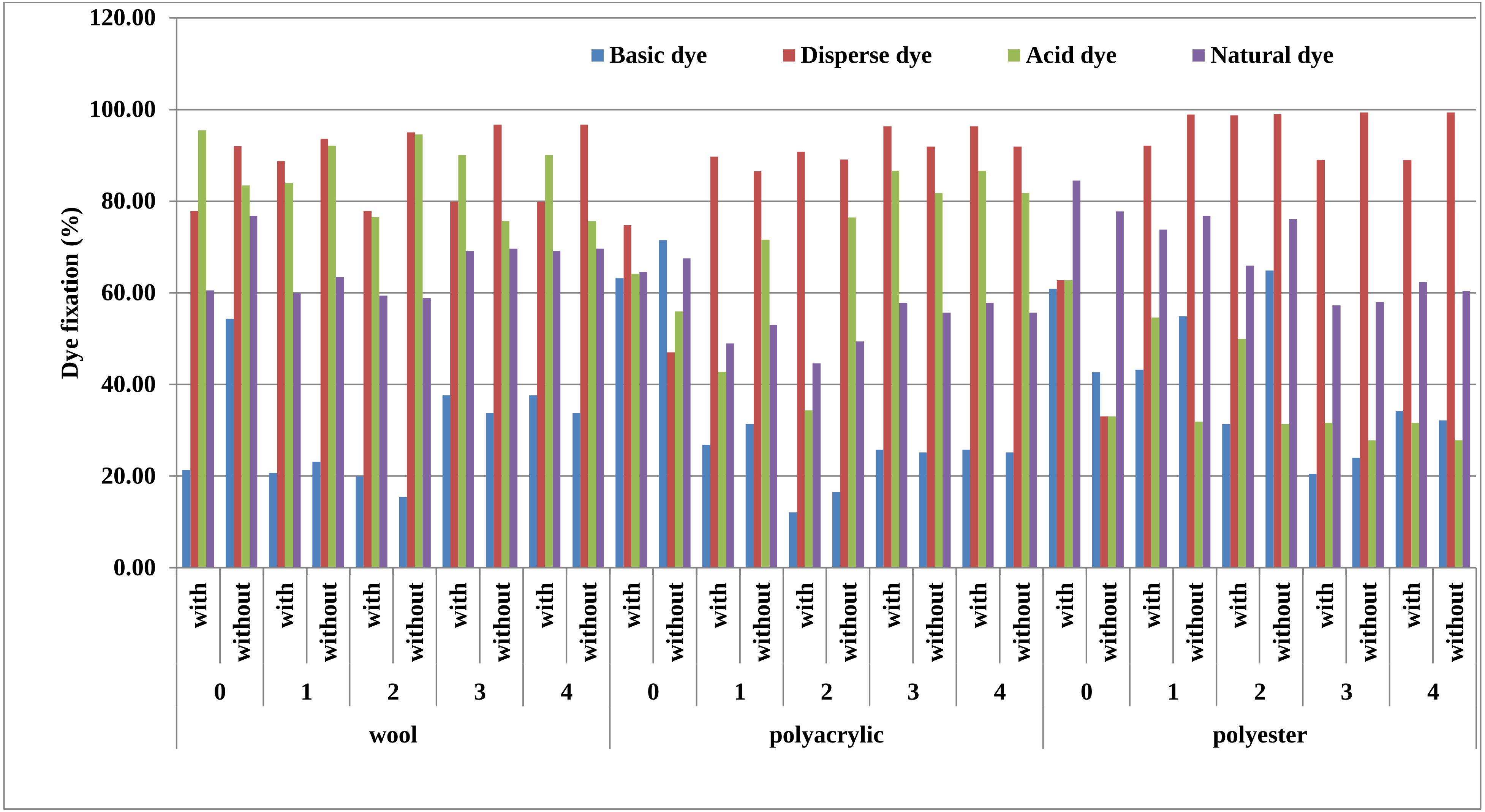

Figure 3. Effect of pectin concentration on the dye fixation (%) of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

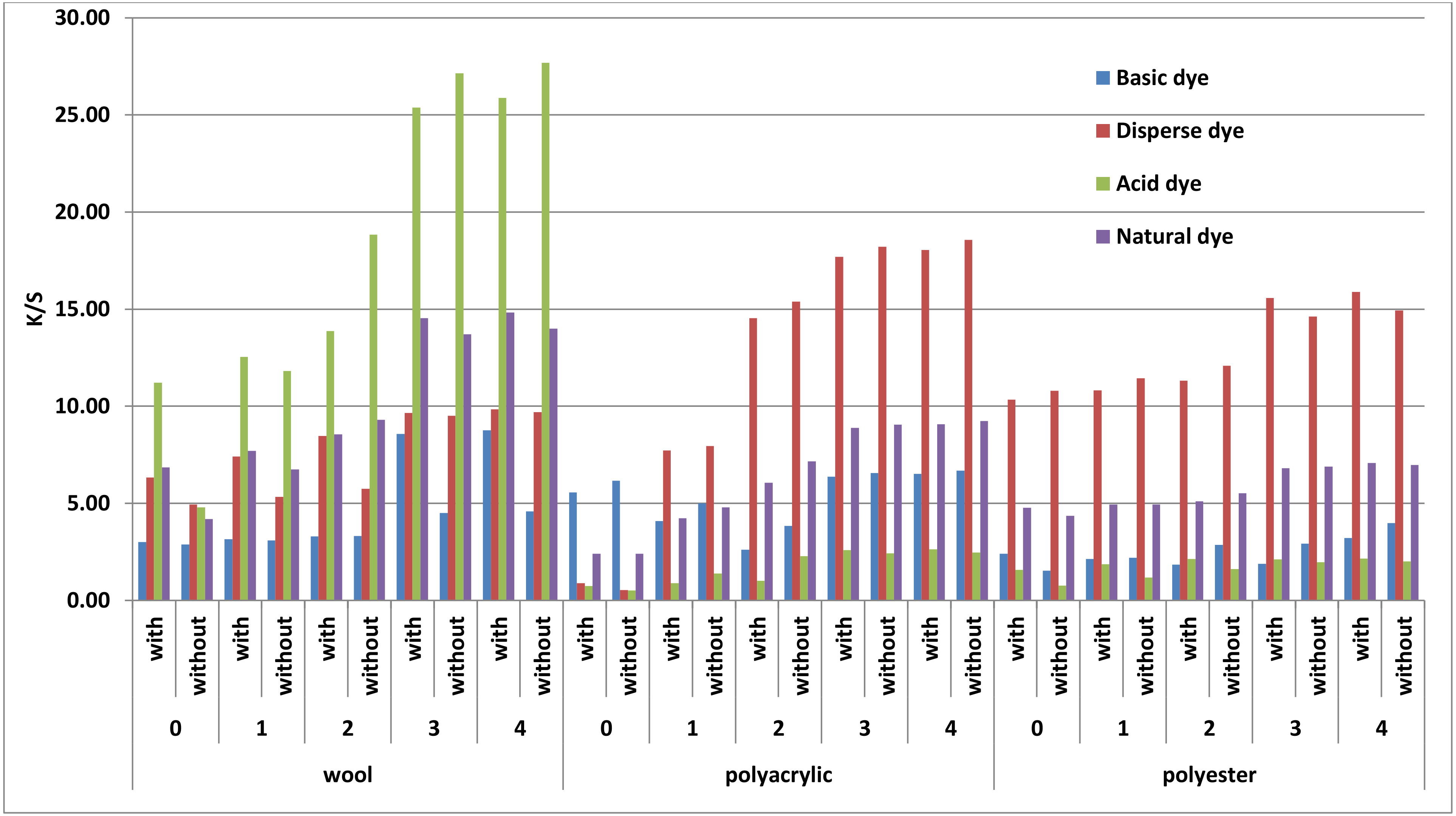

Figure 4. Effect of pectin concentration on the color strength K/S of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

Adding a crosslinker agent (citric acid with sodium hypophosphite) to improve the dye's affinity to various treated materials. Table 1 to Table 3 and Figure 2 to Figure 4 represents the carboxyl content, color strength (K/S), dye fixation, and RUI values of pre-treated dyed fabrics with different concentrations (0, 1, 2, 3, and 4%) of pectin using (Basic, Disperse, Acid and Natural) dyes.

3.2. Effect of pH.

The pH level of the dye solution was one of the most critical elements influencing dye adsorption onto pectin-treated fabrics. When the pH was between 4 and 8, the K/S ratio was improved based on the dye nature.

Table 4 and Figure 5 represent the color strength (K/S) values for the dyed treated fabrics with pectin using (basic, dispersed, acid and natural) dye at different pH values.

It is observed that a slightly acidic pH (pH 6) is advantageous for having stronger color strength for dyed treated wool fabrics with basic and dispersed dyes than pH 4 and pH 8. Increasing the pH values up to 8 causes a decrease in the color strength of treated wool fabrics. An acidic medium (pH 4) is optimal for having increased color strength for treated wool fabrics dyed with acid and extracted natural dye (mint) than pH 6 and pH 8 [48].

In the instance of basic dye, the K/S ratio for the dyed treated wool fabric is 10.86 for RUI (0.448), indicating a good rate of dyeing levelness for dispersed dye. K/S ratio is 10.05 for RUI (0.476), indicating a good rate of dyeing levelness; in the case of natural dye (mint), the K/S ratio is 14.54 for RUI (0.378), indicating a good rate of dyeing levelness. Still, the K/S ratio is 27.14 for RUI (0.199) indicating an excellent rate of dyeing levelness for acid dye.

The color strength of treated polyester and polyacrylic fabrics dyed with basic and dispersed dyes provide increases in the K/S values as the dyeing pH increases from pH 4 to pH 8, which means (the color strength was increased for the treated raw materials of polyester and polyacrylic dyed with basic and disperse dyes at a slightly alkaline medium (pH 8).In the case of dyeing treated polyester and polyacrylic fabrics with acid and natural dye (mint), pH 4 gives higher color strength than pH 6 and pH 8 (that means that color strength decreases by increasing pH up to 6 and 8).

The K/S ratio for the dyed treated polyacrylic fabrics is 8.01 and 18.76 for RUI (0.375) and (0.420), indicating a good rate of dyeing levelness for basic and dispersed dyes, respectively. In the instance of treated polyester fabrics, the K/S ratio is 6.61 and 16.04 for RUI (0.396) and (0.299), indicating a good rate of dyeing levelness for basic and dispersed dyes, respectively.

The K/S ratio for the dyed acid dye polyacrylic fabrics are 2.59 and 9.06 for RUI (0.410) and (0.360), indicating a good rate of dyeing levelness for acid and natural (mint) dye, respectively, the K/S ratio for the treated polyester fabrics are 2.11 and 6.89 for RUI (0.417) and (0.328) indicating a good rate of dyeing levelness for acid and natural (mint) dye respectively.

3.3. Effect of dyeing temperature.

The color strength (K/S) of all fabrics treated with pectin increases by increasing the dyeing temperature from 50°C up to 90°C.Based on the previous results, the ideal dyeing temperature is 80°C. That is because the increase in K/S as a result of raising the dyeing temperature from 80 to 90°C is quite small.

