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REGULAR ARTICLE

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Concurrent Dyeing and Finishing of Textile Fabrics Using Chemically Modified Peanut Red Skin Extract

M. Rehan[1] · N. S. El-Hawary[2] · H. Mashaly[2] · N. S. El-Shemy[2] · H. El-Sayed[3]

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Abstract

Progressive environmental awareness and legislation regarding the pollutants discharged from textile coloration plants allocate natural colorants in the forefront position for the dyeing and printing of many textile substrates. In this study, a genuine dye was synthesized by combining the diazonium salt of *m*-anisidine with a crude extract of peanut skin. The melting point of the synthesized dye (SD) as well as its Fourier transform infrared and UV–Visible spectra was recorded. The SD was used in the dyeing of wool, cotton, Lyocell®, and polyester fabrics with different dye shades, pH, time, and temperature. The color strength, colorimetric data, fastness properties, antimicrobial efficiency, ultraviolet protection factor, and tensile properties of the dyed fabrics were evaluated. The SD was a good colorant for wool and polyester fabrics but of lower substantivity for cotton and Lyocell®. The fastness properties of the dyed fabrics against light, washing, crocking, and perspiration were good to excellent. The dyed fabrics exhibited antimicrobial properties against Gram + ve bacteria, Gram – ve bacteria, and pathogenic fungus (*Candida albicans*) to different extents, depending on the dyed fabric and test species. Most of the dyed wool samples retained their antimicrobial properties even after ten washing cycles. The ultraviolet protection factor of the dyed fabrics was enhanced without deterioration of their tensile properties.

Keywords Fabric · Dyeing · Functional finishes · Peanut skin · *m*-Anisidine

1 Introduction

Textile dyeing and finishing operations of textiles are major sources of harmful pollutants that are usually discharged into the aquatic environment [1]. Recycling these materials from drained water requires complicated technologies, which should be implemented [2]. It would be more convenient to establish new benign procedures that use eco-friendly elements rather than pay the cost of eliminating the discharged pollutants from the currently used aggressive technologies [3].

✉ H. El-Sayed
hosam@trdegypt.org

1 Pre-treatment and Finishing of Cellulosic Fibers Department, National Research Centre, Dokki, Giza 12622, Egypt

2 Dyeing, Printing, and Textile Auxiliaries Department, National Research Centre, Dokki, Giza 12622, Egypt

3 Proteinic and Man-made Fibers Department, National Research Centre, Dokki, Giza 12622, Egypt

Cotton and wool fabrics are the brightest natural cellulosic and proteinic fibers in the clothing industry. They have outstanding appearance, performance, and comfort characteristics that customers demand. Cotton fibers are usually dyed with reactive dyes in an alkaline medium [4], whereas wool fibers are dyed with acid and reactive dyes in an acid medium [5].

Lyocell® is a biodegradable regenerated fiber produced using environmentally friendly technology [6]. Reactive and direct dyes are the proper dye types for coloring Lyocell® in an alkaline medium [7].

Among all other fibers, polyester (PET) is a commonly used dye in the clothing and textile industries. PET is commercially dyed at high temperatures and pressures using disperse dye in the presence of a carrier [8]. Many studies have been conducted to enhance PET dyeability at relatively low temperatures to reduce energy consumption during dyeing [9–11]. Another reported study focused on the production of acid or reactive-dyeable PET fibers [12].

Natural dyes have been used for dyeing and printing on various textile substrates [13–15]. The main sources of natural dyes are plant, animal, and mineral resources, with plant dyes being the most commonly used. Unlike synthetic dyes, natural colorants have high substantivity, ease of application under mild conditions, renewability, and eco-friendliness. Some natural dyes have multiple functions besides dyeing and printing, for example, moth-proofing and ultraviolet protection [16, 17].

Many plant parts may contain colorants, including leaves, stems, roots, shells, and skins. The red skin of peanuts (*Arachis hypogaea L.*) have been used in textile applications [18–20]. Peanut red skin (PRS) is a waste material of low economic value. The primary constituents of PRS are polyphenols, flavonoids, and polymeric procyanidins. The flavonoid class of anthocyanins is responsible for the shading colors (red, purple, and blue) of PRS [21, 22]. The colored extract from PRS was successfully used in the coloration and functionalization of natural fabrics [17, 23].

Many researchers have used natural products extracted from renewable waste materials in textile and nontextile applications to establish sustainable, eco-friendly, and cost-effective technologies. Ahmed et al. reported that most phytochemicals derived from plants can act as reducing and stabilizing agents for in situ preparation of nanoparticles for textile functionalization [24]. Keratin and sericin are two natural biopolymers derived from renewable materials reported for various applications, including tissue engineering [25], the detection of pollutants in wastewater [26, 27], water purification [28], enhancing coloration of textiles [29–31], and improving the performance and comfort attributes of textiles [32, 33]. Lanolin, another natural byproduct of wool scouring, is used to prepare textile auxiliaries for finishing textiles with enhanced softness or hydrophobicity [34, 35]. It has also been used as a binder in pigment printing of cotton and PET fabrics [36].

In this study, we synthesized a new dye by combining PRS extract with *m*-anisidine. The synthesized dye (SD) was used to dye various fabrics of different types, including wool, cotton, PET, and Lyocell® fabrics. The antimicrobial properties of the dyed fabrics were evaluated against Gram − ve and Gram + ve bacteria, as well as the fungus *Candida Albicans*.

