Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Enhancement of Dyeing and Antimicrobial Properties of Chitosan and Chitosan Nanoparticles-Treated Cotton and Viscose Fabrics with Acid Dyes

Fatma A. Mohamed [1], Maysa M. Reda [2] and Hassan Ibrahim[3*]

[1] *Textile Research and Technology Institute, National Research Centre, 33 El Bohouth st., Dokki, Cairo, Egypt, P.O.12622.*
[2] *High institute of applied arts, the 5thP District, Cairo, Egypt*
[3] *Pretreatment and Finishing of Cellulosic Fibers Dept., Textile Research and Technology Institute, National Research Centre, 33 El Bohouth st., Dokki, Cairo, Egypt, P.O.12622.*

Abstract

Two commercial acid dyes, Acid Orange 142 (E1) and Acid Violet 90 (E2), were applied to cotton and viscose fabrics treated with 3, 6 percent concentrations of chitosan and chitosan nanoparticles to impart absorption and antibacterial capabilities. The effect of chitosan and chitosan nanoparticles on the dyeing properties of cotton and viscose was investigated by measuring the colour strength expressed in K/S values of the treated substrates at various chitosan and dye concentrations. The results showed that fabrics treated with chitosan nanoparticles exhibited higher dye uptake and exhaustion than untreated fibres and fabrics treated with chitosan nanoparticles. Furthermore, the higher concentration of chitosan nanoparticles (6%) causes more tiredness than the lower dosage (3%). The antibacterial activity of fabrics treated with chitosan and chitosan nanoparticles is higher than that of untreated fabrics, indicating that chitosan nanoparticles treatment has the best antimicrobial properties. The rubbing, washing, and perspiration fastness properties of dyed cotton and viscose fabrics, as well as pre-treated fabric with chitosan nanoparticles and chitosan, were all tested, and the results revealed that all of the aforementioned dyes are excellent to good, and salt-free dyeing is both satisfactory. The colorimetric CIE L*a*b* C*h data of dyed cotton and viscose were also analyzed, and good results were found.
Keywords dyeability; cotton; viscose; chitosan nanoparticles; antimicrobial; acid dyes

1. Introduction

The use of an acid in the dye solution leads to the naming of the acid dye. It is typically a sodium salt of sulfonic acid or anionic carboxylic acid that converts to an anion in solution. The cationic part in fibers will be dyed with acid dyes [1]. Cationic fabrics such as wool, silk and nylon is substituted with ammonium ion groups and will be absorbed by this fiber [2-4]. The amino group in the fibres will be protonated by the acid, resulting in cationic fibres. An ammonium ion-associated anion is exchanged with a dye anion in the dye bath during the dyeing process from fibre to fibre. [5-7].

Cotton fabrics are hydrophilic fabrics whose structures are cellulose polymers with varying degrees of polymerization (DP). Cellulose's primary -OH group is the afunctional group that bonds with the dyestuff. [8-10]. Cotton fabrics are made of a natural linear polymer that contains a cellobiose repeating unit. Because of its unique properties such as softness, breathableness, and wear comfort, it is very popular among other natural fabrics. [11]. However, this has low UV protection, is hygroscopic, and nonconductive, which limits its use without modification [12-16]. Cotton fabrics with three hydroxyl groups on their structure can form a partial negative charge on their surface in an aqueous medium [10]. Furthermore carboxymethylated cotton was treated with zinc oxide nanoparticles it improve its dyeability and antimicrobial activity, before dyeing it with synthesised acid and basic dyes. [17]. In the absence of an electrolyte in the dyebath, such treated cotton would be dyeable with acid dyes under neutral or mildly acidic conditions [18, 19].

Chitosan is commonly used in the textile industry to provide antimicrobial properties, enhance dyeing functionality, and prepare beneficial fibres. [20]. Chitosan is a deacetylated derivative of chitin found in crab and shrimp shells. It is biodegradable, non-toxic, antimicrobial, and antioxidant. [21-23].