Table 4. Effect of pH on the color strength of treated dyed fabric in the presence and absence of citric acid as a crosslinker

Fabric	pH	Cross linker	Basic dye			Disperse dye			Acid dye			Natural dye		
			K/S	RUI		K/S	RUI		K/S	RUI		K/S	RUI	
				Value	rate		Value	Rate		Value	rate		Value	Rate
Wool	4	with	8.58	0.478	G	9.65	0.457	G	25.38	0.198	E	14.54	0.378	G
		without	4.50	0.370	G	9.50	0.405	G	27.14	0.199	E	13.71	0.325	G
	6	with	10.86	0.448	G	10.05	0.476	G	21.98	0.171	E	12.90	0.335	G
		without	9.43	0.379	G	9.54	0.406	G	19.87	0.146	E	10.37	0.246	G
	8	with	10.81	0.446	G	9.85	0.467	G	19.67	0.153	E	11.27	0.293	G
		without	5.43	0.218	G	9.52	0.406	G	13.91	0.102	E	7.03	0.166	E
Acrylic	4	with	6.38	0.298	G	17.69	0.409	G	2.59	0.410	G	8.89	0.372	G
		without	6.55	0.191	E	18.21	0.408	G	2.42	0.481	G	9.06	0.360	G
	6	with	4.85	0.227	G	17.76	0.410	G	1.90	0.301	G	8.74	0.366	G
		without	4.31	0.126	E	19.63	0.440	G	1.82	0.361	G	8.01	0.318	G
	8	with	8.01	0.375	G	17.95	0.415	G	2.51	0.397	G	8.60	0.360	G
		without	7.28	0.212	G	18.76	0.420	G	1.86	0.369	G	6.96	0.277	G
Polyester	4	with	1.89	0.446	G	15.57	0.201	G	2.11	0.417	G	6.80	0.354	G
		without	2.92	0.384	G	14.63	0.205	G	1.96	0.409	G	6.89	0.328	G
	6	with	3.77	0.464	G	14.49	0.207	G	1.99	0.393	G	6.22	0.324	G
		without	3.46	0.407	G	15.47	0.393	G	1.43	0.299	G	6.72	0.320	G
	8	with	5.89	0.455	G	16.04	0.299	G	2.04	0.402	G	6.84	0.356	G
		without	6.61	0.396	G	15.90	0.402	G	1.71	0.357	G	6.55	0.312	G

Treatment condition: Pectin (3%), citric acid 10 g/L, sodium hypophosphite (SHP), drying at 80°C for 10 min. Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH (4,6 and 8) dyeing time: 30 min, dyeing temperature: 70°C, drying at 100°C for 3 min, curing at 140°C for 3 min. RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.

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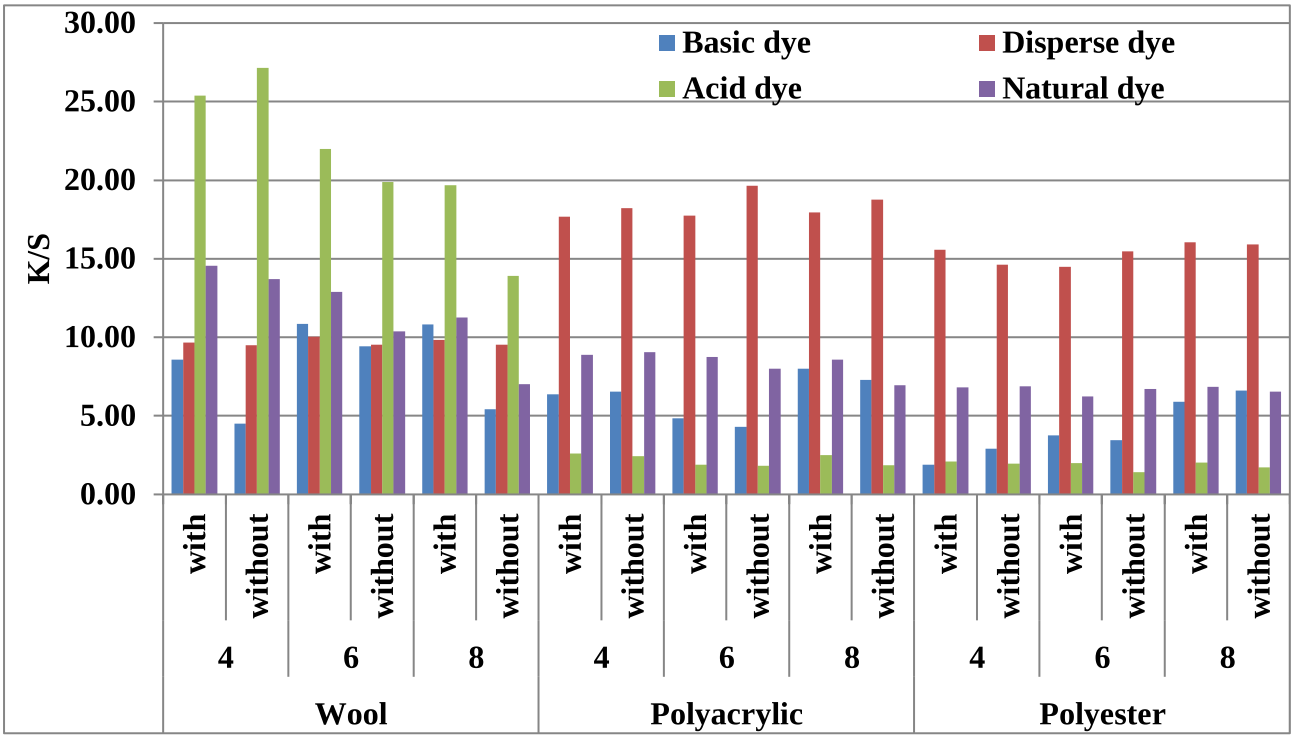


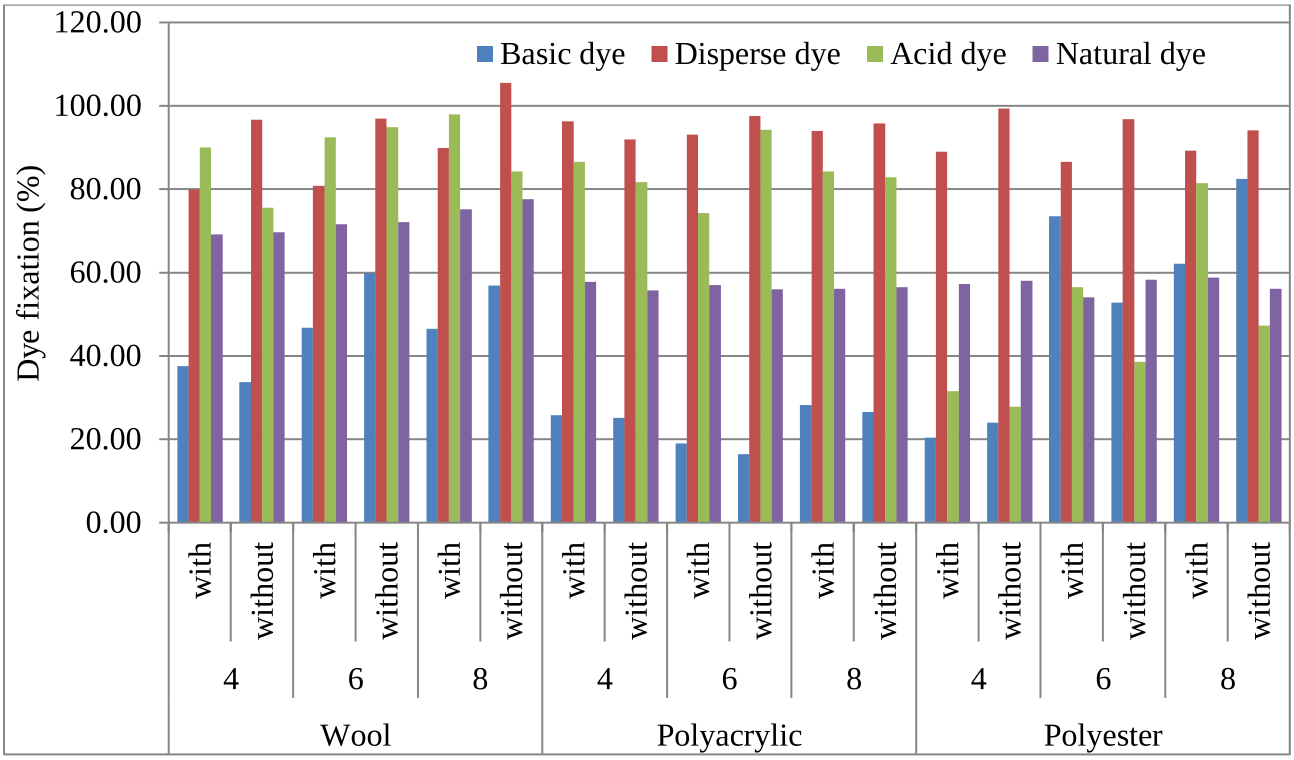


Figure 5. Effect of pH on the color strength and dye fixation (%) of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

Table 5 and Figure 6**,** represent the color strength (K/S) values for the dyed treated fabrics with pectin using (basic, dispersed, acid and natural) dyes at different temperatures (50, 70, 80, and 90°C).

From Table 5 and Figure 6, the color strengths (K/S) of all wool fabrics treated with pectin increase by increasing dyeing temperature from 50°C up to 80°C But increase slightly at 90°C with (basic, acid, and natural) dyes. The color strength (K/S) increases significantly by increasing the temperature up to 90 °C with dispersed dye. The K/S of treated wool fabrics are (12.49), (11.56), (25.28), and (14.84) for (basic, disperse, acid and natural) dyes, respectively, with RUI values (0.446), (0.467), and (0.385) for (basic, disperse and natural) dyes respectively**,** which means good levelness of the fabric surface and (0.197) for acid dye, that means an excellent rate of levelness of dyeing.

From Table 5 and Figure 6, The color strengths (K/S) of all polyacrylic and polyester fabrics treated with pectin increase by increasing dyeing temperature from 50°C up to 80°C But increase slightly at 90°C with (basic, acid, and natural) dyes. The color strength (K/S) increases significantly by increasing the temperature up to 90 °C with dispersed dye.

The K/S of treated polyacrylic fabrics are (9.21), (21.57), (2.98), and (10.42) for (basic, disperse, acid and natural) dyes, respectively, with RUI values (0.431), (0.483), (0.472) and (0.414) for (basic, disperse, acid and natural) dyes respectively, which means good levelness of the fabric surface.

The K/S of treated polyester fabrics are (7.60), (18.45), (2.43), and (7.92) for (basic, dispersed, acid and natural) dyes, respectively, with RUI values (0.455), (0.236), (0.479) and (0.377) for (basic, disperse, acid and natural) dyes, which means good levelness of the fabric surface.

3.4. Effect of dyeing time.

The longer the dying period, the more dye molecules are absorbed by the fiber till equilibrium is reached, at which point more colors enter the polymer, resulting in high percentage exhaustion and darker shade that mean the color strengths (K/S) of all fabrics increases with the increase of dyeing time. The dye exhaustion increases when the time is increased from 30 to 60 minutes [49,50].

Increasing the dyeing time increases the color strength. Therefore, the ideal dyeing time of treatment is 45 minutes; the color strength improves greatly when the dying time is increased from 30 to 45 minutes, whereas the color strength increases very marginally when the time is increased from 45 to 60 minutes.

From Table 6 and Figure 7, the color strength (K/S) values for the dyed treated fabrics with pectin using (basic, acid, disperse, and mint dye) at different times (30, 45, and 60 min.).The K/S of wool-treated fabrics with pectin is (13.87) for basic dye, (13.92) for dispersed dye (16.47) for mint dye, and (28.07) for acid dye with RUI values (0.321) for basic, dispersed, and natural (mint), which means a good rate of levelness of dyeing and (0.121) for acid dye, that means an Excellent rate of levelness of dyeing.