2 Experimental

2.1 Materials

Pure plain weave wool, cotton, and PET fabrics were purchased from the Misr Company for Spinning and Weaving, El-Mahalla El-Kobra, Egypt. Lenzing AG, Austria, provided scoured plain weave nonfibrillating Lyocell® A100 fabric and Modal® fabric. Table 1 summarizes the main characteristics of the used fabrics. Meta anisidine (purity 97%) was purchased from Sigma-Aldrich, Taufkirchen, Germany. Starch and Detergents Company, Alexandria, Egypt, provided nonionic detergent Egyptol PLM.

PRS (*Arachis hypogaea L*) was obtained by manually peeling a peanut purchased from the local market.

2.2 Methods

2.2.1 Extraction of Colorant

The collected PRS was ground into powder to increase its surface area and make a colorant extraction much easier. In 150 ml of boiling water, 30 g of the powdered PRS was heated for 1 h. The liquid extract was filtered and dried at ambient temperature.

2.2.2 Diazotization and Coupling with m-Anisidine

The diazonium salt of *m*-anisidine was prepared in an ice bath (4 °C) by dissolving 0.01 mol of *m*-anisidine in 20 ml distilled water; the pH of the solution was adjusted at 2.5 using HCl (36% w/v). A solution of sodium nitrite (0.01 mol) was added to the mixture dropwise for 15 min while continuously stirring.

The prepared diazonium salt was poured onto 25 mL of PRS extract (PSE) in the same ice bath and stirred (150 rpm) for 1 h. The pH of the reaction mixture was kept at 4.5 using Na_2CO_3, and the mixture was refrigerated overnight at 10 °C.

The pH of the prepared colored solution was adjusted to 6.7. Salting out was performed using sodium chloride (10% w/w of the colored solution) and continuous stirring (150 rpm) at 4 °C for 30 min. The solution was filtered and

Table 1 Fabric properties of the investigated fabrics

Fabric property	Wool	Cotton	Polyester	Lyocell®
Weave structure	Plain weave 1/1	Plain weave 1/1	Plain weave 1/1	Plain weave 1/1
Weight (g/m^2)	149	110	115	110
Thickness (mm)	0.41	0.31	0.33	0.31
Weft density/inch	46	50	55	50
Warp density/inch	60	120	163	130

washed with distilled water, and the solid colorant was separated and dried at 50 °C.

2.2.3 Dyeing

Wool, cotton, PET, or Lyocell® fabric samples were dyed with 0.1%–3.0% (based on the weight of the fabric, o.w.f.) of the SD at a material-to-liquor ratio (MLR) of 1:50. For all fabrics under study, the dyeing process was performed at 60–100 °C (60–130 °C in case of PET fabric) at pH 3, 4.5, 7, and 9 (adjusted by acetic acid or sodium carbonate solution) for 30–90 min. The dyed samples were rinsed with running water, followed by 15 min washing using 3 g/*l* of Egyptol PLM at 30 °C. Finally, the fabrics were rinsed and air-dried.

2.3 Analyses and Testing

2.3.1 UV–Vis Spectroscopy

UV–Vis spectra of the PSE as well as the SD were measured using a UV–Vis spectrophotometer. The aqueous solutions of tested samples were filtered and scanned between 200 and 700 nm.

2.3.2 Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR spectra of the SD were recorded using a JASCO FTIR 4700 spectrometer with an optical system that collects data over a range of 4000–400 cm^{-1} with the best resolution of 0.5 cm^{-1}.

2.3.3 Color Strength

The color strength (*K/S*) of the dyed fabric was evaluated at $\lambda_{max}=80$ nm using the high reflectance technique. The dyed samples were measured using a Perkin–Elmer Lambda 3B UV–Vis spectrophotometer (Perkin Elmer Corp., Shelton, CT, USA). The *K/S* was calculated using the *Kubelka Munk* equation [37] as follows:

$$\text{Color strength (K/S)} = \frac{(1-\text{R})^2}{2\text{R}} - \frac{(1-\text{R}^\circ)^2}{2\text{R}^\circ}, \quad (1)$$

where R and R° are the decimal fractions of the reflectance of the dyed and undyed samples, respectively, K is the absorption coefficient, and S is the scattering coefficient.

2.3.4 Colorimetric Data

The colorimetric attributes of the dyed fabrics over the CIELAB color spaces were determined using a HunterLab Model DP-9000 colorimeter (HunterLab, Reston, VA, USA). The positive L^*, a^*, b^*, and ΔE values indicate the lightness, redness, yellowness, and total color change attributes in the dyed samples, respectively.

2.3.5 Fastness Properties

Various fastness properties of the fabrics dyed with the SD (at the optimum dyeing conditions), as well as the peanut skin extract, were evaluated using the ISO standard methods. The standard test methods for color fastness against washing [38], light [39], dry, and wet rubbing [40], as well as perspiration [41], were used.

2.3.6 Antimicrobial Properties

The antimicrobial activities of the untreated and the corresponding dyed fabrics were assessed using the quantitative method (reduction %) against Gram + ve bacteria (*Staphylococcus aureus* using the standard method ATCC 6538 or *Bacillus cereus* using the standard method ATCC 6629) and Gram − ve bacteria (*Escherichia coli* using the standard method ATCC 25,922 or *Pseudomonas aeruginosa* using the standard method ATCC 27,853), as well as the pathogenic fungus *Candida albicans* (ATCC-10231) using the standard method AATCC TM100-2019 Test Method [42].