*Corresponding author e-mail: hmaibrahim@gmail.com.; (Hassan Ibrahim).
Receive Date: 26 April 2022, **Revise Date:** 08 May 2022, **Accept Date:** 16 May 2022, **First Publish Date:** 16 May 2022
DOI: 10.21608/EJCHEM.2022.136042.5989

The antimicrobial properties of the treated fabrics were discovered, and the chitosan treatment was found to enhance the antimicrobial properties of the dyes [24, 25]. Chitosan films have been tested in the medical field as wound dressings that are curative as well as scaffolds for tissue and bone engineering procedures. [26, 27]. The reactive functional groups in chitosan (amino groups at the C2 position of each deacetylated unit, and hydroxyl groups at the C6 and C3 positions) are also easy to derivatize, allowing for the manipulation of mechanical and solubility properties in chitosan. [28, 29]. Cotton and viscose fabrics were dyed with chitosan nanoparticles. Finally, the treated fabrics' antibacterial and dyeing properties are evaluated. In this study, normal and nano-chitosan solutions were pre-treated on fabric samples. The surface morphology of treated cotton fabric was studied using SEM. [30].

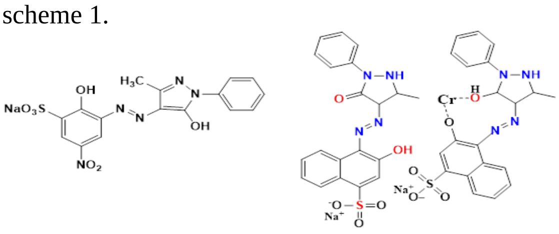
In the presentd study, cotton and viscose fabrics were treated with chitosan and chitosan nanoparticles to improve dyeability and antimicrobial activity, then dyed with commercial acid dyes. We measured the fastness properties of dyed cotton and viscose fabrics untreated and treated with chitosan. A comparison of untreated and treated fabrics was made.

2. Materials and Methods

2.1. Materials

Mill scoured and bleached cotton fabric (130 g/m^2; Misr El- Mahalla Co., Egypt) and viscose fabric (110 g/m^2 weight, 375/10 cm warp count and 320/10 cm weft count) werepurchased from Abou El-Ola Company for spinning and weaving, Egypt. Chitosan (Alfa Aesar Company, Medium molecular weight, viscosity 1860 cps, deacetylation 79.0%), Penta sodium tripolyphosphate (TPP). Sodium hydroxide (Modern Lab chemicals, Egypt). Acetic acid, methyl alcohol, and ethyl alcohol (Sisco Research Laboratories, India). All other chemicals used are of analytical grade and were not purified further.

Two commercial acid dyes were used as shown in scheme 1.



Scheme 1. Acid dyes structure E1; acid orange 142 and E2 acid violet 90

2.2. Methods

2.2.1. Preparation of chitosan nanoparticles

Chitosan nanoparticles were prepared based on the modified ionotropic gelation method [16].

2.2.2. Dyeing procedures:

During the dyeing process, the amount of acid dyes E1 and E2 (scheme 1) applied to treated cotton and viscose by chitosan nanoparticles 3,6 % and chitosan 3,6% at different temperatures (40, 60, and 80 °C) in an Ahiba dyeing machine without salt or alkaline medium, the dying bath at liquor ratio 40:1, and the dyeing bath at liquor ratio 40:1 were determined. After that, the temperature was raised to the fixation temperature at a rate of 2 degrees Celsius per minute, and the cotton and viscose fabrics were dried in the open air.

2.3 Measurements and Analysis

2.3.1. Dye Exhaustion

The uptake of acid dyes by cotton and viscose fabrics pretreated with chitosan and fabrics untreated was measured using a Shimadzu UV-2401PC UV/V spectrophotometer at the λ_{max} value using a calibration curve previously obtained using known dye concentrations (g/l). Eq. 1 was used to calculate the percentage of dyebath exhaustion (E %).

$$\%E = \left[1 - \frac{C2}{C1}\right] X\ 100 \qquad (1)$$

Where C1 and C2 are the dye concentrations in the dyebath before and after dyeing, respectively.

2.3.2 Color measurements:

Measurements were made with an Ultra Scan PRO spectrophotometer (Hunter Lab) equipped with a D65 illuminant and a 10° standard observer to determine the colour parameters of untreated dyed cotton and viscose, as well as cotton and viscose that had been treated with chitosan nanoparticles and chitosan, respectively. The corresponding K/S values were calculated based on the reflectance data collected during the peak of the dyeing procedure.