The K/S of polyacrylic fabrics treated with pectin is (10.23) for basic dye, (25.99) for dispersed dye (3.31) for acid dye, and (11.57) for natural (mint) dye with RUI value (0.321) for basic, (0.311) for dispersing, (0.321) for acid and (0.311) for natural (mint) dye that means a good rate of levelness of dyeing.

Table 5. Effect of dyeing temperature on the color performance of treated dyed fabric in presence and absence of citric acid as a cross linker.

Fabric	Temp C°	Cross linker	Basic dye			Disperse dye			Acid dye			Natural dye		
			K/S	RUI		K/S	RUI		K/S	RUI		K/S	RUI	
				Value	Rate		value	Rate		value	Rate		value	Rate
Wool	50	with	9.23	0.478	G	8.54	0.457	G	25.38	0.198	E	14.54	0.378	G
		without	8.02	0.370	G	8.11	0.405	G	27.14	0.199	E	13.71	0.325	G
	70	with	10.86	0.448	G	10.05	0.476	G	21.98	0.17	E	12.90	0.34	G
		without	9.43	0.379	G	9.54	0.406	G	19.87	0.15	E	10.37	0.25	G
	80	with	12.49	0.446	G	11.56	0.467	G	25.28	0.197	E	14.84	0.385	G
		without	10.84	0.218	G	10.97	0.406	G	22.85	0.168	E	11.93	0.282	G
	90	with	12.68	0.298	G	12.54	0.409	G	25.66	0.200	E	15.06	0.391	G
		without	11.01	0.191	E	11.90	0.408	G	23.19	0.170	E	12.11	0.287	G
Acrylic	50	with	6.81	0.431	G	15.26	0.353	G	2.55	0.472	G	8.75	0.428	G
		without	6.19	0.244	G	15.95	0.357	G	2.38	0.455	G	8.92	0.414	G
	70	with	8.01	0.375	G	17.95	0.415	G	2.59	0.410	G	8.89	0.372	G
		without	7.28	0.212	G	18.76	0.420	G	2.42	0.481	G	9.06	0.360	G
	80	with	9.21	0.431	G	20.64	0.477	G	2.98	0.472	G	10.22	0.428	G
		without	8.37	0.244	G	21.57	0.483	G	2.78	0.553	G	10.42	0.414	G
	90	with	9.35	0.437	G	22.40	0.484	G	3.02	0.479	G	10.37	0.435	G
		without	8.50	0.247	G	23.41	0.317	G	2.82	0.455	G	10.58	0.420	G
Polyester	50	with	5.01	0.387	G	13.63	0.236	G	2.08	0.479	G	6.70	0.407	G
		without	5.62	0.336	G	13.52	0.238	G	1.93	0.471	G	6.79	0.377	G
	70	with	5.89	0.455	G	16.04	0.205	G	2.11	0.417	G	6.80	0.354	G
		without	6.61	0.396	G	15.90	0.207	G	1.96	0.409	G	6.89	0.328	G
	80	with	6.77	0.424	G	18.45	0.236	G	2.43	0.479	G	7.82	0.407	G
		without	7.60	0.455	G	18.29	0.238	G	2.25	0.471	G	7.92	0.377	G
	90	with	6.88	0.430	G	20.01	0.239	G	2.46	0.486	G	7.94	0.413	G
		without	7.72	0.462	G	19.84	0.241	G	2.29	0.478	G	8.04	0.383	G

Treatment condition: Pectin (3 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4 with acid and natural dye for (polyester and polyacrylic fabrics), pH 8 with basic and disperse dyes for (polyacrylic and polyester fabrics), dyeing time: 30 min, dyeing temperature: (50, 70, 80 and 90°C), drying at 100°C for 3 min, curing at 140°C for 3 min.

RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.

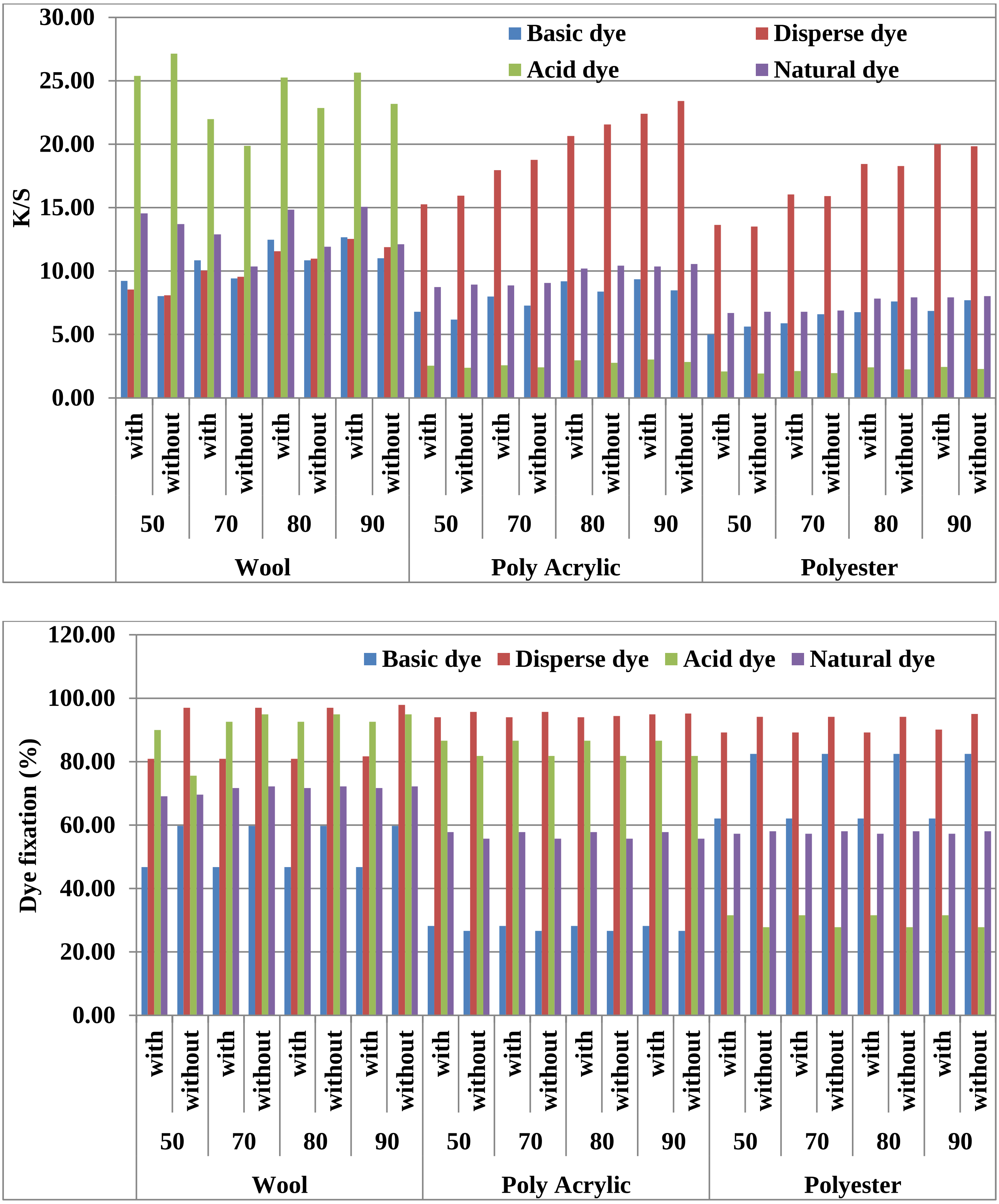


Figure 6. Effect of dyeing temperature on the color strength and dye fixation (%) of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

The K/S of polyester fabrics treated with pectin is (8.44) for basic dye, (22.22) for disperse dye (2.69) for acid dye, and (8.80) for mint dye with RUI value (0.311) for basic, (0.321) for dispersing, (0.321) for acid and (0.311) for natural (mint) dye that means a good rate of levelness of dyeing.

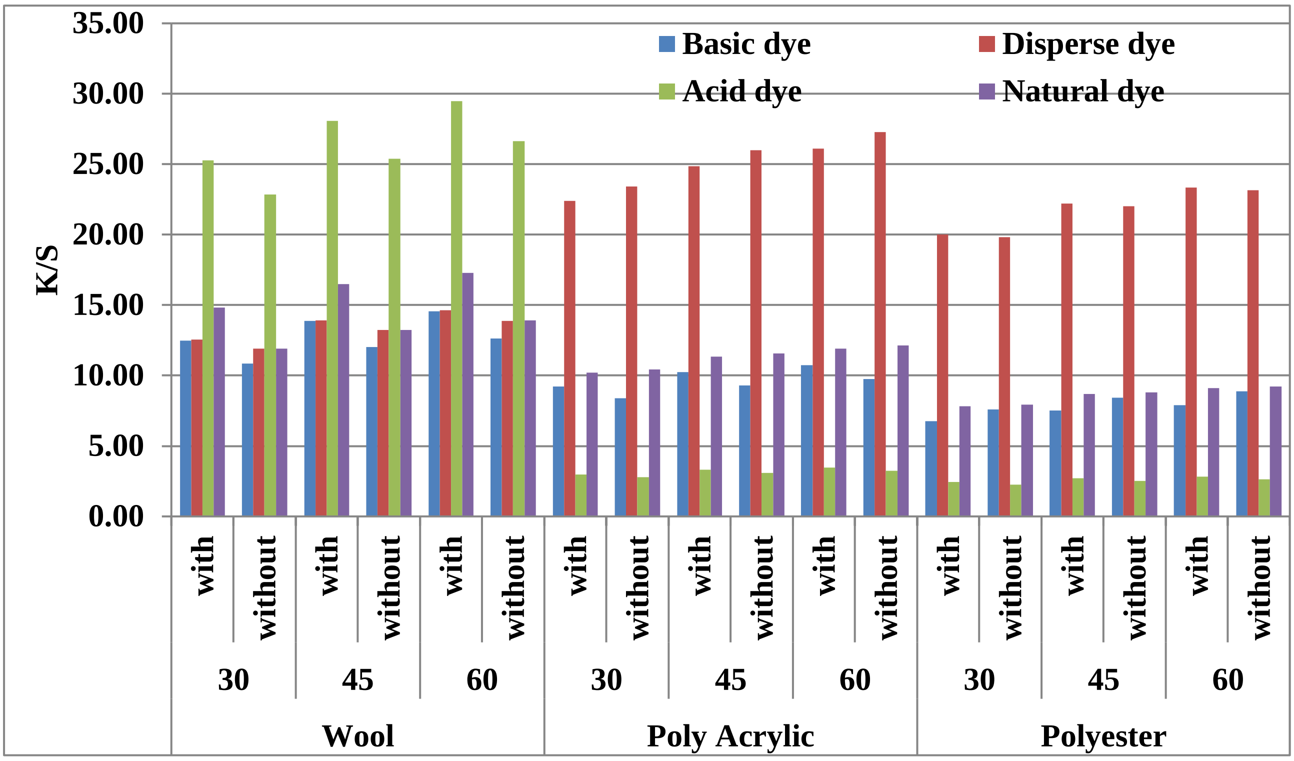
Table 6. Effect of dyeing time on the color strength of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