The durability of the antimicrobial properties of the dyed fabrics was assessed after one, five, and 10 washing cycles in a domestic washing machine. The washed samples were tested for their antimicrobial effect as mentioned above. Only samples with a reduction percentage higher than 50% were subjected to the washing test.

2.3.7 Ultraviolet Protection Factor (UPF)

The UPF of the untreated and dyed samples was assessed using the Australia/New Zealand standard AS/NZS-4399:1996 method [43] and a UV/Vis spectrophotometer with a UPF calculation system as reported in the standard AATCC Test Method 183:2010-UVA Transmittance [44].

2.3.8 Tensile Properties

The tensile properties of untreated and dyed fabrics were evaluated using an Instron Tensile Tester (Instron, Norwood, MA, USA) based on the ASTM D-76 Standard Specification for Textile Testing Machines.

3 Results and Discussion

The colored extracts from natural plants have desirable properties that can be imparted to textiles using appropriate treatment methods. In this study, the natural color of PRS was extracted using water as a solvent. Rehan et al. reported

Fig. 1 A photograph of the peanut red skin peels (left) and the SD (right)

that the total phenolic and flavonoid contents of the aqueous extract of PRS are 76.4 ± 1.07 and 31.6 ± 1.12 mg GAE/g, respectively. Moreover, the high-performance liquid chromatography (HPLC) analysis of the aqueous extract confirmed the presence of catechin as the predominant compound in the extract [18].

Here, the aqueous extract from PRS was combined with diazotized *m*-anisidine to synthesize a new colorant suitable for the dyeing and functionalization of selected textile substrates. Figure 1 shows an image of the dried PRS peals and SD.

The mechanism of diazotization of *m*-anisidine with a polyphenolic compound, such as catechin, in the PSE is illustrated in Eqs. 1 and 2, respectively.

3.1 Characterization of the SD

The SD has a melting point of 165 ± 2 °C, which is completely soluble in dimethyl formamide at room temperature. The FTIR spectra of the SD revealed a strong sharp band near 3500 cm^{-1}, which is associated with the phenolic –OH stretching vibration (Fig. 2). The bands near 3000 cm^{-1} are due to the C–H stretching vibration of aromatic compounds. The C = C (in ring) stretching vibration bands of aromatic compounds appeared as medium bands at 1440 and 1598 cm^{-1}. The characteristic medium band at 1521 cm^{-1} is attributed to the N = N stretch of the azo group, which ensures the synthesized azo compound. This FTIR spectra of the SD differs from that of the PSE previously reported by Kyei et al. [45], indicating that the success of the synthesis of a new dye by reacting the PSE with the diazonium salt of *m*-anisidine.

Figure 3 shows the UV–Vis spectra of the PSE and the SD at pH 4.5 in the wavelength range 200–700 nm. Two major absorption bands were detected in the UV–Vis region of the PSE; a strong one around 212 nm and a weaker one at about 280 nm. The first band is associated with the ring of the benzoyl system and the second one is due to the *β*-ring of cinnamoyl system. These said two bands are characteristics

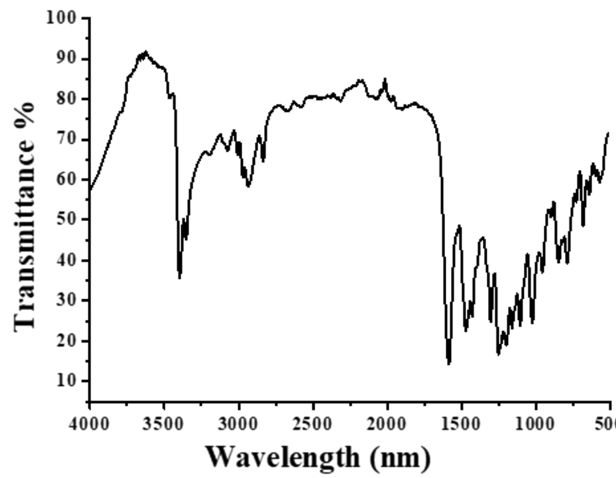

Fig. 2 FTIR spectra of the SD

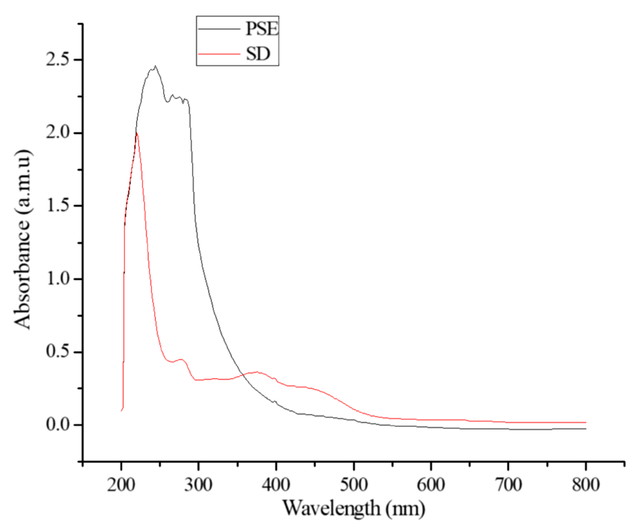

Fig. 3 UV–Vis spectra of the PSE and the SD at pH 4.5

for natural polyphenols [46]. Thorough inspection of Fig. 3 reveals that the UV–Vis spectra of the SD have a new absorption in the range 350–370 nm associated with the azo group (N = N) of the synthesized dye [47].