2.6.3. Fastness Testing:

Standard ISO methods were used to test dyed cotton and viscose fabrics that had been pretreated with chitosan and then washed off with 2 g/L nonionic detergents at 80°C for 15 minutes before being tested. Color change (AATCC Evaluation Procedure (EP) 1—which is similar to ISO 105-A02) and colour staining (AATCC EP 2—which is similar to ISO 105-A03) were all evaluated visually using the ISO Gray Scale for both colour change and colour staining (AATCC EP 2—which is the same as ISO 105-A03). Crock fastness (ISO 105-X12 (1987) and perspiration fastness (ISO 105-E The lightfastness of the material was determined using the ISO 105-B02 standard (carbon arc) [31, 32].

2.5. Evaluation of antibacterial activity in vitro:

2.5.1. Materials:

Staphylococcus aureus (S. aureus, ATCC 6538) as gram-positive bacteria and *Escherichia coli (E. coli*, ATCC 11229) as gram negative bacteria. Antifungal activity was evaluated against

(*Aspergillus Niger*, ATCC 13497) and (Candida, ATCC 10231). It was decided to use these bacterial and fungal strains as test cells because they are the most common microbes associated with wound infections. To prepare fresh inoculants for antibacterial testing, they were incubated at 37°C in nutrient broth for 24 hours.

2.5.2. Test method

The antimicrobial activity of treated and dyed fabrics were evaluated on an agar plate using the disc diffusion method [16].

3. Results and Discussion

3.1. effect of temperature

E1 and E2 were used on cotton and viscose fabrics that had not been treated or that had been treated with chitosan at concentrations 3 and 6% or chitosan nanoparticles concentrations 3 and 6%. Different temperatures (40, 60, and 80^{0}C) and a liquor-to-water ratio of 1:40 were used for dying.

The data showed that cotton and viscose that have been treated with chitosan nanoparticles are easier to dye than those that have not been treated. By using the standard method, the fabric that has been treated is dyed without salt or alkalinity. Figures 1, 2, 3, and 4 show how two dyes react at different temperatures with chitosan nanoparticles that have been treated with cotton or viscose or with chitosan that has not been treated. All the numbers showed that the fabrics that were treated with chitosan nanoparticles wore out faster than those that were treated with chitosan.

Also, all the numbers showed that fabrics that haven't been treated wear out the least. Figures 1 and 2 also showed why the exhaustion values for E1 were higher at 60 °C. They showed that the higher concentration of 6 % had a higher exhaustion than the lower concentration of 3 %. Also, figure 3,4 shows that E2 at a higher concentration of 6 percent than at a concentration of 3 percent of fabric treated with chitosan nanoparticles had a higher exhaustion at 80 0C because it was more planar and had a higher molecular weight than orange dye. This meant that the exhaustion was higher.

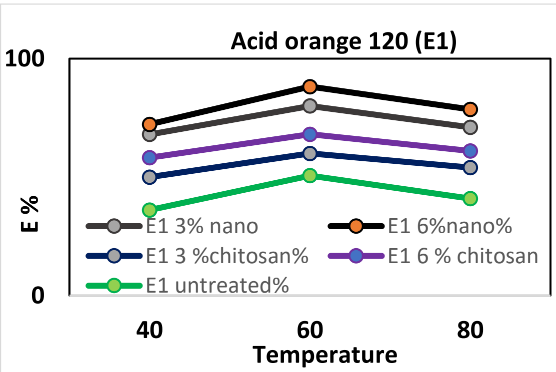


Fig. 1 Exhaustion of cotton treated by chitosan and chitosan nanoparticles and untreated fabric dyed with acid orange 120 (**E1**) at different temperature