Fabric	Time (min)	Cross linker	Basic dye			Disperse dye			Acid dye			Natural dye		
			K/S	RUI		K/S	RUI		K/S	RUI		K/S	RUI	
				Value	Rate		value	Rate		value	Rate		value	Rate
Wool	30	with	12.49	0.446	G	12.54	0.41	G	25.28	0.197	E	14.84	0.385	G
		without	10.84	0.218	G	11.90	0.41	G	22.85	0.168	E	11.93	0.282	G
	45	with	13.87	0.321	G	13.92	0.321	G	28.07	0.121	E	16.47	0.321	G
		without	12.04	0.311	G	13.22	0.311	G	25.37	0.133	E	13.24	0.311	G
	60	with	14.56	0.383	G	14.62	0.365	G	29.48	0.159	E	17.30	0.353	G
		without	12.65	0.265	G	13.88	0.359	G	26.65	0.150	E	13.91	0.297	G
Acrylic	30	with	9.21	0.431	G	22.40	0.48	G	2.98	0.472	G	10.22	0.428	G
		without	8.37	0.244	G	23.41	0.32	G	2.78	0.455	G	10.42	0.414	G
	45	with	10.23	0.321	G	24.87	0.321	G	3.31	0.321	G	11.35	0.321	G
		without	9.30	0.311	G	25.99	0.311	G	3.09	0.311	G	11.57	0.311	G
	60	with	10.74	0.376	G	26.12	0.403	G	3.47	0.396	G	11.92	0.375	G
		without	9.76	0.277	G	27.30	0.314	G	3.25	0.432	G	12.15	0.362	G
Polyester	30	with	6.77	0.424	G	20.01	0.24	G	2.43	0.479	G	7.82	0.407	G
		without	7.60	0.455	G	19.84	0.24	G	2.25	0.471	G	7.92	0.377	G
	45	with	7.52	0.321	G	22.22	0.321	G	2.69	0.321	G	8.68	0.321	G
		without	8.44	0.311	G	22.03	0.311	G	2.50	0.311	G	8.80	0.311	G
	60	with	7.90	0.372	G	23.34	0.280	G	2.83	0.400	G	9.12	0.364	G
		without	8.86	0.383	G	23.14	0.276	G	2.63	0.391	G	9.24	0.344	G

Treatment condition: Pectin (3 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4 with acid and natural dye for wool, pH 6 with basic and disperse dyes for wool fabrics and pH, dyeing time:(30, 45 and 60) min, dyeing temperature: 80°C for wool with (acid, basic and natural dyes), 90°C for wool with disperse dye, drying at 100°C for 3 min, curing at 140°C for 3 min.

RUI value ranges can be classified as follows: If RUI <0.2, it is regarded to be of exceptional levelness. (Excellent). If the value is 0.2 < RUI < 0.49, it is regarded to be of good levelness. (Good), RUI values between 0.5 and 1 indicate inadequate levelness. (Poor), if RUI values are larger than one, this indicates that the level is poor.



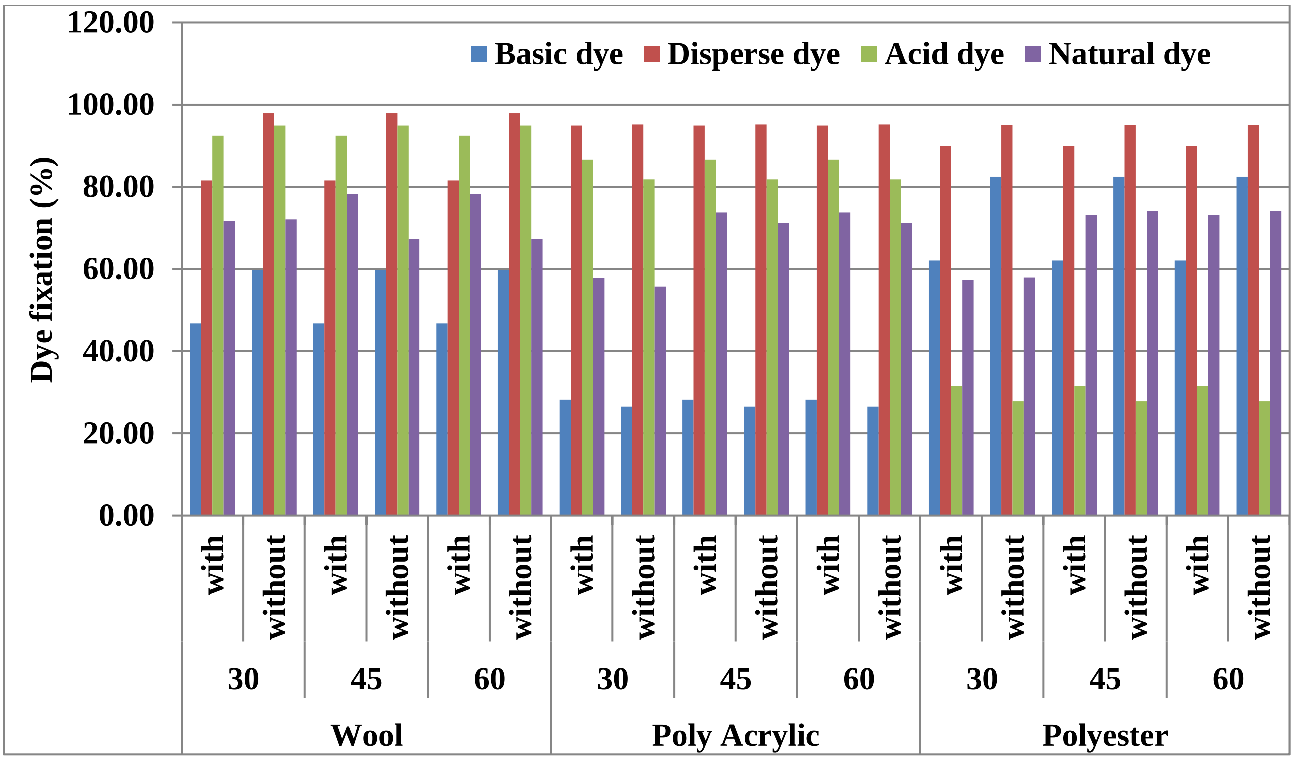


Figure 7. Effect of dyeing time on the color strength and dye fixation (%) of treated dyed fabric in the presence and absence of citric acid as a crosslinker.

Table 7. Effect of dye concentration on the color strength of treated dyed fabric in presence and absence of citric acid

Fabric	Dye conc. (%)	Cross linker	Basic dye			Disperse dye			Acid dye			Natural dye		
			K/S	RUI		K/S	RUI		K/S	RUI		K/S	RUI	
				Value	Rating		Value	Rating		Value	Rating		Value	Rating
Wool	0.5	Blank	2.88	0.675	Poor	4.93	0.611	Poor	4.79	0.498	Poor	4.20	0.594	Poor
		with	13.87	0.332	Good	13.92	0.408	Good	28.07	0.121	Excellent	16.47	0.334	Good
		without	12.04	0.275	Good	13.22	0.408	Good	25.37	0.133	Excellent	13.24	0.308	Good
	1	Blank	3.17	0.709	Poor	5.28	0.642	Poor	5.07	0.522	Poor	4.62	0.624	Poor
		with	15.25	0.349	Good	14.48	0.429	Good	29.47	0.127	Excellent	18.12	0.351	Good
		without	13.24	0.289	Good	13.75	0.429	Good	27.15	0.140	Excellent	14.57	0.324	Good
	2	Blank	3.48	0.762	Poor	5.80	0.690	Poor	5.48	0.562	Poor	5.08	0.671	Poor
		with	16.78	0.375	Good	15.93	0.461	Good	32.42	0.137	Excellent	19.93	0.377	Good
		without	14.57	0.310	Good	15.12	0.461	Good	29.86	0.150	Excellent	16.02	0.348	Good
	3	Blank	3.50	0.773	Poor	5.83	0.700	Poor	5.50	0.570	Poor	5.11	0.681	Poor
		with	16.86	0.380	Good	16.01	0.468	Good	32.58	0.139	Excellent	20.03	0.383	Good
		without	14.64	0.315	Good	15.20	0.468	Good	30.01	0.152	Excellent	16.10	0.353	Good
Acrylic	0.5	Blank	6.17	0.529	Poor	0.54	0.485	Good	0.52	0.400	Good	2.41	0.471	Good
		with	10.23	0.337	Good	24.87	0.400	Good	3.31	0.155	Excellent	11.35	0.421	Good
		without	9.30	0.291	Good	25.99	0.358	Good	3.09	0.354	Good	11.57	0.417	Good
	1	Blank	5.20	0.555	Poor	6.61	0.509	Poor	2.00	0.420	Good	3.12	0.495	Poor
		with	14.29	0.354	Good	25.52	0.420	Good	3.88	0.162	Excellent	12.27	0.442	Good
		without	9.79	0.305	Good	27.38	0.376	Good	3.79	0.371	Good	12.19	0.438	Good
	2	Blank	6.38	0.597	Poor	7.38	0.547	Poor	2.85	0.452	Good	3.38	0.532	Poor
		with	15.19	0.381	Good	27.40	0.452	Good	3.91	0.175	Excellent	12.80	0.475	Good
		without	9.76	0.328	Good	28.30	0.405	Good	3.81	0.399	Good	12.60	0.471	Good
	3	Blank	6.53	0.606	Poor	7.55	0.555	Poor	2.92	0.459	Good	3.46	0.540	Poor
		with	16.01	0.386	Good	27.77	0.459	Good	3.96	0.177	Excellent	12.97	0.482	Good
		without	10.09	0.333	Good	28.68	0.411	Good	3.86	0.405	Good	12.77	0.478	Good
Polyester	0.5	Blank	1.54	0.318	Good	10.79	0.489	Good	0.76	0.353	Good	4.36	0.387	Good
		with	7.52	0.439	Good	22.22	0.240	Good	2.69	0.475	Good	8.68	0.392	Good
		without	8.44	0.447	Good	22.03	0.241	Good	2.50	0.473	Good	8.80	0.385	Good
	1	Blank	2.96	0.334	Good	10.21	0.514	Poor	1.02	0.370	Good	5.21	0.406	Good
		with	10.50	0.461	Good	24.78	0.252	Good	4.27	0.499	Poor	8.80	0.412	Good
		without	8.89	0.469	Good	23.21	0.253	Good	2.64	0.497	Poor	8.68	0.404	Good
	2	Blank	3.12	0.359	Good	10.86	0.552	Poor	1.08	0.398	Good	5.54	0.436	Good
		with	11.17	0.496	Poor	26.35	0.271	Good	4.54	0.536	Poor	9.36	0.443	Good

Fabric	Dye conc. (%)	Cross linker	Basic dye			Disperse dye			Acid dye			Natural dye		
			K/S	RUI		K/S	RUI		K/S	RUI		K/S	RUI	
				Value	Rating		Value	Rating		Value	Rating		Value	Rating
		without	8.86	0.505	Poor	23.12	0.272	Good	2.63	0.534	Poor	8.65	0.434	Good
	3	Blank	3.19	0.364	Good	11.11	0.561	Poor	1.11	0.404	Good	5.67	0.443	Good
		with	11.77	0.503	Poor	27.49	0.275	Good	4.74	0.544	Poor	9.76	0.449	Good
		without	9.16	0.512	Poor	23.90	0.276	Good	2.72	0.542	Poor	8.94	0.441	Good

