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Synchronized Dyeing and Finishing of Natural Silk Fabrics with Mulberry Leaves Extract

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Abstract

The environmental constrains issued recently in many countries reinforce the textile chemists and colorists to adopt eco-friendlier methods during dyeing and finishing of textile substrates. Herein, a genuine colorant extracted from mulberry leaves was used in dyeing of natural silk fabric using conventional heating as well as ultrasonic- or microwave-assisted dyeing. Dyeing of silk fabric was conducted also in presence of iron II sulphate heptahydrate as a mordant using different methods of mordanting. The colour strength, colorimetric data, fastness properties, antimicrobial properties, and the resistance to ultraviolet radiation of the dyed samples were monitored. The results proved that mulberry leaves' extract is a suitable eco-friendlier colorant for dyeing of natural silk fabrics with a high colour strength and satisfactory fastness towards light, washing, perspiration and crocking, in presence of FeSO4.7H2O as a mordant. The dyed fabrics exhibited excellent resistance to microbial attack, including Gram +ve, Gram –ve bacteria and a pathogenic fungus, as well as ultraviolet radiation.

Keywords: Dyeing, mulberry leaves, natural silk, fabric, antimicrobial, ultraviolet protection.

1. Introduction

Coloration of textile substrates is of prime importance regarding the appearance, and in some cases the performance attributes of the final products [1, 2]. Many attempts have been directed towards improving the dyeability as well as printability of different textiles [3–5]. Further work was devoted to reduce the overall cost of the dyeing operations [6–8]. Unfortunately, coloration of textiles is a very polluting process due to discharge of considerable amounts of synthetic dyes and pigments into the dye-houses' effluents [10, 11]. Wastewater treatment units should be usually implemented to remove the discharged pollutants before release into the drainage tubes [12].

Utilization of natural colorants in dyeing and printing of textiles is driven by many environmental legislations as and eco-friendly alternative to the synthetic dyes by virtue of their biodegradability and higher compatibility with the environment [13, 14]. Furthermore, most of natural dyes have multifunctional properties such as the inhibitory effect against pathogens, and adequate protection against ultraviolet rays [15, 16]. The natural dyes, which are usually used for coloration of textiles, are extracted from diverse part of plants; namely leaves, roots, bark, fruit, and skin [17].

Among proteinic fibres which are commonly used in the textile sector, natural silk comes in the second place after wool and before other proteinic substrates such as cashmere, mohair and angora. Natural silk is described as the "Queen of fabrics" among its analogous substances in the field; presumably due to

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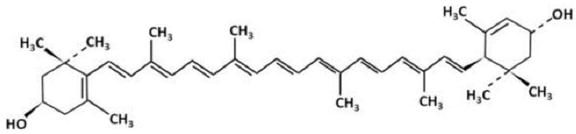
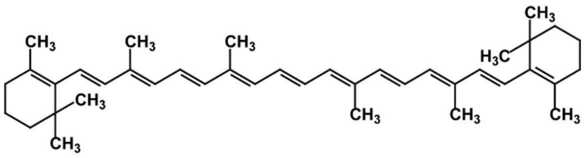
its unique and superior luster, handle and the draping qualities [18]. Coloration of natural silk is usually conducted using acid, basic and reactive dyes [19, 20]. Natural dyes from different sources have great share in coloration of natural silk. Sharma and Jahan utilized Jatropha flowers, Latana flowers, Hamelia leaves, Euphorbia leaves, Kilmora roots, and Walnut barks for dyeing of natural silk [21]. Other plants used in coloration of silk include camphor [22], Bauhinia vahliibark [23], Liriope platyphylla fruits [24], and mango bark [25].

Mulberry leaves extract was used by some researchers for coloration of wool and cotton and the dyed fabrics exhibited a range of colours according to the pH of the dyeing bath [26, 27]. Nevertheless, and up to our knowledge, no systematic study was reported in the literature for the utilization of mulberry leaves extract in dyeing of natural silk. The main coloring materials in mulberry leaves extract are: lutein (30.86%) and β-carotene (26.3%) [28]. The structural formulae of these coloring materials are shown hereafter.