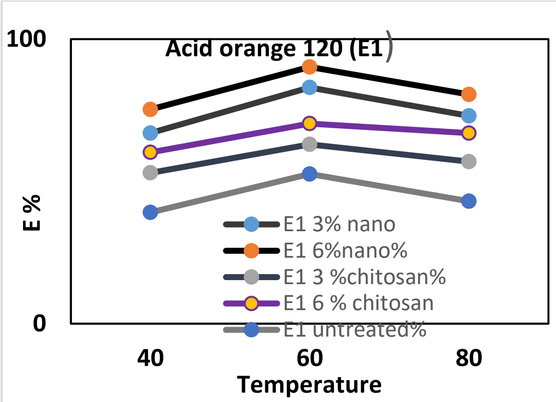


Fig. 2 Exhaustion of viscose treated by chitosan and chitosan nanoparticles and untreated fabric dyed with acid orange 142 (**E1**) at different temperature

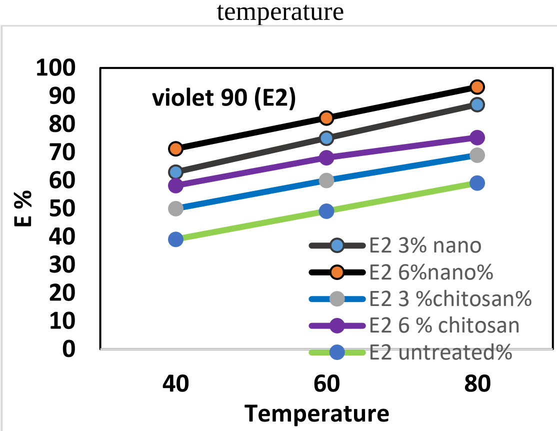


Fig. 3 Exhaustion of cotton treated with chitosan and chitosan nanoparticles and untreated fabric dyed with acid violet 90 (**E2**) at different temperatures

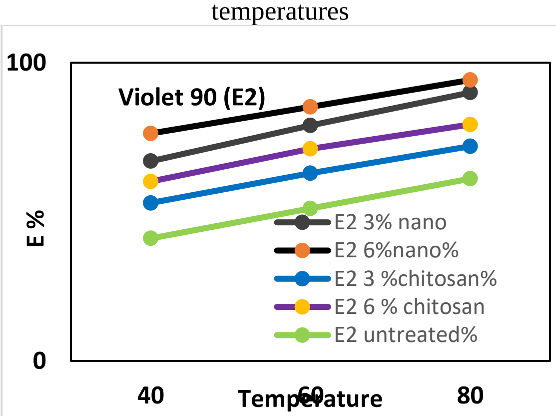


Fig. 4 Exhaustion of viscose treated by chitosan and chitosan nanoparticles and untreated fabric dyed with acid violet 90 at different temperature

3.2. Colorimetric and Fastness properties

The data show that dyed fabrics treated with chitosan or nano chitosan have good wash fastness ratings for staining adjacent fabrics and acceptable ratings for colour change. It should be noted that no colour change was observed; wash fastness was very good with a rating of 4–5, very good rubbing fastness in both dry and wet states was obtained with dry rubbing fastness as high as 4–5, and wet rubbing fastness in the range of 4-5; perspiration fastness properties (in both acidic and alkaline media) of dyed cotton and viscose samples in terms of ratings for staining of adjacent fabrics and change in colour were very good (Table 1).

Also, the K/S of dyed cotton and viscose that had been treated with chitosan nanoparticles and chitosan was shown in (Tables 2-5). The Cielab system and the modified CIE L* C* ho (D65/10o) system were used to measure the colour parameters. The digital Cielab system was used to get the following information about the samples that had been dyed: L* is the lightness, a* is the redness if the coordinate is positive, and b* is the yellowness if the coordinate is positive or the blueness if the coordinate is negative. C* is the color's chromaticity, h is its hue, X is its coordinate x, Y is its coordinate y, and Z is its coordinate z. (McDonald, 1997).

Table 1. Fastness properties of dyed cotton and viscose pretreated with chitosan nanoparticles and chitosan using acid orange 120 **E1** and Acid violet 90 **E2** (2% owf) at 80°C.