3.2 Utilization of the SD in the Dyeing of Textile Fabrics

The substantivity of the SD to natural (wool and cotton), regenerated (Lyocell®), and synthetic (PET) fabrics was investigated. The effects of different dyeing conditions, such as dye concentrations, pH, temperature, and time on the dyeability of the aforementioned fabrics with the SD, were observed.

3.2.1 Effect of pH

Wet processing of textiles, including coloration, is extremely sensitive to variation in the pH of the medium [48, 49]. The effect of pH on the dyeability of wool, cotton, Lyocell®, and PET with the SD was investigated, and the results are summarized in Table 2. The data in the table reveals that the *K/S* of all dyed fabrics showed a maximum value at pH 3. Dyeing at pH 4.5 resulted in *K/S* values for the dyed samples comparable to the corresponding samples dyed at pH 3. At neutral and alkaline pH levels, the *K/S* of all dyed fabrics decreased significantly.

At the same pH, the *K/S* value of the dyed fabrics increased in the following order: Lyocell® < cotton < PET < wool, implying that the SD behaves as either an acid dye in the coloration of wool or a dispersed dye in the coloration of PET. By contrast, the SD has a lower affinity for cellulosic fabric, whether natural (cotton) or regenerated (Lyocell®) cellulosic fabrics under the used dyeing conditions. The SD molecules could bind with the cellulosic substrates, as well as wool, though hydrogen bonding between the polar hydroxyl groups in the SD as well as the dyed substrates.

In all dyed samples with the SD at pH 4.5, the "L^*" value increased to different extents as the pH increased from 3 up to 9, indicating a shift of the dyed fabrics toward darker shades. The higher "a^*" and "b^*" values imply a shift of the dyed fabric toward green and yellow colors, whereas the decrease in the said values indicate shift towards the red and blue areas, respectively.

3.2.2 Effect of Dye Concentration

The effect of dye concentration on the color strength and colorimetric data of the dyed fabrics was investigated, and the results are summarized in Table 3. The data in the

Table 2 Effect of pH of dyeing bath on the color strength and colorimetric data of the dyed fabrics (dyeing conditions: 2% dye at 100 °C for 30 min, MLR: 1:40)

pH of the dyeing bath	*K/S*	L^*	a^*	b^*	Δ*E*
Wool					
3.0	10.39	67.92	13.45	49.48	51.82
4.5	8.37	65.86	11.09	48.95	53.23
7.0	6.86	65.12	11.55	44.86	50.63
9.0	5.68	63.30	14.52	42.89	51.27
Cotton					
3.0	2.84	77.37	8.35	27.16	29.46
4.5	2.41	76.76	9.15	28.67	30.51
7.0	1.93	77.00	11.45	21.60	25.65
9.0	1.77	76.96	11.63	26.58	29.65
Lyocell®					
3.0	1.30	82.34	7.62	34.87	34.66
4.5	1.25	81.19	7.66	33.90	34.06
7.0	0.90	81.99	9.27	28.99	29.74
9.0	0.80	81.65	7.35	26.23	27.29
Polyester					
3.0	6.70	66.37	14.64	45.51	50.78
4.5	4.75	62.39	8.36	40.67	42.32
7.0	4.75	67.76	7.84	37.64	38.11
9.0	3.82	69.19	7.28	41.36	42.74

Table 3 Effect of dye concentration on the color strength and colorimetric data of the dyed fabrics (dyeing conditions: 2% dye for 30 min at pH 3 for wool and polyester, and pH 4.5 for cotton and lyocell; MLR: 1:40)

Dye conc. (o.w.f.)	*K/S*	L^*	a^*	b^*	Δ*E*
Wool					
0.5%	5.81	70.38	7.62	42.32	1.27
1%	8.11	63.29	10.90	45.11	23.21
2%	10.39	60.92	13.45	49.48	41.82
3%	11.33	55.82	23.69	49.91	30.82
Cotton					
0.5%	1.39	78.96	3.49	20.93	23.12
1%	2.04	78.38	5.74	25.25	11.07
2%	2.84	77.37	8.35	27.16	29.46
3%	2.83	68.20	10.99	34.64	19.26
Lyocell®					
0.5%	1.02	88.85	1.99	22.01	22.38
1%	1.12	85.20	7.45	26.09	10.99
2%	1.30	82.34	7.62	34.87	34.66
3%	1.31	64.23	12.89	42.18	19.08
Polyester					
0.5%	3.69	76.43	11.56	37.03	15.94
1%	4.42	70.78	12.47	42.89	29.66
2%	6.70	66.37	14.64	45.51	25.78
3%	7.57	48.42	20.95	49.52	33.92

table show that for each substrate, as the dye concentration increased from 0.5% to 2% (o.w.f.), the color of the dyed fabrics became deeper, as indicated by the *K/S* values. Further increase in the dye concentration resulted in only a minor increase in the *K/S* of the dyed samples. The results of this table also show that as the dye concentration increased, the "L^*" values decreased, whereas the "a^*" and "b^*" values increased.