Structure 1: Lutein



Structure 2: β-carotene

Among other methods [29], microwave irradiation and ultrasonic waves have been widely used to enhance the effectiveness of the dyeing process for various textile substrates using their respective dye classes [30–33]. In the current investigation, we extracted the coloring materials in mulberry leaves and utilized them in the dyeing of natural silk fabric using conventional heating method. In our attempt to save as much water and energy as possible during dyeing of natural silk, the dyeing of natural silk with the said extract was carried out under the influence of microwave irradiation as well as ultrasonic waves.

2. Experimental

2.1. Materials

Mulberry leaves were collected from our experimental unit in Suhag Governorate. Plain weave natural silk fabric (85 g/m^2) was purchased from El-Qammah Stores, Egypt. Before dyeing, silk fabrics were impregnated in a bath containing 2 g/L Triton X-100 (a nonionic detergent) for 1 h and the temperature was kept at 60°C; the liquor ratio (LR) was 1:50. The scoured fabrics were rinsed thoroughly with warm water, and dried at ambient conditions.

2.2. Methods

2.2.1. Extraction of colorant

Extraction of the colorant material from mulberry leaves was carried by heating the dried leaves in distilled water. The amounts of dried mulberry leaves ranged from 10 to 50 % (w/v), the extraction temperature was 60-100°C, and the extraction duration time was in the range 15-90 min. The colored extract was filtered while hot and left to cool down before dyeing operation.

2.2.2. Dyeing

Dyeing of natural silk fabrics with mulberry leaves extract (MLE) was conducted using conventional heating method, microwave irradiation, and ultrasonic waves as shown hereafter.

Conventional dyeing

To assign the optimum extraction conditions, the extracted colorants (using different extraction conditions) were used for dyeing of silk fabric at for 30 min at 100 °C and pH 4.5 (using acetic acid); the LR was 1:40.

Microwave-assisted dyeing

Microwave-assisted dyeing was carried out using the coloring extract from mulberry leaves at the optimum extraction conditions which were assigned from the conventional dyeing process. The dyeing process was carried out in a microwave oven at a power range from 50 to 80 % and pH 3 – 10 for 5–20 min; the MLR was 1:40.

Ultrasonic-assisted dyeing

Adopting the optimum extraction conditions, ultrasonic-assisted dyeing of natural silk fabrics was carried out at pH 3–10 for 20–100 min. The dyeing temperature was in the range 40–80 °C using ultrasonic power level 9; the MLR was 1:40.

Dyeing with a mordant

Pre-mordanting method

The mrodanting medium was prepared by dissolving iron II sulphate heptahydrate (2% o.w.f) in water. The fabric was submerged in the mordanting bath and the temperature was raised to 100ºC within 30 min in an infrared dyeing machine. The sample was then removed from the bath and dried at ambient conditions. Afterwards, the dried fabric was dyed with the MLE at the optimum conditions of conventional dyeing method, microwave-assisted method, and ultrasonic-assisted method.

Post-mordanting method

In this method, natural silk was dyed with the MLE, followed by soaking in the mordanting solution under the same conditions used in pre-mordanting method.

Meta-mordanting (Simultaneous) method

Concurrent dyeing and mordanting of natural silk fabric was implemented, following the same conditions used in the aforementioned pre-mordanting process.

2.3. Analyses and testing

2.3.1. Colour strength

The reflectance of the dyed fabrics was determined using a Perkin Elmer Lambda 3B UV/Vis spectrophotometer. The relative colour intensities (K/S) were calculated using the following *Kubelka-Munk* equation [33]. All K/S were measured at λ_{max}365 nm for silk fabric.

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

where R and R° denote the decimal fractions of the reflectance of the colored and uncolored fabrics, respectively; and “K” and “S” are the absorption and scattering coefficients, respectively.

2.3.2. Colorimetric data

The colorimetric parameters of all colored samples were measured using the CIELAB color spaces using a Hunter-Lab spectrophotometer (Hunter Lab DP-9000). The positive values of $L*$, $a*$ and $b*$ indicate the lightness, redness, and yellowness of the dyed fabrics, respectively [17].

2.3.3. Fastness properties

The fastness properties of some dyed silk fabrics were evaluated using the respective ISO standard methods. The standard test methods for color fastness against washing [34], light [35], dry, and wet rubbing [36], as well as perspiration [37], were used.