Fabrics	**Dye**	**Fastness to rubbing**		**Wash fastness**			**Fastness to Perspiration**						**Light**
							Alkaline			**Acidic**			
		Dry	**Wet**	**Alt**	**SC**	**SW**	**Alt**	**SC**	**SW**	**Alt**	**SC**	**SW**	
Cotton treated by nano chitosan	**E1**	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	5-6
	E2	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	5-6
Viscose treated by nano chitosan	**E1**	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	5-6
	E2	4-5	4-5	4-5	4-5	4-5	4	4	4	4-5	4-5	4-5	5-6
Cotton treated by chitosan	**E1**	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
Viscose treated by chitosan	**E2**	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5

Table 2. Colorimetric data of the dyed cotton **(C)** and viscose **(V)** fabrics using chitosan CS (3%,6%) and chitosan nanoparticles CSNP (3%,6%) using acid orange 142at 60 ◦C

Fabric	**treated**		**K/S**	**L***	**a***	**b***	**ΔE**	**C***	**h0**
C	**CSNP**	**3%**	1.74	65.67	17.84	21.84	16.64	28.20	50.76
		6%	2.81	59.08	24.33	23.60	24.87	33.89	44.12
	CS	**3%**	1.06	67.71	13.30	12.94	7.42	18.56	44.21
		6%	0.67	71.20	7.93	5.10	4.95	9.43	32.73
V	**CSNP**	**3%**	1.30	68.61	23.14	16.13	4.66	28.21	34.88
		6%	1.65	65.07	26.46	16.57	9.34	31.22	32.05
	CS	**3%**	0.51	77.23	15.36	7.95	12.03	17.30	27.36
		6%	0.48	76.70	11.35	4.41	16.48	12.17	21.22

Table 3. Colorimetric data of the dyed cotton **(C)** and viscose **(V)** fabrics using chitosan CS (3%,6%) and chitosan nanoparticles CSNP (3%,6%) using acid orange 142 at 80 ◦C

Fabric	**treated**		**K/S**	**L***	**a***	**b***	**ΔE**	**C***	**h^0**
C	**CSNP**	**3%**	1.61	65.57	16.08	19.87	14.29	25.56	51.01
		6%	1.85	63.53	18.85	20.57	17.35	27.90	47.50
	CS	**3%**	1.05	66.75	12.67	10.73	7.06	16.60	40.2
		6%	0.78	66.20	11.93	5.10	٨.95	١٣.43	3٧.73
V	**CSNP**	**3%**	1	72.34	19.25	16.73	1.29	25.50	41.00
		6%	1.17	70.08	21.72	17.57	2.41	27.94	38.97
	CS	**3%**	0.44	77.93	13.65	7.04	13.77	15.36	27.30
		6%	0.40.	77.77	12.54	3.47	17.04	13.01	15.47

Table 4. Colorimetric data of the dyed cotton **(C)** and viscose **(v)** fabrics using chitosan CS (3%,6%) and chitosan nanoparticles CSNP (3%,6%) using acid violet 90 at 60 ◦C

Fabric	**treated**		**K/S**	**L***	**a***	**b***	**ΔE**	**C***	**h^0**
C	**CSNP**	**3%**	0.94	63.33	12.99	-5.62	4.51	14.15	336.58
		6%	0.68	66.92	9.97	-4.47	3.62	10.93	335.83
	CS	**3%**	0.62	68.27	9.78	-5.07	3.37	11.02	332.59
		6%	0.35	73.46	4.57	-7.19	9.76	8.52	302.41
V	**CSNP**	**3%**	2.71	51.29	26.67	-5.38	21.74	27.21	348.60
		6%	2.93	59.58	18.01	-6.10	9.83	19.01	341.28
	CS	**3%**	1.32	49.57	25.53	-4.96	22.40	26.01	349.01
		6%	0.49	70.35	7.31	-7.15	5.75	10.23	315.63

Table 5. Colorimetric data of the dyed cotton **(C)** and viscose **(V)** fabrics using chitosan CS (3%,6%) and chitosan nanoparticles CSNP (3%,6%) using acid violet 90 at 80 ˚C

