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Enhancing the functional properties of polyester and polyester/cotton fabric via treatment with impregnated metal oxide nanoparticles in the polymer network

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Abstract
The research concentrates on improving the characteristics of polyester and blended textiles through the application of chitosan and PVA-containing metal oxide nanoparticles, particularly for sublimation printing. The goal of the study is to enhance the efficiency and longevity of sublimation printing, a commonly used method for transferring designs to textiles. The study aims to improve dye fixation, color fastness, UV protection, and antimicrobial properties of printed fabrics by adding biopolymers such as chitosan and PVA, as well as TiO_2 nanoparticles. The results show that it is possible to make these improvements to the fabric without reducing its strength, which makes it a favorable method for creating long-lasting, high-quality textile prints.

Keywords: Biopolymers, Sublimation Printing, Synthetic Fabrics, Nanoparticles.

Introduction

Sublimation printing is a digital printing method that creates personalized images with custom colors on various surfaces like plastics, fabrics, and metals. Solid dye turns into gas at high temperatures during printing, bonding with the surface to create lasting connections. This process gives high-resolution and permanent coloration resistant to peeling and cracking. It is increasingly used in various industries to create durable, aesthetic prints on textile products.

Heat-sensitive inks are used for printing purposes. Anticipated growth in the dye sublimation printing market is expected due to its numerous uses across different industries. Primarily utilized in the textile printing sector, the market growth of this product will be directly impacted by the growing population. Dye sublimation printing is believed to be environmentally friendly because: 1. Low waste of dye as it does not go through liquid phase 2. It could be used many times to print more than once[1].

Due to the increasing need in the textile market, the production of synthetic and blended fabrics has been growing more than any other fiber group. On the other hand, this kind of fiber comes with its own drawbacks, with its hydrophobic characteristic being the primary issue. Efforts were made to enhance its characteristics through the development of chemical functionalization. By applying PVA and Chitosan onto the fabric surface, these agents act as a binder and create a protective layer, facilitating the adherence of sublimation printing to the fabric[2]. This results in enhanced dye fixation and improved color fastness properties of the printed fabrics. Additionally, the antimicrobial properties of Chitosan further contribute to the functionality of the fabric by inhibiting the growth of bacteria and reducing odors [3].

Chitosan is a polysaccharide with anticancer properties, nontoxicity, biodegradability, and biocompatibility [4]).

Chitosan was first used as a dye-deepening agent for textiles. Chitosan causes a homogenous coating film to develop on the surface of the fiber, enhancing the fiber's surface characteristics, considerably increasing the dye absorption rate[2].

Chitosan has caught the interest of researchers because of environmental and toxic issues related to heavy metal use in nanoparticle production. It is a derivative of chitin that has been de-acetylated. Chitin is predominantly found in the exoskeletons of shrimp and crabs, as well as in the internal structures of mollusks, insects, and certain fungi cell walls [5]. Chitosan consists of D-glucosamine and N-acetyl-D-glucosamine connected by a (1–4)-glycosidic bond. The antibacterial quality of chitosan is believed to be from its amino groups, which aid in breaking down bacteria and fungi [6]. Chitosan has advantageous characteristics such as lack of toxicity, compatibility with living organisms, ability to break down naturally, antimicrobial capabilities, and chemical reactivity. Its main use is for treating anti-shrinkage and improving dyeability [7].

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Polyvinyl Alcohol (PVA) is a biodegradable polymer that is safe for living organisms, having flexible chemical properties due to its hydroxyl (–OH) groups. These groups allow various grafting and crosslinking reactions to modify the secondary –OH group, resulting in varied material properties [8].

PVA is a versatile polymer that is often used in the textile industry due to its beneficial qualities like strength, smoothness, and resistance to damage. PVA is predominantly utilized in cotton textiles for warp sizing to enhance weaving performance and fabric look. Connecting cotton fibers to PVA is crucial for increasing fabric performance and tensile strength. Studies highlight the importance of crosslinking in fabric properties, demonstrating significant improvements in tensile strength. Furthermore, the mechanical properties of cotton textiles are enhanced by PVA layers, which also offer water resistance and antibacterial properties, allowing for versatile applications.