3.2.3 Effect of Dyeing Time and Temperature

Tables 4 and 5 summarize the effects of dyeing time and temperature on the *K/S* and colorimetric date of wool, cotton, Lyocell®, and PET fabrics dyed, with the SD, as well as PSE. The data in these tables show that the best conditions for dyeing the aforementioned fabrics were given as follows: 2% dye for 60 min at 100 °C at pH 3, MLR: 1:40. The maximum color change was obtained in the case of dyed wool fabrics ($\Delta E = 21.10$) with comparable results in the case of the dyed PET fabrics, as indicated by ΔE values of the dyed samples. By contrast, the dyed Lyocell® fabrics had the lowest color change, with comparable results in the case of cotton fabrics.

Table 4 Effect of dyeing time on the color strength and colorimetric data of the dyed fabrics (dyeing conditions: 2% dye at 100 °C and pH 3 for wool and polyester, and pH 4.5 for cotton and lyocell; MLR: 1:40)

Dyeing time (min)	*K/S*	L^*	a^*	b^*	ΔE
Wool					
30	10.39	67.92	13.45	49.48	51.82
45	17.59	57.18	20.15	49.10	22.66
60	24.86	54.17	20.27	50.67	21.10
90	25.09	52.86	21.47	51.04	20.90
Cotton					
30	2.84	77.37	8.35	27.16	29.46
45	3.11	67.35	14.73	30.36	15.25
60	3.53	66.38	16.13	34.66	12.65
90	3.58	66.65	17.05	35.16	14.69
Lyocell®					
30	1.30	82.34	7.62	34.87	34.66
45	2.98	70.30	13.09	39.88	6.77
60	3.26	70.56	15.00	39.98	9.08
90	3.37	70.48	15.87	40.27	7.83
Polyester					
30	6.70	66.37	14.64	45.51	50.78
45	10.12	63.52	22.21	62.40	26.20
60	13.49	63.39	21.29	61.60	20.11
90	13.51	61.95	22.90	60.87	26.02

Table 5 Effect of dyeing temperature on the color strength and colorimetric data of the dyed fabrics (dyeing conditions: 2% dye for 60 min at pH 3 for wool and polyester, and pH 4.5 for cotton and lyocell; MLR: 1:40)

Dyeing temperature (°C)	*K/S*	L^*	a^*	b^*	ΔE
Wool					
70	10.51	75.70	14.09	42.47	21.53
80	12.74	71.32	16.17	42.00	21.47
90	20.16	66.09	19.54	47.92	20.61
100	24.86	54.17	20.27	50.67	21.10
Cotton					
70	2.70	76.10	13.72	30.49	10.33
80	2.78	77.36	14.22	32.66	11.67
90	2.88	70.52	14.46	33.48	11.86
100	3.53	66.38	16.13	34.66	12.65
Lyocell®					
70	2.31	81.67	9.55	33.93	10.51
80	2.50	77.18	11.00	36.21	19.03
90	2.98	74.10	12.64	39.65	10.34
100	3.26	70.56	15.00	39.98	9.08
Polyester					
70	1.54	70.70	8.44	48.66	11.12
80	7.25	67.20	11.08	52.58	12.78
90	7.61	67.39	16.10	55.32	14.40
100	13.49	63.39	21.29	61.60	20.11

3.2.4 Fastness Properties

The various fastness properties of the dyed fabric with either the SD or the PSE were evaluated, and the results are summarized in Table 6. The data show that the fastness properties of the fabrics dyed with the SD against light, washing, crocking (rubbing), and perspiration were the brightest in the case of wool and PET fabrics and rather lower in the case of

Table 6 Fastness properties of the wool, cotton, Lyocell®, and polyester fabrics dyed with the SD (dyeing conditions: 2% dye for 60 min at 100 °C and pH for wool and polyester, and pH 4.5 for cotton and lyocell; MLR: 1:40)

Fabric	Dyed with	Fastness toward			
		Light	Washing	Crocking	Perspiration
Wool	PSE	4–5	4	4	4
	SD	6–7	4–5	4–5	4–5
Cotton	PSE	3–4	3	3	3–4
	SD	4–5	3–4	3–4	3–4
Lyocell®	PSE	3	3–4	3	3
	SD	4–5	3–4	3–4	3–4
Polyester	PSE	4	3–4	3–4	3
	SD	6–7	4–5	4–5	4–5

cotton and Lyocell®. The samples dyed with the PSE had the least fastness properties in all fabrics compared with the corresponding samples dyed with the SD.

3.3 Antimicrobial Properties

The function of textile fabrics is critical in improving the performance attributes of the final products [50–52]. Antimicrobial finishing is critical. The resistance of treated samples to Gram – ve bacteria (*Escherichia coli* and *Pseudomonas aeruginosa*), Gram + ve bacteria (*Staphylococcus aureus* and *Bacillus cereus*), and the pathogenic fungus *Candida albicans* was quantified, and the results are summarized in Table 7. Based on the data in Table 7, the untreated wool, cotton, and Lyocell® fabrics showed insufficient resistance to Gram + ve, Gram – ve, and pathogenic fungus. PET fabrics have a higher resistance to the test species. The resistance of the fabrics to microbes was improved to different extents depending on the fabric and microbes. The dyed wool fabric had the maximum antimicrobial activity against *Candida albicans* (94.9% reduction) and *Bacillus cereus* (93.7% reduction), whereas Lyocell® fabric had the lowest antimicrobial resistance against *Pseudomonas aeruginosa* (34.2% reduction) and PET fabric against *Candida albicans* (36.2% reduction). Peanut extract has been reported as an antimicrobial agent because of its high content of phenolic compounds, such as flavonoids, phenolic acids, and procyanidin dimers [53].