Fabric	treated		K/S	L*	a*	b*	ΔE	C*	h⁰
C	CSNP	3%	0.24	78.88	9.25	-10.67	12.28	14.12	310.93
		6%	0.42	73.97	14.56	-11.12	7.90	18.32	322.63
	CS	3%	1.26	61.44	23.40	-10.51	13.08	25.66	335.81
		6%	0.23	79.19	8.88	-12.47	13.27	15.31	305.45
V	CSNP	3%	0.78	67.33	18.86	-7.06	6.56	20.14	339.46
		6%	1.31	60.46	21.23	-5.48	11.50	21.93	345.53
	CS	3%	0.50	72.33	15.86	-9.88	6.57	18.69	328.10
		6%	0.26	78.20	10.45	-12.53	12.10	16.32	309.84

3.2. Antimicrobial Activity:

Figures 5 and 6 show that when chitosan and chitosan nanoparticles are added to cotton and viscose fabrics, they make them less likely to grow bacteria. Four strains of bacteria and fungi were used to test how well chitosan, chitosan nanoparticles, and the two acid dyes killed bacteria (orange acid 120 and violet acid 90). Figures 5 and 6 show that changing the strains of bacteria and fungi changes the antimicrobial activity. Figures 5 and 6 show that the rate of the inhibition zone goes up as the amount of chitosan and chitosan nanoparticles goes up. The amount of growth depends on the types of bacteria and fungus that are present. The size of the area where bacteria and fungi can't grow is one way to measure antimicrobial activity. The amino groups on chitosan nanoparticles stop bacteria from making mRNA by stacking up at the cell surface and interacting with DNA. . [33-35]. Increasing the concentration of chitosan nanoparticles makes it easier for dye molecules to stick to them. This is because more amino groups are available to the dye molecules [36, 37].

Due to the structure of bacterial cell walls, fabrics treated with chitosan are more effective against Gram-positive bacteria than Gram-negative bacteria. However, fabrics treated with chitosan nanoparticles are more effective against both Gram-positive and Gram-negative bacteria.

4. Conclusion

The dyeability of treated fabrics increased and was independent of dye concentration, and treated cotton and viscose fabrics with varying concentrations of chitosan impart fibre high antimicrobial effect with high growth reduction, as found in this study. Chitosan was introduced as a potential non-toxic bio-polymer for multifunctional finishing of cotton and viscose fabrics. In addition, treated fabrics were reduced in salt and alkalinity using traditional methods. It was discovered that treated fabrics have a higher K/S than untreated fabrics. Overall, Chitosan-poly (propylene imine) has the potential to be a novel efficient eco-friendly finishing compound for the multifunctional treatment of cotton and viscose fabrics

Acknowledgment

The authors gratefully acknowledge National Research Centre, for financial support for facilities provided through project ID: E120302

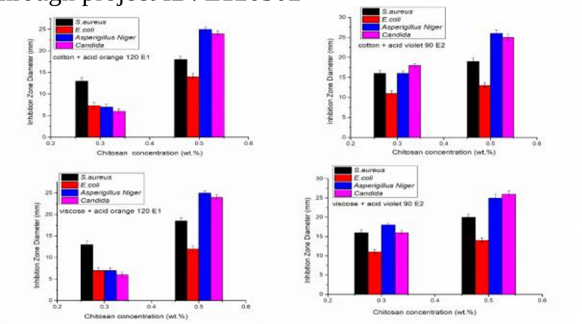


Fig. 5 Antimicrobial activity of dyed cotton and viscose fabrics with two acid dyes E1 and E 2 with various amounts of pretreated with chitosan concentrations

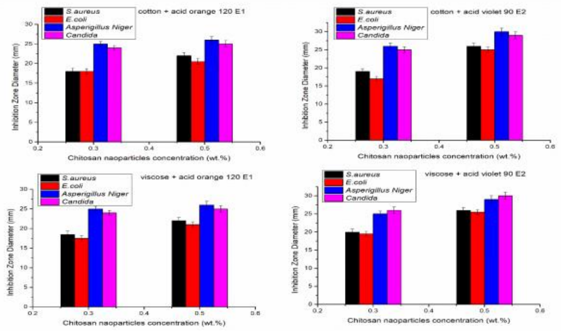


Fig. 6 Antimicrobial activity of dyed cotton and viscose fabrics with two acid dyes E1 and E2 with various amounts of pretreated with chitosan nanoparticles concentrations