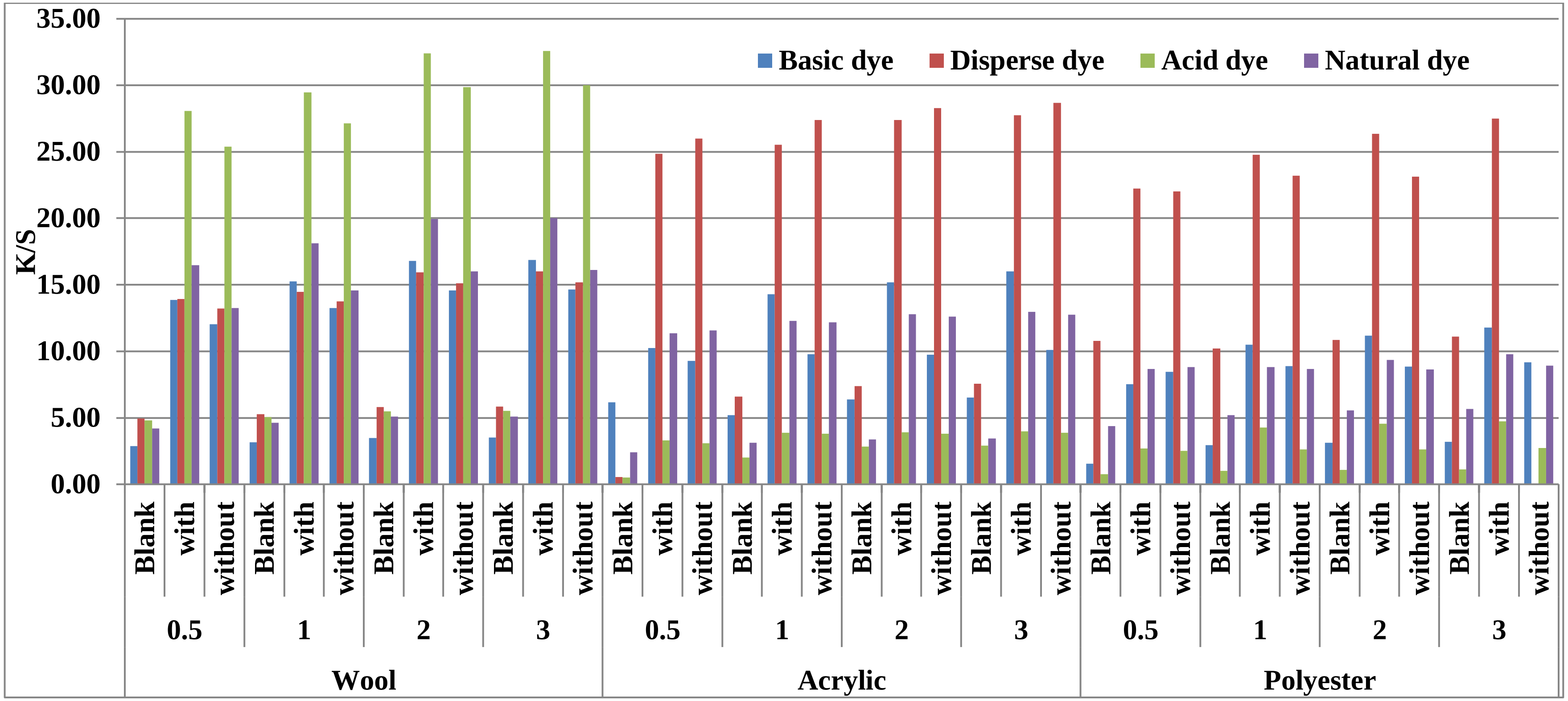


Figure 8. Color strength of treated dyed fabric with dye concentration in presence and absence of citric acid.

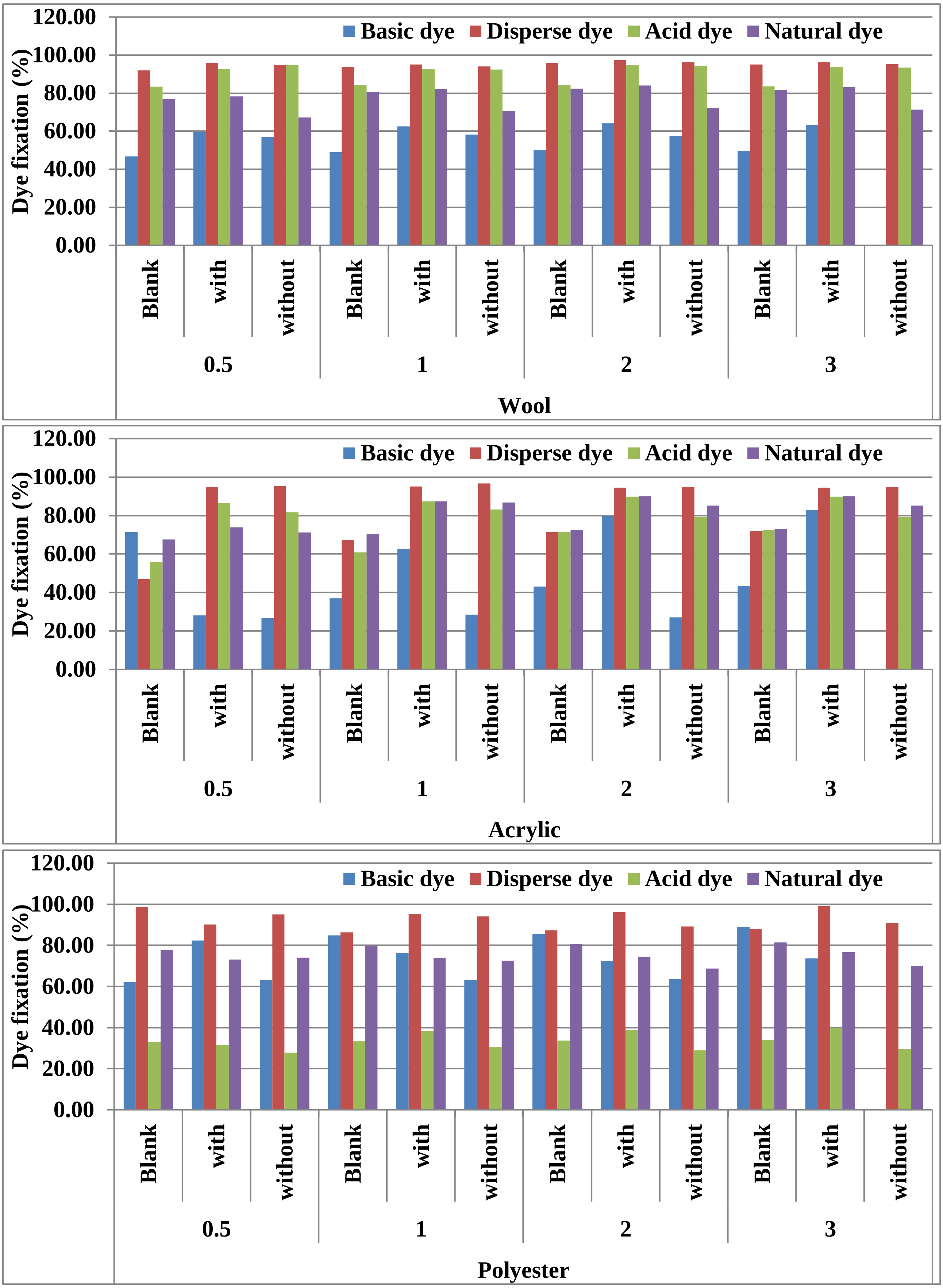


Figure 9. Dye fixation (%) of treated dyed fabric with dye concentration in the presence and absence of citric acid.

3.5. Effect of dye concentration.

The color strength (K/S) of all fabrics treated with pectin increases by increasing dye concentration from 0.5 g/l up to 3 g/l. The optimal dye concentration is 0.5 g/l, based on the previous results because the rise in K/S as a result of increasing the dye concentration from 0.5 g/l to 3 g/l is quite small. To minimize pollution and rationalize consumption while getting excellent color shades, the objective is to use less dye, chemicals, and other ingredients in the dyeing bath by treating fabrics with biopolymer (pectin) that increases dyeability.

Table 7, Figure 8, and Figure 9 present the color strength (K/S) values for the dyed treated fabrics with pectin using (basic, dispersed, acid and natural) dyes at different dye concentrations from 0.5 g/l up to 3 g/l.

From Table 7, Figure 8, and Figure 9, the K/S of wool-treated fabrics with pectin is (13.87) for basic dye, (13.92) for disperse dye (16.47) for mint dye, and (28.07) for acid dye with RUI value (0.321) for basic, disperse and natural (mint) that means a good rate of levelness of dyeing and (0.121) for acid dye, that means an Excellent rate of levelness of dyeing.

The K/S of polyacrylic fabrics treated with pectin is (10.23) for basic dye, (25.99) for dispersed dye (3.31) for acid dye, and (11.57) for natural (mint) dye with RUI value (0.321) for basic, (0.311) for disperse, (0.321) for acid and (0.311) for natural (mint) dye that means a good rate of levelness of dyeing.

The K/S of polyester fabrics treated with pectin is (8.44) for basic dye, (22.22) for disperse dye (2.69) for acid dye, and (8.80) for mint dye with RUI value (0.311) for basic, (0.321) for dispersing, (0.321) for acid and (0.311) for natural (mint) dye that means a good rate of levelness of dyeing.

3.6. Characterization of treated dyed fabrics.

3.6.1. Colorfastness properties.

All treated dyed textiles (wool, acrylic, and polyester fabrics) were evaluated for color strength (K/S) and various fastness properties, such as light, washing, perspiration, and rubbing fastness, with different dyes nature (basic, acid disperse, and natural) for each fabric and the results were listed in Table 8.

The light fastness of dyed textiles treated with pectin was outstanding (6), which is better than untreated (3 to 4). The washing ability of all textiles was satisfactory (4-5). Both acidic and alkaline sweat revealed 3-4 to 4-5 color variations in perspiration fastness. The colorfastness to rubbing was tested in both dry and wet conditions, and it was revealed that dry and wet rubbing had identical effects.

Furthermore, compared dyed blank fabrics treated with pectin offer exceptional color strength and fastness properties. In addition, dyed-treated polyester or acrylic textiles with dispersed dye provide excellent color strength and fastness properties to untreated ones, while dyed-treated wool fabric provides very good color value.

Depending on the dyeing condition of each fabric and its overall performance, pectin as a polymer (used in pretreatment) can be used to enhance the color performance of wool, acrylic, and polyester fabrics.

Table 8. Color strength (K/S) and fastness properties of different treated dyed fabrics using a different dye nature in the presence and absence of crosslinker.