2.3.4. Determination of the Ultraviolet protection factor (UPF)

The UPF of the dyed fabrics was automatically calculated using the Australia/New Zealand standard AS/NZS 4399:1996 using the UPF calculation system of a UV/Vis spectrophotometer (AATCC Test Method 183:2010-UVA Transmittance).

2.3.5. Antimicrobial properties

The antimicrobial activity of selected dyed as well as the undyed natural silk fabrics were assessed against the Gram-ve bacteria *E. Coli* (ATCC 25922), the Gram+ive bacteria *S. aureus* (ATCC 6538), and the pathogenic yeast *C. albicans* (ATCC 10231).

The samples were applied to the said strains by using shake flask method to calculate the antimicrobial activity expressed throughout the (%) reduction of bacterial count. This was brought about by calculating the colony forming unit (CFU) of the tested strains after being treated with that tested samples compared to the number of microorganisms cells surviving in the control flask after 24 hours incubation period and at 37 ºC for bacteria and pathogenic yeast [38]. All results were expressed according the following equation:

Relative Reduction (%) = (A- B /A) × 100

Where "A" is the number of microorganisms present on control flask contains pathogenic strains only without any treatment, and "B" is the number of microorganisms which present in the tested flasks after applying tested treated sample.

3. Results and discussion

3.1. Conventional extraction of dye

***3.1.1*. Effect of colorant concentration**

The extraction of dry mulberry leaves was carried out at 100 °C for 60 min and at different concentrations (20–100 g/L). Figure1illustrates that as the dye amount % (amount of dye used per 100 ml distilled water) increased, the K/S of the dye extract also increased. The maximum extractability was attained upon using 80 g/L of the colored material. Nevertheless, and for the sake of saving materials, we decided to use an amount of 8 g colorant/L which provided adequate colour strength of the extract that would assure higher colour strength of the dyed fabrics.

3.1.2. Effect of extraction temperature

The extraction of the colorants from dry mulberry leaves was conducted at the boil using 80 g/L of the leaves for 1 h and at different temperatures (60–100 °C). The effect of extraction temperature on the colour intensity of the colored extract was examined and the results were shown in Figure 2. It is clear from this figure that in case of conventional heating, there is a direct relationship between the extraction temperature and the colour intensity of the dye extract. The maximum K/S value for an extract was attained if the extraction temperature was maintained at 100 °C.

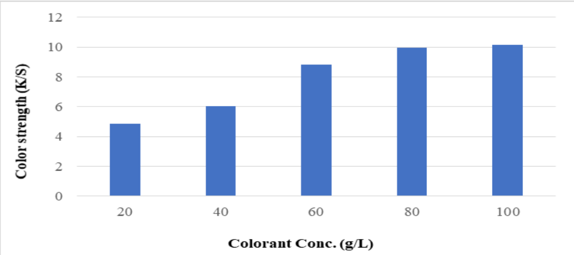


Fig. 1: Effect of colorant concentration on the colour intensity of the dyed silk fabric by conventional heating method (Extraction conditions: 1 h, LR, 1:40, pH 4, and temperature 100°C)

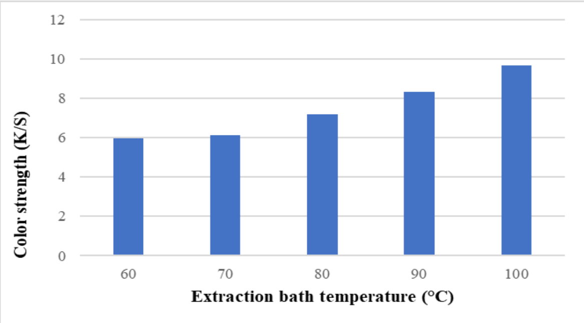


Fig. 2: Effect of extraction temperature on the colour intensity of the dyed silk fabric by conventional heating method (Extraction conditions: 80 g/L, 1 h, L.R. 1:40, and pH 4,)

3.1.3. Effect of extraction time

The extraction of colorant from dry mulberry leaves was carried out using80 g/L dry mulberry leaves at 100 °C for different times (20–100min). Figure3 shows that there is a direct correlation between the extraction time and the colour intensity of the extract.