The impactful effects of advancements in nanoscience and nanotechnology are being experienced in various sectors and aspects of daily living. Despite the considerable progress in nanotechnology, there are still many issues and obstacles to overcome, including the application of nanomaterials and products on a commercial scale, environmental effects, and safety and health concerns[9].Metal nanoparticles and metal oxide nanoparticles like TiO_2 are often utilized as photocatalysts under UV light to aid in self-cleaning by eliminating organic compounds from polluted water and air because of their semiconductor characteristics. They are proficient at decreasing bacterial colonization as well. Exposure to UV light that is the same as or higher than the band gap energy of photocatalysts causes a redox reaction by creating electron-hole pairs, resulting in the creation of reactive oxygen species (ROS) like singlet oxygen (O_2), superoxide ion (O_2 •-), and hydroxyl radicals (•OH) that break down organic compounds[10].

In this research TiO_2 nanoparticles were added to biopolymers in synthetic fibers and blended fabrics to improve features like self-cleaning, UV protection, crease recovery, and antimicrobial activity without compromising strength. The crosslinking ability of PVA combined with the antimicrobial properties of chitosan has been effectively utilized to enhance the performance of textiles.

Each sample that was treated was assessed for its functional properties following global regulations.

MATERIALS AND METHODS

Materials

Fabrics:

100% polyester fabrics, and blended fabrics(polyester/cotton) used for this study were supplied from Opera Textiles Co., Cairo, Egypt.

Other Chemicals:

Chitosan, PVA, obtained from SD fine-CHEM limited (SDFCL) company, Cairo, Egypt, TiO_2 nanoparticles , acetic acid, citric acid, and sodium hypophosphate were also used from El-gomhouria, Cairo, Egypt. All of which were of laboratory grade.

Methods

All fabrics were washed with a solution containing 2g/ liter non-ionic detergent (TERGITOLTM NP-9 Surfactant), at 50°C for 30 minutes, then rinsed thoroughly with water and dried with air at room temperature. The fabrics are all pretreated with both chitosan and PVA, with or without a crosslinking agent, in the following method:

Pretreatment with polymers (chitosan/PVA):

Every sample was treated with freshly prepared aqueous solutions that had different concentrations (1, 2, 3% W.O.F) of Chitosan (dissolved in distilled water mixed with 2% acetic acid), and PVA. The specimens were soaked in the solutions for one hour at 60°C, with a liquor ratio of 1:30, before being air-dried at ambient temperature [11].

Pretreatment with polymers (chitosan/PVA) by crosslinking agent:

The samples were first treated in a mixture containing 10g/l of citric acid, 5g/l of sodium hypophosphate, using a liquid ratio of 1:30 for 15 minutes at 50oc, then compressed and dehydrated at 80oc[12].

Afterwards, newly made liquid solutions with varying ratios (1, 2, 3% W.O.F) of Chitosan (dissolved in distilled water and combined with 2% acetic acid), and PVA. The specimens were immersed in the solutions for one hour at a temperature of 60°C with a liquor ratio of 1:30, then wrung out and dried in the air.

Synthesis of TiO_2 nanoparticles:

In an ice bath, 3.5 ml of Titanium tetra chloride (TiCl4) was mixed with 50 ml of deionized water, followed by adding 35 ml of ethanol and vigorous stirring for 30 min at room temperature while under a fume hood. Ammonium hydroxide was carefully dripped into a mixture of titanium tetra chloride ($TiCl_4$), ethanol, and deionized water to balance the solution, resulting in the formation of a solid substance. After being stirred vigorously, the solution was allowed to settle for twelve hours. Next, the sediment was spun in a centrifuge. The residue was washed with deionized water until the chloride ions were removed by centrifugation. After that, the precipitate was dried in the oven at a temperature of 200°C for a duration of 4 hours to eliminate some of the absorbed water, resulting in the production of amorphous TiO_2. The amorphous TiO_2 was slowly calcinated at 400°C for a duration of four hours. In the end, the nano TiO_2 material in powder form was achieved[13].

Preparation of Polymers (chitosan/PVA) and Polymers/TiO_2:

Initially, polymers with varying concentrations (1, 2, and 3 % of W.O.F) were dissolved in 50 mL of distilled water at room temperature for each sample. Subsequently, the mixture was heated to 50˚C and stirred with a magnetic stirrer to fully dissolve polymer in water. The liquid solution was cooled down to the temperature of the room. Concurrently, different quantities of TiO_2 nanoparticles (0.5, 1, 2 wt% based on polymer weight) were individually mixed with 50 mL of distilled water and stirred for 20

minutes for optimal particle distribution. Next, the TiO_2 nanoparticle solution slowly dripped into the PVA solution while vigorously stirring at 1000 rpm for 5 minutes. Subsequently, a uniform mixture was obtained[14].**Printing technique:**
All fabrics were printed with sublimation printing technique at 225°C for 20 sec[15].