The antimicrobial resistance of the aforementioned fabric after dyeing with the SD was even higher than those of the analogous samples dyed with PSE. The dyed wool fabric had the highest reduction % (≥ 98%) against *Pseudomonas aeruginosa* and *Candida albicans*, and the dyed Lyocell® fabric had the highest reduction percentage against *Staphylococcus aureus* and *Candida albicans*. The enhanced antimicrobial activity of the SD could be attributed to the synergetic effect of the methoxy and hydroxyl groups (Eq. (1)) [17]. By contrast, the samples with the least resistance to microbial attack (≤ 50% reduction) were the dyed cotton fabrics against *Escherichia coli* and the dyed PET fabric against *Candida albicans*.

To assign the durability of these treatments against washing, the antimicrobial properties of the dyed fabrics with the SD were evaluated after one, five, and 10 washing cycles. The samples that retained their excellent antimicrobial properties (≥ 90%) after five washing cycles are the dyed wool fabrics against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Candida albicans* and dyed Lyocell® fabrics against *Candida albicans*. Only wool fabrics dyed against the above species retained their antimicrobial activity after 10 washing cycles.

Table 7 Antimicrobial activity of the dyed wool, cotton, Lyocell®, and polyester fabrics (S: undyed, S2: dyed with the Peanut red skin extract, and S3: dyed with the SD

Sample	Species	Reduction in colony count (%) after											
		No washing			1 wash cycle			5 wash cycles			10 wash cycles		
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Wool	*S. aureus*	16.2	82.0	95.3	–	81.1	95.2	–	77.8	92.3	–	72.5	90.1
	B. cereus	13.5	93.7	86.8	–	86.5	86.0	–	50.9	81.7	–	46.8	76.9
	E. coli	15.8	69.6	93.7	–	59.8	92.9	–	55.5	89.1	–	50.2	85.6
	P. aeruginosa	11.0	62.1	98.6	–	60.7	97.5	–	88.7	95.2	–	84.6	92.0
	C. albicans	11.6	94.9	98.3	–	90.3	96.6	–	88.0	93.4	–	85.3	90.7
Cotton	*S. aureus*	19.9	83.5	83.9	–	81.4	83.6	–	78.7	80.0	–	72.5	76.2
	B. cereus	18.8	74.8	75.5	–	72.0	73.4	–	66.5	68.6	–	62.4	63.0
	E. coli	10.4	42.7	45.7	–	40.8	41.4	–	–	–	–	–	–
	P. aeruginosa	19.5	70.3	91.0	–	65.7	90.0	–	64.8	86.4	–	61.1	83.3
	C. albicans	16.1	77.6	88.9	–	74.6	88.8	–	71.7	85.6	–	65.5	82.0
Lyocell®	*S. aureus*	12.2	67.6	98.0	–	59.2	90.5	–	55.8	87.2	–	51.2	81.8
	B. cereus	10.5	58.2	75.7	–	55.4	71.4	–	52.1	69.4	–	48.4	63.9
	E. coli	13.8	43.4	50.8	–	39.8	48.6	–	–	–	–	–	–
	P. aeruginosa	12.4	34.2	82.8	–	33.3	76.7	–	–	73.4	–	–	68.7
	C. albicans	19.9	73.3	98.9	–	71.8	96.5	–	67.5	92.3	–	62.4	88.5
Polyester	*S. aureus*	25.5	63.9	65.2	–	59.4	60.1	–	54.3	57.1	–	49.8	51.0
	B. cereus	20.5	72.7	77.0	–	68.6	73.9	–	63.6	70.7	–	58.7	66.6
	E. coli	30.7	54.7	73.3	–	44.2	61.7	–	–	56.9	–	–	52.6
	P. aeruginosa	32.6	51.3	63.6	–	44.6	54.6	–	–	49.8	–	–	–
	C. albicans	20.2	36.2	41.8	–	30.1	36.9	–	–	–	–	–	–

Table 8 Tensile properties and UPF of wool, cotton, Lyocell®, and polyester fabrics dyed with the synthesized

Fabric	UPF	Loss in tensile strength (%)	Elongation at break (%)
Untreated wool	214.8	–	22.0
Dyed wool	495.1	3.28	21.7
Untreated cotton	8.6	–	8.2
Dyed cotton	15.5	4.09	8.4
Untreated Lyocell®	6.2	–	21.9
Dyed Lyocell®	12.3	3.88	22.2
Untreated polyester	7.8	–	42.1
Dyed polyester	15.1	2.97	40.9

3.4 UPF and Tensile Properties

The effect of dyeing wool, cotton, Lyocell®, and PET fabrics with the SD on their resistance to ultraviolet radiation (expressed as ultraviolet protection factor, UPF), tensile strength, and elongation at break was assessed, and the results are summarized in Table 8.

Wool has adequate resistance to ultraviolet radiation, which can be enhanced after dyeing [54]. However, the UPF of cotton and PET fabrics was improved from poor to good resistance to ultraviolet radiation after the dyeing process. Although the UPF of the dyed Lyocell® fabric is almost twice that of the untreated fabric, it was still within the poor range. The presence of phenolic compounds with the PSE is the main reason for the induced ultraviolet protection. It has been reported that phenolic compounds can scavenge any free radicals created under the influence of UV radiation and produce anti-ultraviolet radiation properties [55]. The tensile strength and elongation at the break of the dyed fabrics were not significantly affected.