Dye type	**Fabric**	**Cross linker**	**K/S**	**Fastness Properties**								
				Washing		**Rubbing**		**Perspiration**				**Light**
								Acidic		Alkaline		
				Alt.	St.	Dry	wet	Alt.	St.	Alt.	St.	
Basic Dye	Wool	Blank	2.88	3	3	3	3	3	3	3	3	3-4
		with	13.87	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		without	12.04	3	3	4	4-5	3	3-4	3-4	3	4-5
	Acrylic	Blank	6.17	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		with	10.23	4	4	3-4	4	3-4	3-4	3-4	3	5
		without	9.30	4	4	3-4	4	3-4	3-4	3-4	3	5
	Polyester	Blank	1.54	3	2-3	3	2-3	3	2-3	3	3	4
		with	7.52	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		without	8.44	4	3	3	3	3	3	3	3	6
Disperse Dye	Wool	Blank	4.93	2	2	2	2	2-3	2-3	2	2	3-4
		with	13.92	4	3	3	3	3	3	3	3	4-5
		without	13.22	3-4	3	3	3-4	3-4	3	3	3	4
	Acrylic	Blank	0.54	2	2	2	2	2	2	2	2	4
		with	24.87	4-5	3-4	4	3-4	4	4	4	4	6
		without	25.99	4-5	4	4-5	4-5	4-5	4-5	4-5	4-5	6
	Polyester	Blank	10.79	4	3	3	3	3	3	3	3	6
		with	22.22	4-5	3-4	4	3-4	4	4	4	4	6
		without	22.03	4-5	4	4-5	4-5	4-5	4-5	4-5	4-5	6
Acid Dye	Wool	Blank	4.79	4	3	3	3	3	3	3	3	6
		with	28.07	4-5	4	4-5	4-5	4-5	4-5	4-5	4-5	6
		without	25.37	4-5	3-4	4	3-4	4	4	4	4	6
	Acrylic	Blank	0.52	2	2	2	2	2	2	2	2	2-3
		with	3.31	3-4	3	3	3-4	3-4	3	3	3	4
		without	3.09	4	4	4	4	4	3-4	4	4	4-5
	Polyester	Blank	0.76	2	2	2	2	2-3	2-3	2	2	3-4
		with	2.69	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		without	2.50	3-4	3	3	3-4	3-4	3	3	3	4
Natural Dye	Wool	Blank	4.20	3	2-3	3	2-3	3	2-3	2-3	3	4
		with	16.47	4	4	3-4	3-4	3-4	4	3-4	3-4	5
		without	13.24	4	3-4	3-4	4	3-4	3-4	3-4	3	5
	Acrylic	Blank	2.41	2-3	2-3	3	3	3	2-3	3	3	3
		with	11.35	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		without	11.57	4	4	4	4	4	3-4	4	4	4-5
	Polyester	Blank	4.36	2	2	2	2	2	2	2	2	4-5
		with	8.68	4	4	3-4	3-4	3-4	3-4	4	4	4-5
		without	8.80	4	4	3-4	3-4	3-4	3-4	4	4	4-5

Treatment condition: Pectin (3 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4 with acid and natural dye for wool, pH 6 with basic and disperse dyes for wool fabrics and pH, dyeing time:(30, 45 and 60) min, dyeing temperature: 80°C for wool with (acid, basic and natural dyes), 90°C for wool with disperse dye, drying at 100°C for 3 min, curing at 140°C for 3 min.

3.6.2. Mechanical and physical properties.

Tensile strength, elongation at break, bending length, crease recovery angle, and surface roughness of dyed treated fabrics have been studied, and the results are shown in Table 9, Figure 10 to Figure 12.

The presence of an anionic group in treated textile materials produces changes in physicomechanical characteristics, as seen in Table 9, Figure 10 to Figure 12. As seen by the results in Table 9, the pretreatment with pectin boosted the tensile strength and elongation at the break of the dyed treated fabrics. Rather than that, pectin aids in forming and modifying a thin film in the fabric's microstructure, which fills gaps on the fabric's surface and enhances both tensile strength and elongation at break [51-54].

According to the findings in Figure 11, dyed-treated fabrics with pectin had a better bending length than blank-dyed-treated fabrics. According to these investigations, the employment of a polymer (pectin) in the pretreatment of various textiles has shown a slightly increasing in the stiffness of all examined fabrics with all dye's nature.

Further investigation into the angle of crease recovery of dyed treated fabrics in both directions (warp and weft) revealed that all dyed treated fabrics have higher crease recovery angles than blank dyed fabrics. These findings show that the pretreatment with pectin enhances the dyed fabric's angle of crease recovery.

The influence of citric acid catalyzed by sodium hypophosphite (SHP) in the pre-crosslinking treatment of wool, acrylic, and/or polyester fabrics on the performance of the evaluated properties was also noteworthy. Covalent crosslinking linkages between neighboring chains would develop during this pretreatment, providing the fabric structure stiffness.

Table 9. Physical and mechanical properties of different treated dyed fabrics using a different dyes nature in the presence and absence of crosslinker.

Dye type	Fabric	Cross linker	Physical and Mechanical properties					
			Tensile Strength (N/mm^2)	Changing in Tensile Strength (%)	Elongation at a break (%)	Bending Length (cm)	Crease Recovery Angle (warp + weft) (°)	Surface Roughness
Basic Dye	Wool	Blank	17.45	--	8.10	3.42	137.28	15.28
		with	18.79	7.67	10.34	3.76	162.89	15.03
		without	17.98	3.04	9.84	3.63	153.05	14.19
	Acrylic	Blank	26.22	--	15.03	2.97	209.64	18.00
		with	27.46	4.74	17.63	3.21	214.88	17.22
		without	27.80	6.03	17.74	3.21	212.79	17.22
	Polyester	Blank	20.28	--	9.95	3.01	183.28	15.39
		with	21.34	5.24	12.17	3.15	187.85	14.71
		without	21.63	6.67	12.26	3.22	186.96	14.71
Disperse Dye	Wool	Blank	17.87	--	8.29	3.50	140.51	15.64
		with	19.24	7.67	10.58	3.85	166.73	15.39
		without	18.41	3.04	10.07	3.71	156.65	14.53
	Acrylic	Blank	24.43	--	14.01	2.76	195.38	16.78
		with	25.59	4.74	16.43	2.99	200.26	16.05
		without	25.91	6.03	16.53	2.99	198.31	16.05
	Polyester	Blank	22.12	--	10.85	3.29	199.87	16.78
		with	23.27	5.24	13.27	3.44	204.86	16.05
		without	23.59	6.67	13.37	3.51	203.88	16.05
Acid Dye	Wool	Blank	20.42	--	9.48	4.01	160.59	17.88
		with	21.49	5.26	11.82	4.30	186.29	17.19
		without	21.78	6.70	11.92	4.40	185.39	17.19
	Acrylic	Blank	16.98	--	9.73	1.92	135.79	11.66
		with	17.79	4.74	11.42	2.08	139.18	11.15
		without	18.00	6.03	11.49	2.08	137.83	11.15
	Polyester	Blank	15.37	--	7.54	2.28	138.91	11.66
		with	16.18	5.24	9.22	2.39	142.37	11.15
		without	16.39	6.67	9.30	2.44	141.70	11.15
	Wool	Blank	11.63	--	15.34	3.91	157.71	14.56

Dye type	Fabric	Cross linker	Physical and Mechanical properties					
			Tensile Strength (N/mm^2)	Changing in Tensile Strength (%)	Elongation at a break (%)	Bending Length (cm)	Crease Recovery Angle (warp + weft) (°)	Surface Roughness
		with	12.72	9.40	15.83	4.01	159.26	14.46
		without	12.18	4.70	15.58	3.96	158.49	14.51
	Acrylic	Blank	22.54	--	12.92	2.55	180.27	15.48
Natural Dye		with	23.61	4.74	15.16	2.76	184.78	14.80
		without	23.08	2.37	14.04	2.65	182.52	15.14
	Polyester	Blank	19.25	--	9.44	2.86	174.02	14.61
		with	20.26	5.24	11.55	2.99	178.36	13.97
		without	19.76	2.62	10.50	2.93	176.19	14.29

Treatment condition: Pectin (3 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4 with acid and natural dye for wool, pH 6 with basic and disperse dyes for wool fabrics and pH, dyeing time:(30, 45 and 60) min, dyeing temperature: 80°C for wool with (acid, basic and natural dyes), 90°C for wool with disperse dye, drying at 100°C for 3 min, curing at 140°C for 3 min.

3.6.3. Antimicrobial activity of printed fabrics**.**

Pectin is a biopolymer with good biological activity, including antibacterial and antifungal properties. It has been proven that when the pectin percentage increase, the rate of bacterial growth decreases.

Table 10, Figure 13, and Figure 14 depict the antimicrobial effects of wool, acrylic, and polyester fabrics treated with pectin and dyed with four different dye natures (acid, basic, disperse, and natural (mint extract)) on three different microorganisms (i) gram-positive (*Staphylococcus aureus*), (ii) gram-negative (*Escherichia coli*), and (iii) fungal (*Candida albicans*).

The results show that both types of bacteria (gram-positive and negative bacteria) and fungus (Candida albicans) had a greater inhibitory influence on dyed treated textile materials than dyed blank textile materials. This action is caused by the presence of anionic groups in pectin, cationic groups in the dye, as well as phenolic acids and flavonoid compounds in natural dye extract.

The treated textiles are more effective against gram-negative bacteria than gram-positive bacteria because the cell walls of both tested bacterial strains differ in composition. Ergosterol, a crucial component of the fungal cell membrane, is likewise blocked by the polycations used [55-61].

Pectin-treated textiles have a greater antibacterial effect than untreated textiles. This is due to the presence of many carboxyl groups, which damage microbial cell membranes while also having a strong antibacterial effect [47,51].

Metals, phenolic acids, and flavonoids included in natural coloring extract (mint extract) have successfully interacted with the bacterium's cells. The pectin polymers in the cover disseminate and stable the extract dyes' components (metals, phenolic acids, and flavonoids) well on the fabric surface, reducing their ability to interact with microorganisms [62-65].

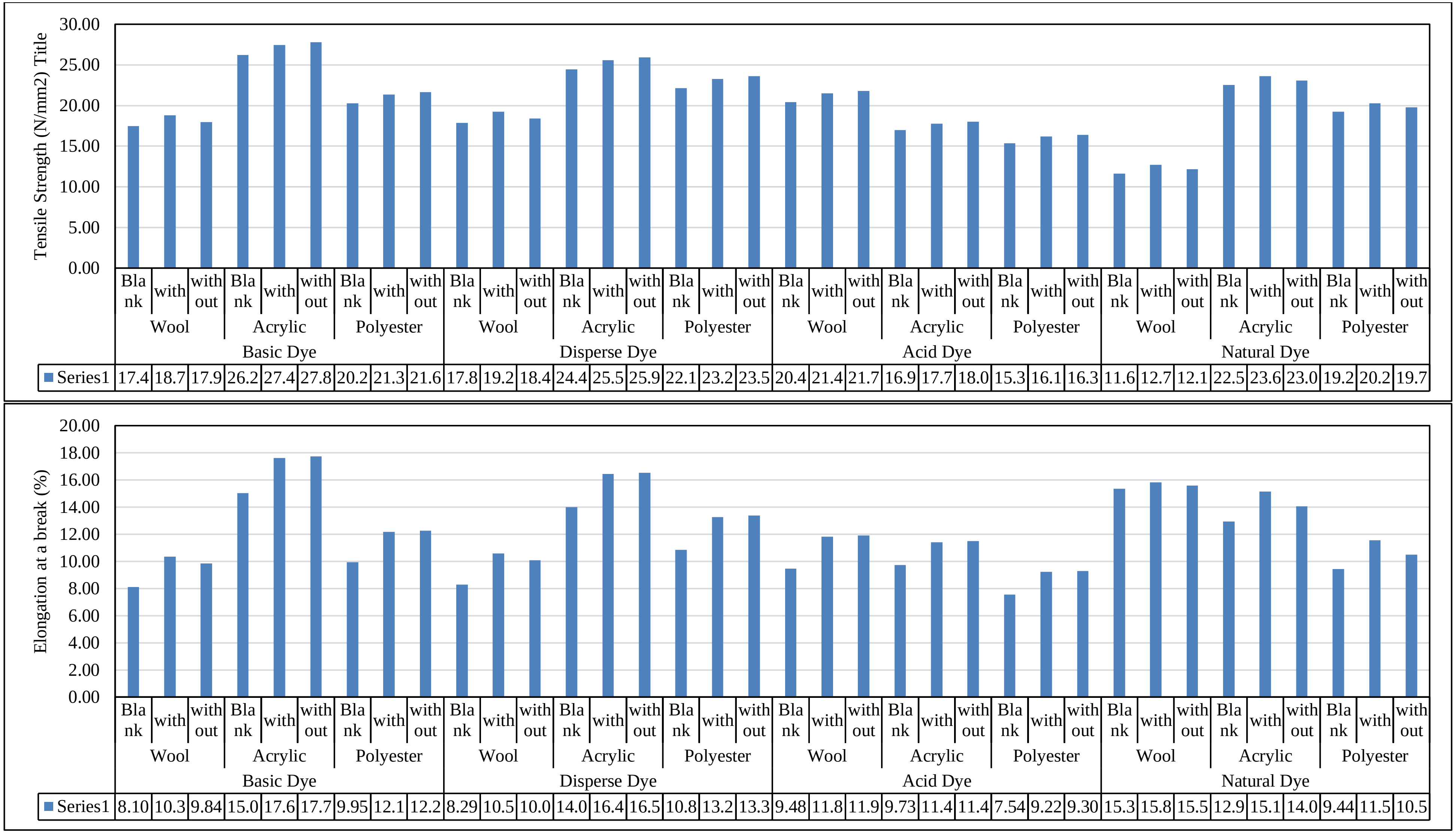


Figure 10. Tensile strength and elongation at a break of different treated dyed fabrics using a different dyes nature in the presence and absence of crosslinker.