Measurements:

Transmission Electron microscope (TEM):

TEM was based on the same premise as SEM. Transmission electron microscopy (TEM) was used to analyze the size, morphology, crystalline structure, and chemical composition of a wide range of nanometers (NM). JEOL (TEM-1230, Japan) was used in the transmitter electron microscope.

Coloring Evaluation &Fastness Properties:

The visible range of the spectrum from 400 to 700 nm was used to evaluate the reflectance of the printed fabrics on a Minolta CM1000R spectrophotometer from Japan, with illuminant D65 and a standard observer at 10°. The colorimetric data includes average values of L*, a*, and b* from five measurements. The formula used to determine color difference (ΔE) was applied in the calculation.:

$$\Delta E = [(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2]^{1/2}$$

Equation 1:ΔE of printed fabrics[16].

The change in color ΔE compared to the control (fabric printed without treatment).
The K/S value of the printed fabrics was found by measuring the reflectance at 610 nm, where maximum absorption takes place, through the Kubelka-Munk
equation.

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

Equation 2:The K/S value of the printed fabrics
K represents the absorbance of the substrate, S indicates the scattering of the substrate, and R is the reflection of the colored fabric at the highest absorption wavelength.[17].
The optimum printed samples according to the color difference ΔE underwent rubbing, washing, perspiration and light fastness in accordance with ISO standard method, ISO 105-X12 (1987), ISO 105-co4 (1989), and ISO 105-EO4. (1989), ISO 105-BO2 (1988) was published.

UV-protecting properties of printed optimum treated fabrics:

The UV protection levels of processed synthetic and blended fabrics were evaluated using AATCC Test Method 183-2010, which is a recognized standard procedure for assessing UV protection in textiles. This method assesses the Ultraviolet Protection Factor (UPF) of the material in order to gauge
its effectiveness in protecting against UV rays[18].

Antimicrobial measurement:

The antimicrobial properties were examined by using the colony-forming method (CFU) on four different types of test microorganisms: Staphylococcus aureus (gram positive), Escherichia coli (gram negative), and Candida albicans (yeast). The quantity of live bacterial colonies on the agar plate for treated and untreated items was tallied, and the outcomes of bacterial decrease were presented following the formula. R (%) is calculated by subtracting A from B, dividing by B, and then multiplying by 100, where A represents the CFU/ml of the treated sample after 16 hours and B represents the CFU/ml of the untreated sample at the same time [19].

Results and Discussion

Transmitting electron microscopy (TEM) for TiO_2 nanoparticles:

Transmission Electron Microscopy (TEM) analysis of TiO_2 nanoparticles revealed that the size of the nano particles ranged between 10, and 40nm.

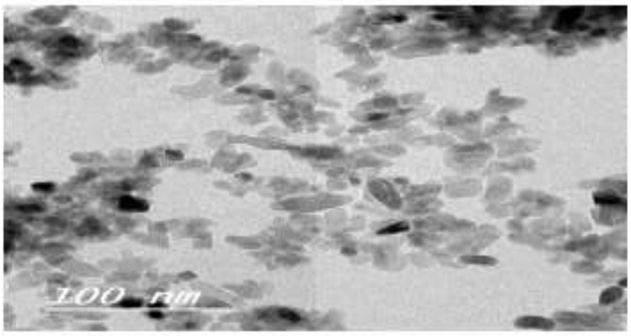

Fig 1:TEM images showing TiO_2 nanoparticles[20]

Coloring Evaluation

Tables 1, 2, 3, and 4 in the research show that as the amounts of polymers and cross-linking materials in the printed samples increase, the color difference represented as ΔE also increases. Samples containing 2% TiO_2 and polymers exhibited a minor rise in ΔE when the concentration increased to 3%, but it was too small to be significant.

Various polymers exhibit unique chemical compositions and molecular arrangements that can impact how they interact with dyes and nanoparticles, ultimately altering the color characteristics (ΔE) of the material[21].

In general, these factors together play a part in the variations in color characteristics and the success of the improvements in functionality seen in the treated fabrics. The research emphasizes the significance of maximizing these factors to reach the intended enhancements in dye fixation, colorfastness, UV protection, and antimicrobial properties, all while preserving the fabric's durability and excellence[22].