4 Conclusion

Based on the results of this investigation, we conclude that the dye synthesized by combining the diazonium salt of *m*-anisidine with PSE is suitable for dyeing wool and PET fabrics. The SD has a low substantivity toward cotton and Lyocell® fabrics. The dyed fabrics have excellent to good fastness to light, washing, crocking, and perspiration; dyed wool has the highest value. Depending on the fabric and test species, the dyed fabrics exhibit excellent to fair resistance to Gram + ve and – ve bacteria, as well as a pathogenic fungus. The dyed wool fabric retained its antimicrobial activity after 10 wash cycles. Except for Lyocell®, dyeing the aforementioned fabrics with the SD resulted in adequate UPF improvement. No deterioration in the strength of the dyed fabrics was recorded.

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. X. Chen, D. Sheng, H. Xia, W. Xu, B. Deng, G. Cao, Fibers Polym. **21**, 2842 (2020). https://doi.org/10.1007/s12221-020-9976-7
2. H. El-Sayed, M. Abou Taleb, S. Mowafi, Egypt J. Chem. **64**, 4429 (2021)
3. K. Lachguer, M. El Ouali, I. Essaket, S. El Merzougui, O. Cherkaoui, M.A. Serghini, Fibers Polym. **22**, 3368 (2021). https://doi.org/10.1007/s12221-021-0256-y
4. R. Penthala, H. Oh, S.H. Park, I.Y. Lee, E.H. Ko, Y.-A. Son, Dyes Pigm. **198**, e110003 (2022)
5. H. El-Sayed, Color. Technol. **122**(1), 57 (2006). https://doi.org/10.1111/j.1478-4408.2006.00004.x
6. K.E. Perepelkin, Fibre Chem. **39**, 163 (2007). https://doi.org/10.1007/s10692-007-0032-9
7. N. El-Sheemy, H. El-Sayed, K. Haggag, Egypt. J. Chem. **53**, 843 (2010)
8. S. Yu, H. Zhang, L. Pei, S. Liang, A. Dong, J. Wang, Fibers Polym. **23**, 443 (2022). https://doi.org/10.1007/s12221-021-2327-5
9. R. Penthala, R.S. Kumar, G. Heo, H. Kim, I.Y. Lee, E.H. Ko, Y.-A. Son, Dyes Pigm. **166**, 330 (2019). https://doi.org/10.1016/j.dyepig.2019.03.027
10. N.S. El-Shemy, M.H. El-Shakankery, S.M. Shahien, K. Haggag, H. El-Sayed, Egypt. J. Chem. **60**, 79 (2017)
11. R. El-Newashy, S. Mowafi, K. Haggag, M. Abou Taleb, H. El-Sayed, Fibers Polym. **20**, 1992 (2019). https://doi.org/10.1007/s12221-019-9275-3
12. N.S. El-Shemy, N. El-Hawary, H. El-Sayed, J. Chem. Eng. Proc. Technol. **7**(1), 2 (2016)
13. N. El-Shemy, H. El-Sayed, J. Nat. Fibers **19**, 10306 (2021). https://doi.org/10.1080/15440478.2021.1993499
14. E.A. El-Alfy, H.M. Ibrahim, H.M. Mashaly, N.S. El-Hawary, M.M. Kamel, Der Pharm. Chem. **9**(24), 84 (2017)
15. N. Elshemy, M. Megaly, K. Haggag, A. Hashem, Egypt. J. Chem. **62**, 231 (2019)
16. A. Nazari, A. Davodi-Roknabadi, A. Matin-Moghadam, M. Dehghani-Zahidani, Fibers Polym. **23**, 136 (2022). https://doi.org/10.1007/s12221-021-0292-7
17. H.M. Helmy, M.M. Kamel, K. Haggag, N. El-Hawary, N. El-Shemy, Egypt. J. Chem. **60**, 103 (2017)