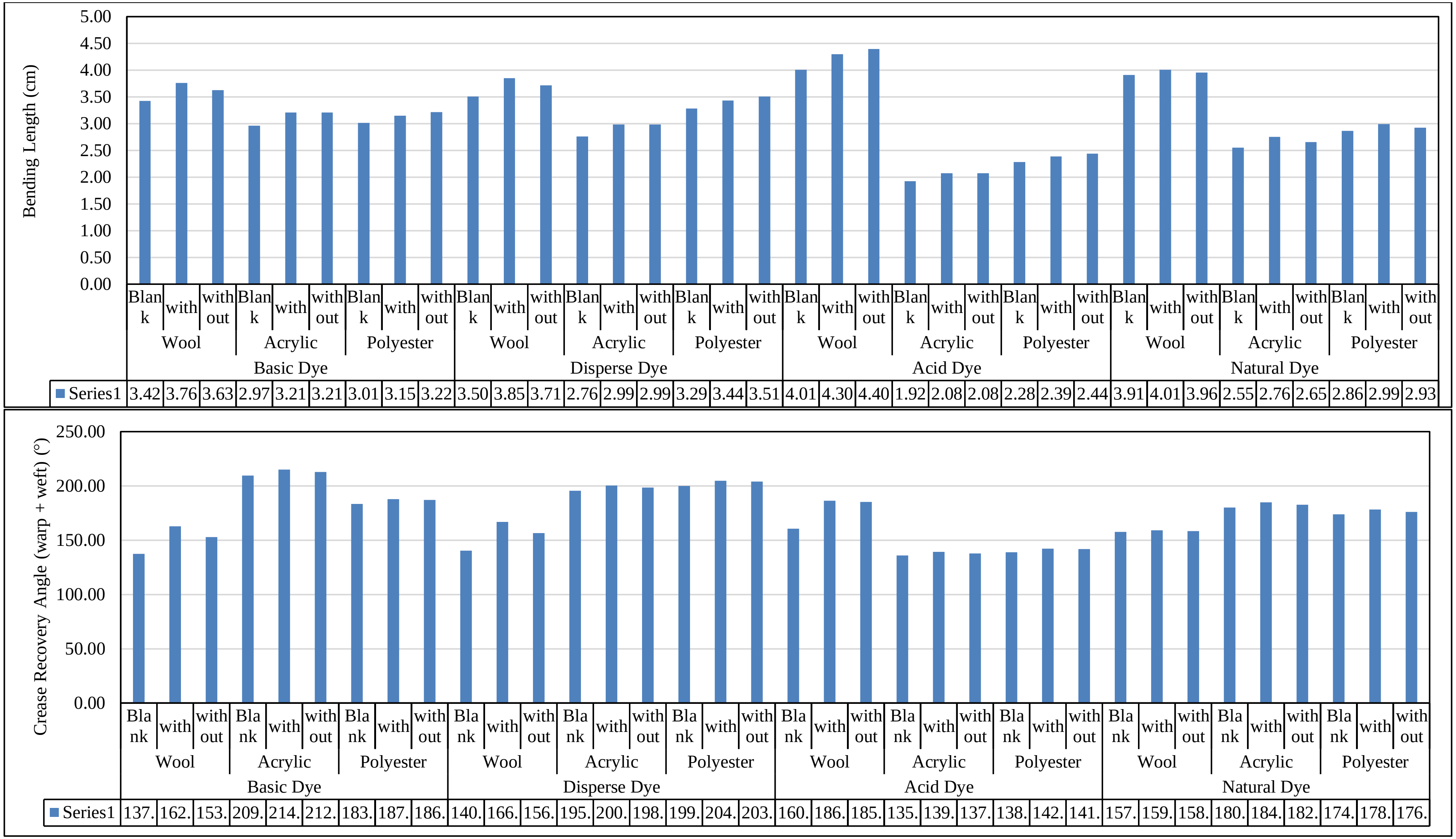
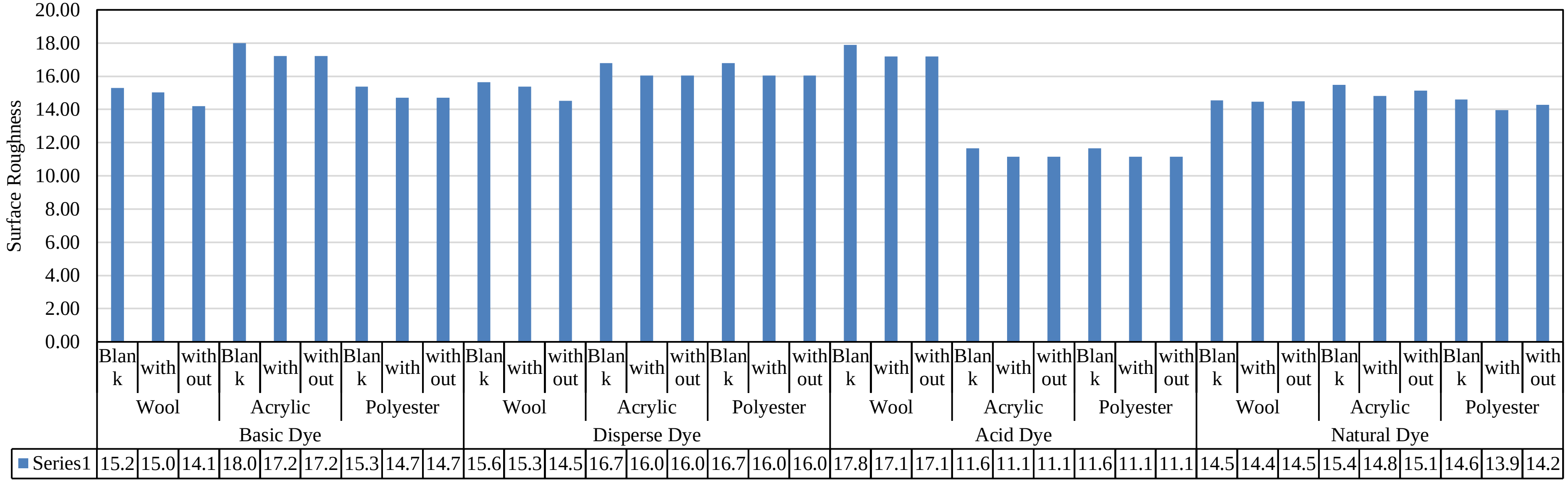


Figure 11. Bending length and crease recovery angle of different treated dyed fabrics using a different dyes nature in the presence and absence of crosslinker.



Dye	Fabric	Blank	with	without
Basic Dye	Wool	15.2	15.0	14.1
Basic Dye	Acrylic	18.0	17.2	17.2
Basic Dye	Polyester	15.3	14.7	14.7
Disperse Dye	Wool	15.6	15.3	14.5
Disperse Dye	Acrylic	16.7	16.0	16.0
Disperse Dye	Polyester	16.7	16.0	16.0
Acid Dye	Wool	17.8	17.1	17.1
Acid Dye	Acrylic	11.6	11.1	11.1
Acid Dye	Polyester	11.6	11.1	11.1
Natural Dye	Wool	14.5	14.4	14.5
Natural Dye	Acrylic	15.4	14.8	15.1
Natural Dye	Polyester	14.6	13.9	14.2

Figure 12. Surface roughness of different treated dyed fabrics using a different dyes nature in the presence and absence of crosslinker.

Furthermore, treated and colored textile materials have better antibacterial properties than untreated textile fabrics before and after washing. The treated fabrics' durability provides strong antibacterial activity against all pathogens tested after 10 washing.

Table 10. Microbial reduction % of different treated dyed fabrics using a different dyes nature in the presence and absence of crosslinker before and after 10 washing cycles

Dye type	**Fabric**	**Cross linker**	**Microbial reduction %**					
			***E. coli* (ATCC 25922)**		***S. aureus* (ATCC 29213)**		***C. albicans* (ATCC 10231)**	
			Before washing	**After washing**	**Before washing**	**After washing**	**Before washing**	**After washing**
Basic Dye	Wool	Blank	53.95	49.32	60.27	42.98	46.42	39.70
		with	66.83	63.30	69.63	59.38	60.62	52.43
		without	75.36	72.64	77.61	69.95	74.98	60.80
	Acrylic	Blank	66.80	60.49	53.45	38.12	48.84	43.59
		with	76.63	70.01	60.38	51.49	62.31	53.03
		without	91.39	81.96	67.23	60.59	76.43	62.18
	Polyester	Blank	56.66	51.61	45.83	40.55	41.74	40.00
		with	65.00	61.68	51.77	47.44	53.25	47.44
		without	77.12	69.87	57.79	45.23	65.32	50.76
Disperse Dye	Wool	Blank	55.22	50.48	61.69	43.99	47.52	40.64
		with	68.40	64.79	71.27	60.78	62.05	53.67
		without	77.14	74.35	79.44	71.59	76.74	62.23
	Acrylic	Blank	62.25	56.37	49.81	35.53	45.51	40.62
		with	71.42	65.25	56.27	47.99	58.07	49.42
		without	85.17	76.38	62.65	56.46	71.23	57.95
	Polyester	Blank	61.79	56.28	49.98	44.22	45.51	43.62
		with	70.88	67.26	56.45	51.73	58.07	51.74
		without	84.10	76.19	63.02	49.32	71.23	55.36
Acid Dye	Wool	Blank	63.11	57.70	70.50	50.28	54.31	46.44
		with	76.42	72.39	79.63	67.91	69.33	59.96
		without	91.29	87.99	94.01	84.73	90.82	73.65
	Acrylic	Blank	43.27	39.18	34.62	24.69	31.63	28.23
		with	49.63	45.35	39.11	33.35	40.36	34.35
		without	59.19	53.09	43.54	39.24	49.51	40.28
	Polyester	Blank	42.94	39.11	34.73	30.73	31.63	30.31
		with	49.26	46.75	39.24	35.96	40.36	35.96
		without	58.45	52.95	43.80	34.28	49.51	38.47
Natural Dye	Wool	Blank	45.83	41.89	81.95	63.26	77.60	52.58
		with	52.86	50.07	84.39	64.60	78.66	57.33
		without	49.34	47.56	83.17	63.93	78.13	55.75
	Acrylic	Blank	57.44	52.01	45.96	32.78	42.00	37.48
		with	65.89	60.20	51.92	44.28	53.58	45.60
		without	61.67	56.11	48.94	38.53	47.79	41.54
	Polyester	Blank	53.79	49.00	43.51	38.50	39.63	37.97
		with	61.72	58.56	49.15	45.04	50.56	45.05
		without	57.76	53.78	46.33	41.77	45.09	41.51

Treatment condition: Pectin (3 %), citric acid 10 g/L, sodium hypophosphite (SHP) 5 g/L, drying at 80°C for 10 min.