Table 1:Assessment of coloring evaluation of various chitosan concentrations

No	Type of fabric	Chitosan Without Crosslinking					Chitosan With Crosslinking				
		Conc. %	L*	a**	b***	ΔE****	Conc. %	L*	a**	b***	ΔE****
1	Polyester100%	1%	40.4	-29.3	14.8	16.6	1%	41.0	38.4	-2.6	23.7
		2%	36.1	-29.4	22.5	23.2	2%	30.4	-28.5	24.5	29.0
		3%	33.5	-34.0	25.3	25.6	3%	52.2	48.9	-3.3	30.2
2	Blended(polyester/cotton)	1%	49.6	49.9	24.2	2.59	1%	47.9	50.1	24.7	3.1
		2%	50.7	47.5	23.2	4.6	2%	118.0	123.5	60.9	7.8
		3%	49.4	48.0	21.3	5.9	3%	47.8	44.4	22.0	8.2

*** Lightness index ** Red to green index *** Blue to yellow index **** Color difference index**
ΔE was calculated by comparing to the control sample for each color

Table 2:Assessment of coloring Evaluation of various PVA concentrations

No	Type of fabric	PVA Without Crosslinking					PVA With Crosslinking				
		Conc.%	L*	a**	b***	ΔE****	Conc.%	L*	a**	b***	ΔE****
1	Polyester100%	1%	35.9	-5.0	-26.1	49.03	1%	48.3	-6.2	-25.8	49.62
		2%	35.2	-4.0	-27.8	51.03	2%	35.3	-2.8	-30.1	53.49
		3%	37.7	-3.5	-29.9	53.0	3%	34.3	-1.5	-30.5	54.64
2	Blended(polyester/cotton)	1%	59.8	48.8	-2.9	31.0	1%	51.0	45.3	0.6	26.43
		2%	44.5	50.3	-9.8	36.88	2%	47.5	53.6	-10.4	39.34
		3%	44.8	50.6	-9.9	37.14	3%	56.5	42.3	-13.4	41.36

*** Lightness index ** Red to green index *** Blue to yellow index **** Color difference index**
ΔE was calculated by comparing to the control sample for each color

Table 3:: Assessment of coloring Evaluation of various chitosan/TiO_2 Nanoparticles

Type of fabric	Chitosan /TiO_2 Nanoparticles Without Crosslinking						Chitosan /TiO_2 Nanoparticles With Crosslinking					
	Chitosan Conc.%	**TiO_2 Conc. %**	**L***	**a****	**b*****	**ΔE********	**Chitosan Conc. %**	**TiO_2 Conc. %**	**L***	**a****	**b*****	**ΔE********
polyester 100%	**1%**	0.5%	60.9	-28.31	20.5	15.83	1%	0.5%	35.4	-28.8	27.8	27.08
		1%	40.0	-29.8	23.7	20.95		1%	30.1	-27.9	19.5	27.44
		2%	33.6	-29.6	24.5	26.16		2%	26.7	-24.7	21.8	32.34
	2%	0.5%	29.8	-30.7	27.4	30.45	2%	0.5%	64.3	-30.4	24.5	19.30
		1%	27.7	-30.4	27.5	32.24		1%	24.5	-28.9	24.5	33.85
		2%	25.3	-29.3	25.4	33.45		2%	23.2	-28.9	24.0	34.81
	3%	0.5%	39.0	-28.1	19.5	20.05	3%	0.5%	42.9	-26.0	18.3	18.13
		1%	35.2	-30.0	22.5	23.75		1%	39.5	-27.4	21.4	20.99
		2%	31.9	-29.8	24.7	27.47		2%	26.831	-27.5	22.9	31.66
Blended (polyester/cotton)	**1%**	0.5%	17.8	21.1	11.6	4.17	**1%**	0.5%	22.9	27.1	14.9	5.36
		1%	43.9	49.9	26.9	6.65		1%	44.1	48.3	27.3	6.79
		2%	44.9	46.1	24.6	7.46		2%	55.9	47.3	22.2	7.72
	2%	0.5%	44.2	49.9	26.8	6.31	**2%**	0.5%	43.9	49.9	26.9	6.65
		1%	43.9	49.9	26.9	6.65		1%	42.832	49.918	28.554	7.96
		2%	44.9	46.1	24.6	7.46		2%	50.4	44.1	21.4	8.38
	3%	0.5%	52.1	48.9	23.4	3.94	**3%**	0.5%	27.2	32.2	17.7	6.36
		1%	46.2	51.7	26.0	4.40		1%	47.0	45.9	23.9	6.43
		2%	45.6	48.4	25.0	5.58		2%	30.4	36.0	19.7	7.12