5. References

1. Dos Santos, A.B., F.J. Cervantes, and J.B. Van Lier, *Review paper on current technologies for decolourisation of textile wastewaters: perspectives for anaerobic biotechnology.* Bioresource technology, 2007. **98**(12): p. 2369-2385.
2. Sun, J., et al., *Synthesis of some surfactant-type acid dyes and their low-temperature dyeing properties on wool fiber.* Journal of Cleaner Production, 2019. **218**: p. 284-293.
3. Khan, M.M.R., et al., *Physical properties and dyeability of silk fibers degummed with citric acid.* Bioresource technology, 2010. **101**(21): p. 8439-8445.
4. Burkinshaw, S.M. and Y.-A. Son, *The dyeing of supermicrofibre nylon with acid and vat dyes.* Dyes and Pigments, 2010. **87**(2): p. 132-138.

5. Hassan, M.M. and M. Bhagvandas, *Sustainable low liquor ratio dyeing of wool with acid dyes: Effect of auxiliaries on agglomeration of dye molecules in a dyebath and dyeing uniformity.* Journal of cleaner production, 2017. **152**: p. 464-473.
6. Patel, H.M. and B.C. Dixit, *Synthesis, characterization and dyeing assessment of novel acid azo dyes and mordent acid azo dyes based on 2-hydroxy-4-methoxybenzophenone-5-sulfonic acid on wool and silk fabrics.* Journal of Saudi Chemical Society, 2014. **18**(5): p. 507-512.
7. Mohamed, F.A., et al., *Synthesis, Application and Antimicrobial Activity of New Acid Dyes Based on 3-Amino-2-thioxo-4-thiazolidinone Nucleus on Wool and Silk Fabrics.* Current Organic Synthesis, 2022. **19**(1): p. 166-176.
8. Siddiqua, U.H., et al., *Relationship between structure and dyeing properties of reactive dyes for cotton dyeing.* Journal of Molecular Liquids, 2017. **241**: p. 839-844.
9. Mu, B., et al., *High sorption of reactive dyes onto cotton controlled by chemical potential gradient for reduction of dyeing effluents.* Journal of environmental management, 2019. **239**: p. 271-278.
10. Mohamed, F.A., S.A. Abd El-Megied, and R.M. Mohareb, *Synthesis and application of novel reactive dyes based on dimedone moiety.* Egyptian Journal of Chemistry, 2020. **63**(11): p. 4447-4455.
11. Mohamed, F.A., E. Shaban, and H.M. Ibrahim, *Synthesis and antibacterial activity of some novel nucleus N-aminorhodanine based bis monofunctional and bifunctional reactive dyes and their application on wool and cotton fabrics.* Egyptian Journal of Chemistry, 2022. **65**(2): p. 597-608.
12. Shahin, M., *The influence of cationization on the dyeing performance of cotton fabrics with direct dyes.* International Journal of Engineering Research and Applications, 2015. **5**(8): p. 62-70.
13. Park, S. and H.-M. Choi, *Microwave-Mediated Rapid Oxidation and Cationization of Cotton Cellulose.* Cellul. Chem. Technol, 2018. **52**: p. 311-322.
14. Ru, J., X. Qian, and Y. Wang, *Low-salt or salt-free dyeing of cotton fibers with reactive dyes using liposomes as dyeing/level-dyeing promotors.* Scientific Reports, 2018. **8**(1): p. 1-9.
15. Salama, R., H. Osman, and H.M. Ibrahim, *Preparation of biocompatible chitosan nanoparticles loaded with Aloe vera extract for use as a novel drug delivery mechanism to improve the antibacterial characteristics of cellulose-based fabrics.* Egyptian Journal of Chemistry, 2022. **65**(3): p. 581-595.
16. Ibrahim, H.M., M.M. Saad, and N.M. Aly, *Preparation of single layer nonwoven fabric treated with chitosan nanoparticles and its utilization in gas filtration.* International Journal of ChemTech Research, 2016. **9**(6): p. 1-16.