18. M. Rehan, N.S. El-Shemy, K. Haggag, A.S. Montaser, G.E. Ibrahim, Cellulose **27**, 9893 (2020). https://doi.org/10.1007/s10570-020-03452-8
19. R. Pandey, S. Patel, P. Pandit, S. Nachimuthu, S. Jose, J. Clean. Prod. **172**, 1319 (2018). https://doi.org/10.1016/j.jclepro.2017.10.268
20. Q. Zhou, L.J. Rather, A. Ali, W. Wang, Y. Zhang, Q.M.R. Haque, Q. Li, Dyes Pigm. **176**, e108230 (2020)
21. J.M. Lorenzo, P.E.S. Munekata, A.S. Sant'Ana, R.B. Carvalho, F.J. Barba, F. Toldrá, L. Mora, Trends Food Sci. Technol. **77**, 1 (2018). https://doi.org/10.1016/j.tifs.2018.04.007
22. M.L. Francisco, A. Resurreccion, LWT Food Sci. Technol. **47**, 189 (2012). https://doi.org/10.1016/j.lwt.2011.12.008
23. M. Verma, S.J. Singh, N.M. Rose, Chem. Sci. Rev. Lett. **9**(34), 313 (2020)
24. S. Ahmed, M. Ahmad, B.L. Swami, S. Ikram, J. Adv. Res. **7**, 17 (2016). https://doi.org/10.1016/j.jare.2015.02.007
25. C. Vineis, I. Cruz Maya, S. Mowafi, A. Varesano, D.O. Sánchez Ramírez, M. Abou Taleb, C. Tonetti, V. Guarino, H. El-Sayed, Int. J. Biol. Macromol. **190**, 375 (2021). https://doi.org/10.1016/j.ijbiomac.2021.09.007
26. M. Abou Taleb, S. Mowafi, H. El-Sayed, J. Mol. Struct. **1202**, e127379 (2020). https://doi.org/10.1016/j.molstruc.2019.127379
27. S. Mowafi, M. Abou Taleb, H. El-Sayed, J. Clean. Prod. **202**, 45 (2018). https://doi.org/10.1016/j.jclepro.2018.08.141
28. H. El-Sayed, C. Vineis, A. Varesano, S. Mowafi, R.A. Carletto, F.T. Giachet, M. Abou Taleb, Nanotechnol. Rev. **8**, 236 (2019). https://doi.org/10.1515/ntrev-2019-0022
29. M. Abou Taleb, K. Haggag, T.B. Mostafa, A. Abou El-Kheir, H. El-Sayed, Indian J. Fibre Text. Res. **43**(1), 83 (2018)
30. A. Kantouch, O.G. Allam, L. El-Gabry, H. El-Sayed, Indian J. Fibre Text. Res. **37**(2), 157 (2012)
31. K. Haggag, F. Kantouch, O.G. Allam, H. El-Sayed, J. Nat. Fibers **6**, 236 (2009). https://doi.org/10.1080/15440470902975292
32. O.G. Allam, H. El-Sayed, A. Kantouch, K. Haggag, J. Nat. Fibers **6**, 14 (2009). https://doi.org/10.1080/15440470802699802
33. H. El-Sayed, J. Nat. Fibers **19**, 10293 (2021). https://doi.org/10.1080/15440478.2021.1993498
34. M. Abou Taleb, H. El-Sayed, J. Appl. Res. Technol. **19**, 508 (2021). https://doi.org/10.22201/icat.24486736e.2021.19.5.1443
35. T.A. Khattab, S. Mowafi, H. El-Sayed, Cellulose **26**, 9361 (2019). https://doi.org/10.1007/s10570-019-02721-5
36. N. El-Shemy, N. El-Hawary, K. Haggag, H. El-Sayed, Egypt. J. Chem. **63**, 3259 (2020)
37. S.H. Amirshahi, M.T. Pailthorpe, Text. Res. J. **64**(6), 357 (1994)
38. Tests for colour fastness – Part C06: Colour fastness to domestic and commercial laundering. ISO 105-C06:2010 (Updated in 2020).
39. Tests for colour fastness – Part C06: Colour fastness – Part B02: Colour fastness to artificial light: Xenon arc fading lamp test. ISO 105-B02:2014 (Updated in 2020).
40. Test for Colorfastness to Crocking: Crockmeter. AATCC Test Method 8–2016.
41. Test for Colorfastness to Perspiration: AATCC Test Method 15–2002.
42. Test for Assessment of Antibacterial Finishes on Textile Materials. AATCC TM100–2019.
43. Sun Protective Clothing – Evaluation and classification. Australian/New Zealand Standard®, AS/NZS 4399:1996.
44. Test Method for Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics. AATCC 183–2020.
45. S.K. Kyei, O. Akaranta, G. Darko, Sci. Afr. **8**, e00406 (2020)
46. E.H. Anouar, J. Gierschner, J.L. Duroux, P. Trouillas, Food Chem. **131**, 79 (2012). https://doi.org/10.1016/j.foodchem.2011.08.034
47. I.A. Mohamed, A. Moustapha, Molecules **15**, 7498 (2010). https://doi.org/10.3390/molecules15107498
48. N. El-Shemy, K. Haggag, E. El-Kharadly, H. El-Sayed, J. Nat. Fibers **14**, 10 (2017). https://doi.org/10.1080/15440478.2015.1133364
49. M. Abou Taleb, S.K. Gomaa, M.I. Wahba, R.A. Zaki, A.F. El-Fiky, H.A. El-Refai, H. El-Sayed, Int J. Biol. Macromol. **194**, 800 (2022). https://doi.org/10.1016/j.ijbiomac.2021.11.128
50. A. Kantouch, H. El-Sayed, A. El-Sayed, J. Text. Inst. **98**, 65 (2007). https://doi.org/10.1533/joti.2005.0249
51. R. El-Newashy, S. Mowafi, M. Abou Taleb, H. El-Sayed, Egypt J. Chem. **63**, 3191 (2020)
52. A. Kantouch, S. Mowafi, O.G. Allam, H. El-Sayed, Egypt. J. Chem. **54**, 189 (2011). https://doi.org/10.21608/ejchem.2011.1388
53. Y. Ma, W.L. Kerr, R.B. Swanson, J.L. Hargrove, R.B. Pegg, Food Chem. **145**, 883 (2014). https://doi.org/10.1016/j.foodchem.2013.08.125
54. R. Mongkholrattanasit, A. Cholachatpinyo, N. Tubtimthai, N. Rungruangkitkrai, Chiang Mai J. Sci. **41**(5), 1208 (2014)
55. H.L. Wang, J. Liu, D.R. Pang, T. Li, R.H. Liu, J. Funct. Foods **52**, 603 (2019). https://doi.org/10.1016/j.jff.2018.11.037