*** Lightness index ** Red to green index *** Blue to yellow index **** Color difference index**
ΔE was calculated by comparing to the control sample for each color

Table 4:Assessment of coloring Evaluation of various PVA/TiO_2 Nanoparticles

Type of fabric	PVA /TiO_2 Nanoparticles Without Crosslinking						PVA /TiO_2 Nanoparticles With Crosslinking					
	PVA Conc.%	TiO_2 Conc.%	L*	a**	b***	ΔE****	PVA Conc.%	TiO_2 Conc.%	L*	a**	b***	ΔE****
Polyester 100	1%	0.5%	28.7	-1.7	-24.4	45.01	1%	0.5%	30.3	-3.5	-24.9	49.54
		1%	35.8	-5.3	-26.2	48.9		1%	36.0	-4.2	-27.8	50.86
		2%	35.1	-4.8	-26.1	49.1		2%	33.8	-2.1	-28.7	53.01
	2%	0.5%	35.0	-5.1	-26.2	49.0	2%	0.5%	36.8	-4.4	-27.7	50.71
		1%	34.8	-4.0	-26.5	50.0		1%	38.6	-3.2	-28.4	52.1
		2%	35.2	-4.0	-27.8	51.0		2%	41.5	-1.7	-36.0	59.0
	3%	0.5%	38.2	-5.8	-26.1	48.5	3%	0.5%	34.0	-3.8	-26.6	50.23
		1%	33.4	-4.7	-26.3	49.4		1%	35.2	-4.0	-27.8	51.03
		2%	34.4	-3.7	-27.8	51.1		2%	36.1	-3.0	-30.0	53.31
Blended	1%	0.5%	43.2	51.1	0.6	26.9	1%	0.5%	50.5	52.0	-0.4	27.06
		1%	49.9	66.0	3.2	27.8		1%	60.7	54.3	-1.4	30.06
		2%	51.8	56.9	-1.4	28.6		2%	37.2	51.8	-2.8	32.25
	2%	0.5%	49.0	65.2	0.5	29.7	2%	0.5%	49.0	65.2	-0.8	31.04
		1%	51.7	51.8	-5.3	31.9		1%	53.5	65.9	-1.7	32.24
		2%	53.7	72.0	2.5	32.2		2%	41.9	61.6	-6.4	35.81
	3%	0.5%	46.3	56.3	1.2	26.2	3%	0.5%	56.6	49.3	-3.6	30.90
		1%	51.4	53.3	-3.3	30.0		1%	48.5	51.9	-4.8	31.49
		2%	53.0	57.3	-3.8	31.1		2%	44.5	60.5	-4.7	33.3

*** Lightness index ** Red to green index *** Blue to yellow index **** Color difference index**
ΔE was calculated by comparing to the control sample for each color

Table 5:: color fastness values

Type of fabric	polymers	Con.	K/S	Washing fastness			Perspiration fastness						Rubbing fastness		Light fastness
							acidic			alkaline					
				Al.	SC	SW	Al.	SC	SW	Al.	SC	SW	dry	wet	
Polyester 100%	without	-	r	3	2-3	3-4	3-4	3	3-4	3-4	4	4	4	3-4	5
	Chitosan with crosslinking	2%	5.7	3-4	3	4-5	5	4	4	4-5	4-5	4-5	5	4-5	6
	PVA with crosslinking	2%	5.64	4	3-4	4-5	5	4	3-4	4	4-5	4	4-5	4-5	6
	Chitosan /TiO_2 Nanoparticles With Crosslinking	2% chitosan 2% TiO_2	5.7	5	4	4-5	5	4-5	4-5	5	5	4-5	5	4-5	7
	PVA /TiO_2 Nanoparticles With Crosslinking	2% PVA 2% TiO_2	5	5	4	4-5	4-5	4-5	4	5	5	4-5	5	4-5	6
Blended	without	-	2.51	2-3	3	3	3-4	3	3-4	3-4	3	3-4	4	3-4	5
	Chitosan with crosslinking	2%	2.63	4	3-4	4-5	5	4	4	4-5	4-5	4-5	4-5	4-5	6
	PVA with crosslinking	2%	2.67	4	4	4-5	5	4	4	4-5	4-5	4	4-5	4-5	6
	Chitosan /TiO_2 Nanoparticles With Crosslinking	2% chitosan 2% TiO_2	2.89	5	4-5	5	5	4-5	5	5	5	4-5	4-5	5	7
	PVA /TiO_2 Nanoparticles With Crosslinking	2% PVA 2% TiO_2	2.67	4-5	4	4-5	4-5	4-5	4-5	5	5	4-5	5	4-5	7