17. Mohamed, F.A., *Eco-friendly dyeing of wool and silk fabrics using mixed synthesized acid and natural dyes and antibacterial activity for the dyed fabrics.* Bioscience Research, 2018. **15**(3): p. 1480-1486.
18. Nallathambi, A. and G.D.V. Rengaswami, *Industrial scale salt-free reactive dyeing of cationized cotton fabric with different reactive dye chemistry.* Carbohydrate polymers, 2017. **174**: p. 137-145.
19. Zhang, F., et al., *Synthesis of an amino-terminated hyperbranched polymer and its application in reactive dyeing on cotton as a salt-free dyeing auxiliary.* Coloration Technology, 2007. **123**(6): p. 351-357.
20. Zhang, R.P., *Influence of wool anti-felting performance with chitosan/protease combination finishing.* Wool Textile Journal, 2008. **4**: p. 1-4.
21. Yang, H.-C., et al., *Preparation and application of nanochitosan to finishing treatment with anti-microbial and anti-shrinking properties.* Carbohydrate Polymers, 2010. **79**(1): p. 176-179.
22. Sadeghi-Kiakhani, M. and S. Safapour, *Eco-friendly dyeing of treated wool fabrics with reactive dyes using chitosanpoly (propylene imine) dendreimer hybrid.* Clean Technologies and Environmental Policy, 2015. **17**(4): p. 1019-1027.
23. Abdel Sayed, N.I., K. El Badry, and H.M. Abdel Mohsen, *Conductimetric studies of charge transfer complexes of p-Chloranil with some alicyclic amines in polar media.* Journal of the Chinese Chemical Society, 2003. **50**(2): p. 193-199.
24. Dev, V.R.G., et al., *Dyeing and antimicrobial characteristics of chitosan treated wool fabrics with henna dye.* Carbohydrate Polymers, 2009. **75**(4): p. 646-650.
25. Mohamed, F.A., et al., *Improvement of dyeability and antibacterial properties of gelatin treated cotton fabrics with synthesized reactive dye.* Bioscience Research, 2018. **15**(4): p. 4403-4408.
26. Goy, R.C., D.d. Britto, and O.B.G. Assis, *A review of the antimicrobial activity of chitosan.* Polímeros, 2009. **19**(3): p. 241-247.
27. Mohamed, F.A. and R.M. Mohareb, *Synthesis and applications of new bifunctional dyes bis (monochlorotriazine) based on tetrahydrobenzo[b]thiophene moiety.* Pigment and Resin Technology, 2013. **42**(4): p. 264-270.
28. Blencowe, A., et al., *Core cross-linked star polymers via controlled radical polymerisation.* Polymer, 2009. **50**(1): p. 5-32.
29. Mohamed, F.A. and R.M. Mohareb, *Synthesis and Application of Novel Reactive Disperse Dye Based on Tetrahydrobenzo[b] Thiophene Moiety.* Research Journal of Textile and Apparel, 2014. **18**(3): p. 28-34.
30. Chattopadhyay, D. and M. Inamdar, *Improvement in properties of cotton fabric through synthesized nano-chitosan application.* 2013.
31. Hu, J.-z., P. Skrabal, and H. Zollinger, *A comparison of the absorption spectra of a series of blue disperse dyes with the colorimetric evaluation of their dyeings.* Dyes and Pigments, 1987. **8**(3): p. 189-209.
32. Savarino, P., et al., *Disperse and cationic dyes from aminophenyl-X-azolo-pyridines.* Dyes and pigments, 1989. **11**(3): p. 163-172.
33. Purwar, R. and M.J.A.r. Joshi, *Recent Developments in Antimicrobial Finishing of Textiles--A Review.* 2004. **4**(3).
34. Tanner, B.J.A.r., *Antimicrobial fabrics-issues and opportunities in the era of antibiotic resistance.* 2009. **9**(11): p. 30-33.
35. Gao, Y. and R.J.T.r.j. Cranston, *Recent advances in antimicrobial treatments of textiles.* 2008. **78**(1): p. 60-72.
36. Hebeish, A., et al., *Green strategy for development of antimicrobial printed textile fabrics.* 2012. **16**(1): p. 77.
37. Ali, N., et al., *Antimicrobial activity of wool fabric dyed with natural dyes.* 2011. **15**(3): p. 1.