Dyeing condition: dye conc.: 0.5 g/L (Basic, Disperse, and Acid dye) (λ = 590) and extract of mint leaves as 125g leaves /L water (λ= 305), pH 4 with acid and natural dye for wool, pH 6 with basic and disperse dyes for wool fabrics and pH, dyeing time:(30, 45 and 60) min, dyeing temperature: 80°C for wool with (acid, basic and natural dyes), 90°C for wool with disperse dye, drying at 100°C for 3 min, curing at 140°C for 3 min.

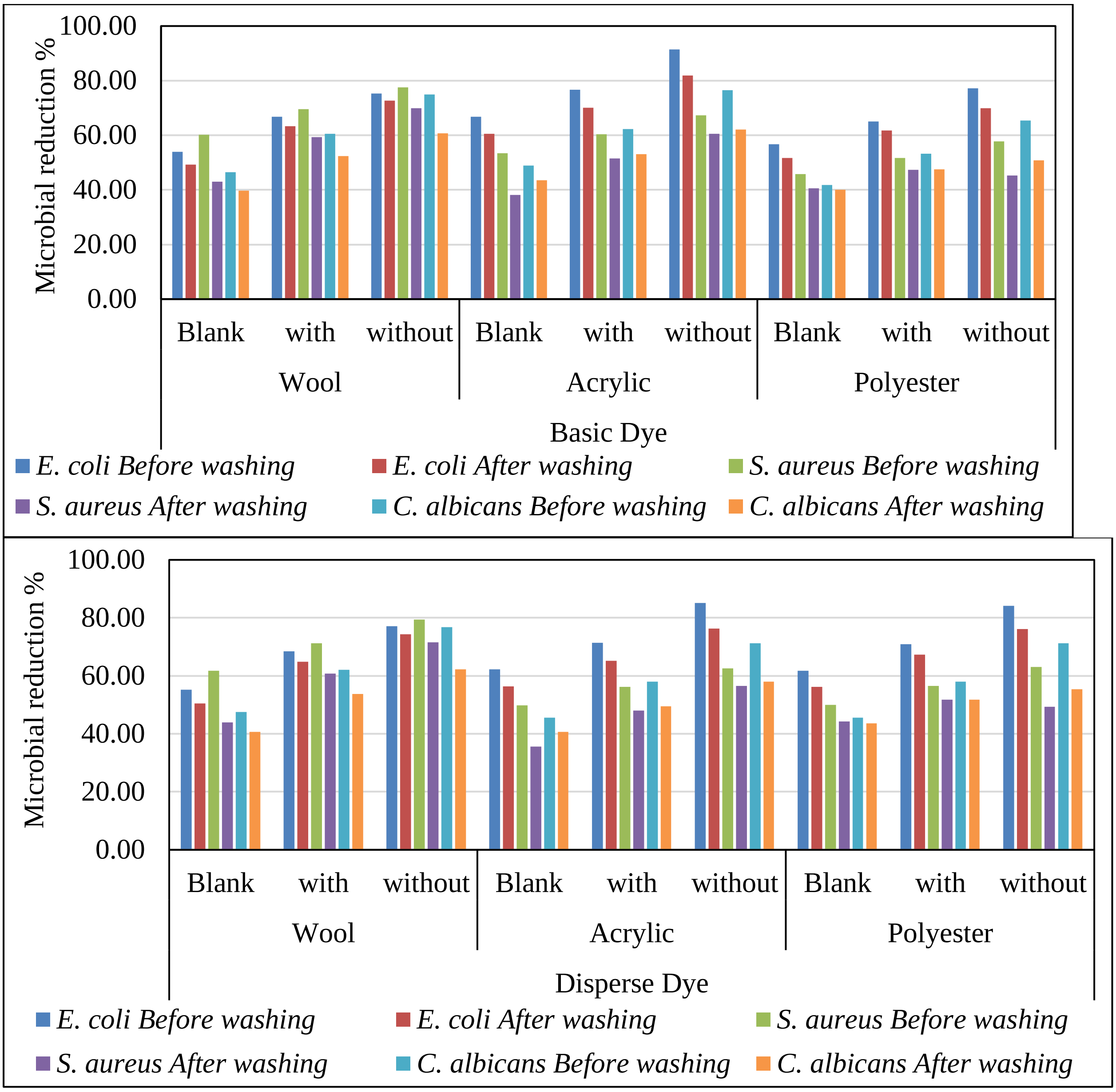
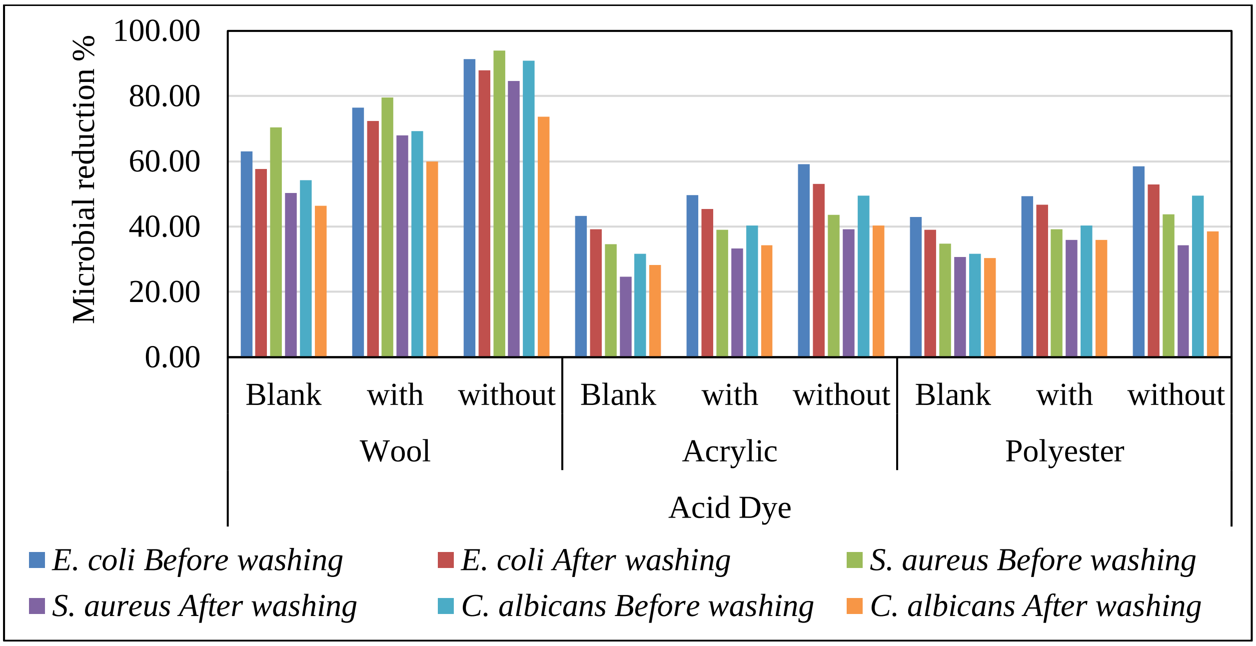


Figure 13. Microbial reduction % of different treated dyed fabrics using basic and dispersed dyes in the presence and absence of crosslinker before and after 10 washing cycles



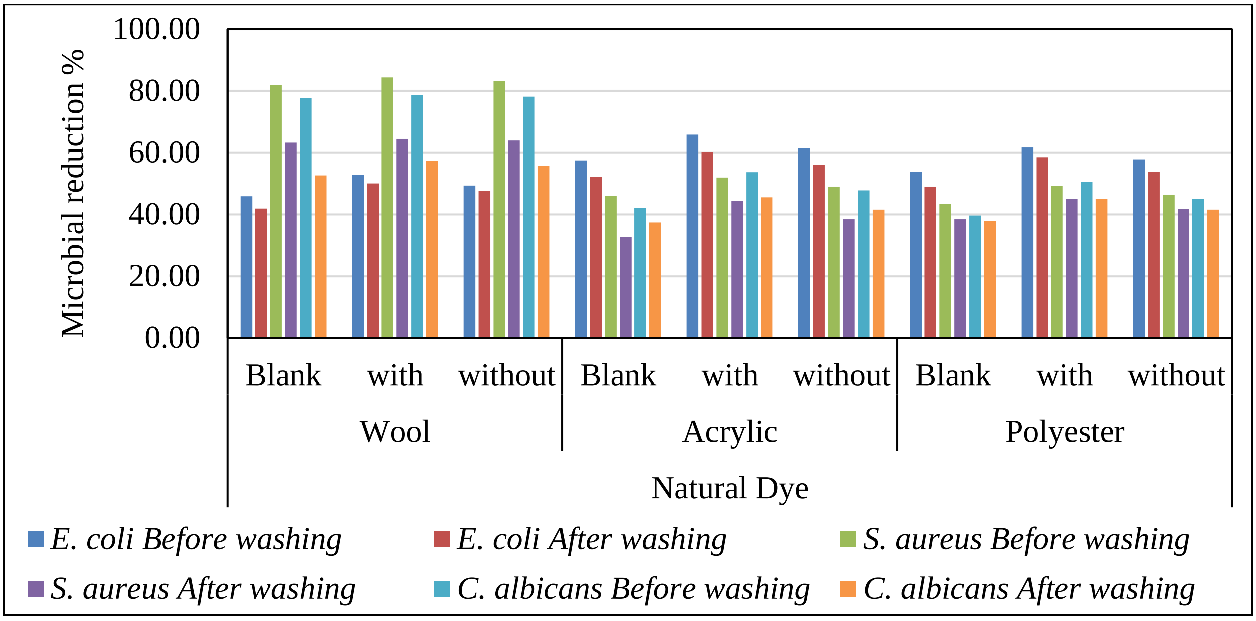


Figure 14: Microbial reduction % of different treated dyed fabrics using acid and natural dyes in the presence and absence of crosslinker before and after 10 washing cycles

4. Conclusions

As a result of the growing focus on sustainable development and environmental concerns, the textile industry has attempted to use renewable resources several times, including biopolymers. Natural polymers are gaining popularity year after year and considerably enhance textile products' environmental aspects and sustainability. These polymers have several attractive properties, including biocompatibility, biodegradability, nontoxicity, and high biological activity.

In this study, materials such as wool, polyester, and acrylic were treated with various concentrations of anionic biopolymer as pectin before being dyed with four distinct dye types (basic, acid, disperse, and natural). The ideal dyeing conditions were (polymer concentration 3%; 80°C; 45 minutes; L: R 1:50) with pH 4 for wool with acid and natural dye, pH 6 for polyester with basic and dispersed dye, and pH 8 for polyacrylic with basic and disperse dye. The color strength of dyed treated textiles (K/S), mechanical and physical characteristics, and antibacterial impact of treated dyed fabrics against various bacteria and fungi have all been enhanced.

This treatment is very effective for dyeing since it uses less energy, water, and chemicals and has fewer environmental dangers.

As the environmental elements of production gain greater attention worldwide, biopolymers may be used to replace a wide range of chemicals used in the dyeing process.

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Conflict of interest

The authors declare that there is no conflict of interest

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