Al. Alteration on color **SC** staining on cotton **SW** staining on wool

Table 6:Ultraviolet Protective Factors

Type of fabric	*sample*	**Con.**	*UPF*	
			AS/NZ S4399:1996-UPF	*AATCC Test Method 183:2010-UPF*
Polyester100%	**Blank**	-	*7.4*	*7.4*
	Control	-	*23.8*	*23.7*
	Chitosan with crosslinking	2%	*36.5*	*36.2*
	PVA with crosslinking	2%	*30.7*	*30.5*
	Chitosan /TiO_2 Nanoparticles With Crosslinking	2% chitosan 2% TiO_2	*50.1*	*50*
	PVA /TiO_2 Nanoparticles With Crosslinking	2% PVA 2% TiO_2	*40.8*	*40.7*
Blended (polyester/cotton)	**Blank**	-	*4.5*	*4.4*
	Control	-	*7.6*	*7.4*
	Chitosan with crosslinking	2%	*10.7*	*10.5*
	PVA with crosslinking	2%	*8.3*	*8.1*
	Chitosan /TiO_2 Nanoparticles With Crosslinking	2% chitosan 2% TiO_2	*12.4*	*12.1*
	PVA /TiO_2 Nanoparticles With Crosslinking	2% PVA 2% TiO_2	*10.7*	*10.5*

Color Fastness

The printed samples which acquire the color difference ΔE were chosen and subjected to overall color fastness measurements. Table (5) shows the various types of fastness found in treated printing fabrics, such as washing, rubbing, acid perspiration, alkali perspiration, and light fastness. The results showed that adding TiO_2 nanoparticles to chitosan and PVA polymers improved the wash fastness of printed cotton fabrics.

Treated printed samples displayed higher color endurance to alkaline perspiration compared to acidic, nanoparticles loaded on polymers provided great resistance against staining on synthetic and blended fabrics.

All printed fabrics showed excellent color fastness when subjected to rubbing after treatment, especially during dry rubbing with polymers/nanoparticles. This suggests that most dye molecules are firmly bound to the fibers with only a small number of dye molecules found on the surface. The result might be that the dye molecules attached to both the treated material and cotton fabrics. The treated printed samples in (Table5) exhibited excellent light stability because of the cross-linkage agent connecting biopolymers /NPs with the dye reaction on all fabrics.

From the given data, we can observe the color strength values for polyester and blended fabrics with and without different additives.

Based on the data, it can be observed that the color strength is generally higher for polyester fabrics compared to blended fabrics. Among the additives, Chitosan/TiO_2 Nanoparticles have the highest color strength for both polyester and blended fabrics.

We conducted three replicates for K/S experiment to ensure the reliability and statistical significance of our results. PVA/TiO_2 Nanoparticles have the lowest color strength for polyester fabrics, whereas PVA has the lowest color strength for blended fabrics.

It's important to note that color strength is influenced by various factors such as dye concentration, dyeing method, and fabric type. Therefore, these values should be interpreted within the context of the specific experimental conditions.

Measurement of UPF Printed Fabrics:

The test showed that polyester and blended fabrics treated with a mix of chitosan, PVA, and TiO_2 nanoparticles resulted in improved UV protection. The TiO2 nanoparticles, which are recognized for their capability to obstruct and bounce back UV rays, played a major role in enhancing the UV shielding characteristics. The test results revealed that the fabrics treated had a higher UPF rating than those untreated, demonstrating increased protection against harmful UV rays. The enhanced UV protection is a result of the combined impact of biopolymers and nanoparticles, which not only boosts the functional characteristics of the fabric, but also provides extra advantages like antimicrobial properties and improved strength.

Information in Table 6 displays the results of testing the Ultraviolet Protection Factor (UPF) of polyester, and blended fabric samples that have been treated with different combinations of chitosan, PVA, and TiO2 nanoparticles.

Standards Used for UPF Calculation:

AS/NZS 4399:1996 - Australian/New Zealand Standard for sun protective clothing, and AATCC Test Method 183:2010 - American Association of Textile Chemists and Colorists' method for measuring the UV protection of fabrics.

The findings indicate that typically, untreated fabrics have low UPF values, suggesting limited UV protection. Fabrics treated with Chitosan displayed higher UPF values compared to untreated fabric, indicating improved UV protection.

Fabrics treated with PVA showed a slight rise in UPF values, indicating improved UV protection. Combining chitosan with TiO_2 resulted in a notable increase in UPF values, with TiO_2 nanoparticles playing a key role in enhancing UV protection. Improved UPF values were achieved by combining PVA and TiO_2, resulting in effective UV protection. The UPF values of the blended fabric samples differed depending on the composition blend and treatment used, typically mirroring polyester fabrics' trends but with minor differences due to the blend's nature.

Therefore: Chitosan, PVA, and TiO_2 Nanoparticles: All demonstrated a capacity to improve the UPF of polyester and blended textiles, with the polymer-nanoparticles blend offering the greatest UV protection.

Standards Evaluation: Both standards are dependable for evaluating UPF, with some minor differences between them.

This summary emphasizes how various treatments can enhance UV protection in fabrics, emphasizing the need to consider combinations of treatments for best results.

Determination of antimicrobial activity

Experiments were carried out to evaluate how well the treated polyester and blended fabrics could resist bacteria. A comparison was conducted between the number of colony-forming units (CFU) on fabrics that were treated and untreated to determine the percentage reduction of each microorganism. The results revealed a significant reduction in the number of living colonies of Staphylococcus aureus, Escherichia coli, and Candida albicans on the fabrics that were treated, compared to the fabrics that were not treated. Fig.1 displays how various treated samples perform against three microorganisms: Candida albicans, Escherichia coli, and Staphylococcus aureus. The control sample was not treated, while all other fabrics were treated with chitosan, PVA, a combination of chitosan and TiO_2 nanoparticles, and a combination of PVA and TiO_2 nanoparticles.

The information in the table shows how well various treatments work against germs on fabrics made of polyester and polyester/cotton blends. A thorough examination of antimicrobial effectiveness against Escherichia coli, Staphylococcus aureus, and Candida albicans revealed the following results: Polyester Fabric Blank Sample: Displays minimal antimicrobial impact, with values of 0.83, 0.45, and 0.32 for the three organisms. Control Sample: Shows higher microbial presence, with values of 23.71, 21.48, and 9.31. Chitosan with Crosslinking: Dem). Chitosan significant increase in antimicrobial effectiveness (31.4, 30.75, 31.55). PVA with Crosslinking: Also shows improved antimicrobial properties (29.08, 22.56, 20.83). Chitosan/TiO_2 Nanoparticles with Crosslinking: Displays a further boost in antimicrobial activity (33.46, 33.78, 33.68). PVA/TiO_2 Nanoparticles with Crosslinking: Exhibits the highest antimicrobial activity for Escherichia coli and Staphylococcus aureus (37.13, 43.68), although slightly lower for Candida albicans (28.79).

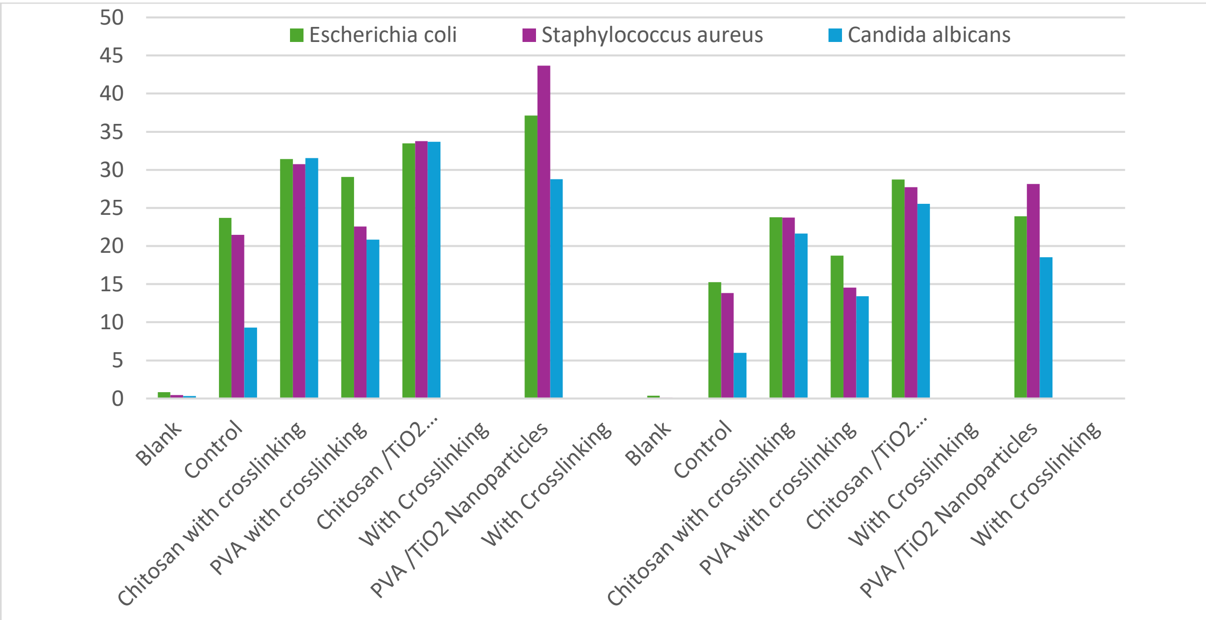

Fig. 2:The antimicrobial activities of different fungal ethyl acetate extracts against Escherichia coli, staphylococcus aureus, and Candida albicans

Regarding Polyester/Cotton Blended Fabric: blank Sample Shows very minimal antimicrobial effectiveness with values of 0.37, 0.11, and 0.05. The control sample had significant microbial presence (15.27, 13.84, 6). Chitosan with crosslinking showed improved antimicrobial properties (23.78, 23.73, 21.65). PVA with crosslinking also demonstrated enhanced antimicrobial activity (18.73, 14.53, 13.42). Chitosan/TiO2 nanoparticles with crosslinking exhibited even better antimicrobial performance (28.73, 27.73, 25.55). PVA/TiO2 nanoparticles with crosslinking displayed high antimicrobial activity (23.91, 28.13, 18.54), but lower than Chitosan/TiO_2 for Candida albicans.

In other words, PVA/TiO_2 nanoparticles with crosslinking exhibit the most potent antimicrobial activity for polyester.

Chitosan/TiO_2 nanoparticles with crosslinking show the best antimicrobial effectiveness on all three microbes for mixed fabric.

Chitosan and PVA both demonstrate a notable enhancement in their antimicrobial characteristics. Nevertheless, the effectiveness of these combinations is enhanced by the presence of TiO_2 nanoparticles, especially in Chitosan/TiO_2 and PVA/TiO_2 combinations.

Microbe Specificity: The treatments show the highest effectiveness towards Escherichia coli and Staphylococcus aureus, while also demonstrating notable activity against Candida albicans.

This evidence indicates that integrating biopolymers and TiO_2 nanoparticles improves the antimicrobial characteristics of textiles, rendering them more effective.

Microbe Specificity: The treatments work best against Escherichia coli and Staphylococcus aureus and have notable effectiveness against Candida albicans.

This information suggests that adding biopolymers and TiO_2 nanoparticles to fabrics can improve their antimicrobial properties, making them better suited for uses that need long-lasting, high-quality textile materials with extra benefits.

1. Conclusions

The research findings suggest that incorporating chitosan and PVA containing TiO2 nanoparticles greatly improves the characteristics of polyester and blended textiles for sublimation printing. Main findings are: Enhanced Dye ixation and Color Fastness: Applying chitosan and PVA as binders to fabrics forms a protective layer that boosts dye fixation and color fastness, leading to durable and vivid textile designs. Improved UV Protection: Adding TiO2 nanoparticles provides better UV protection for the fabrics, making them more ideal for outdoor use and prolonging the prints' lifespan. TiO2 nanoparticles on fabrics provide antimicrobial properties, decreasing microbial growth and improving cleanliness. Fabric properties are improved without weakening the fabric's strength, guaranteeing long-lasting durability. The research highlights how factors like the polymer type (chitosan and PVA), nanoparticle size, and preparation method play a crucial role in achieving the desired enhancements in fabric functionality. In general, blending chitosan, PVA, and TiO2 nanoparticles offers an encouraging method to improve the efficiency of synthetic and mixed fabrics for sublimation printing, thereby enhancing their functionality and making them more appropriate for durable, high-quality textile uses.

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3. Conflicts of interest

There is no conflicting interest in the release of this article.

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