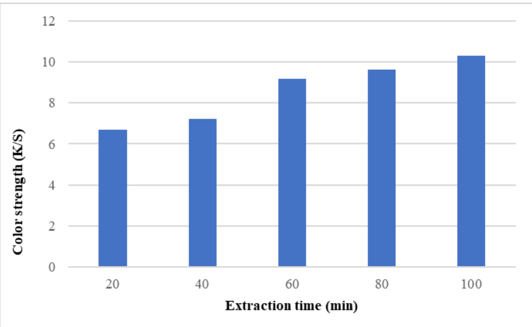


Fig. 3: Effect of extraction time on the colour intensity of the dyed silk fabric by conventional heating method (Extraction conditions: 80 g/L, 100°C, 1 h, L.R. 1:40, pH 4)

3.2. Factors affecting the dyeing process

3.2.1. Effect of dye bath pH

The dyeing temperature and pH are crucial during dyeing of textile substrates using natural colorants [39]. The effect of the dye-bath pH on the colour intensity of the dyed silk fabric using mulberry leaves extract (MLE) was shown in Figure 4. From this figure, it can be concluded that the pH of the dyeing process is crucial up on dyeing of silk fabric with MLE using conventional heating method. Silk fabric exhibited maximum dyeability at pH 4; the increase in the pH of the dyeing bath towards neutral then basic media declined the fabric dyeability sharply. These results can be attributed to the presence of acidic groups within the chemical structure of one or more components in the extracted colorant. It has been reported that the berry leaves extract contains many phenolic acids, such as caffeic acid, gallic acid, ferulic acid, and vanillic acid [40]. These groups can form salt link with the protonated amino groups of proteinic biopolymers such as wool and silk [41]. Another factor which may decreases the dyeability of silk with MLE in basic medium is the presence of small ratios of transition metal ions in the chemical composition of MLE, viz. iron II, zinc, copper II, cobalt II, manganese IV, chromium III, molybdenum VI, nickel II, and cadmium ions [42]. These ions may start to precipitate in basic medium as metal hydroxides, and hence the colorant substantivity towards silk fabric would decrease accordingly.

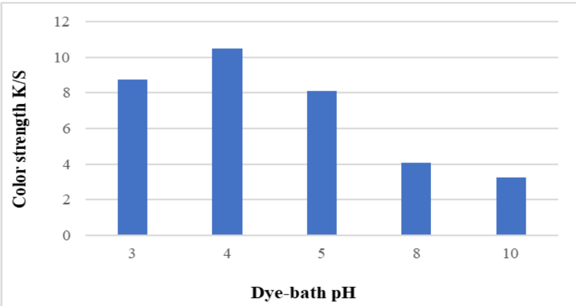


Fig. 4: Effect of pH of dyeing bath on the colour strength of silk fabrics dyed with mulberry leaves extract (Dyeing conditions: 1 h, L.R. 1:40, temperature 100°C)

3.2.2. Effect of temperature

The dyeability of silk fabric with MLR was examined different temperatures. As would be expected, increasing the dyeing temperature led to enhancing the K/S of the dyed silk fabric. The maximum colour intensity was obtained upon dyeing silk fabric at 100 ºC (Figure5).

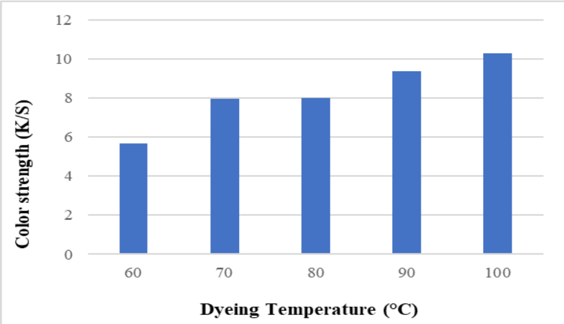


Fig. 5: Effect of dyeing temperature on the colour strength of the silk fabrics dyed with mulberry leaves extract (Dyeing conditions: 1 h, L.R. 1:40, pH 4)

3.2.3. Effect of dyeing time

As in most of the dyeing operations for textile substrates dyed with various classes of dyes, the data in Figure 6 implies that the colour strength of silk fabric dyed with MLE increased as the dyeing time was increased.

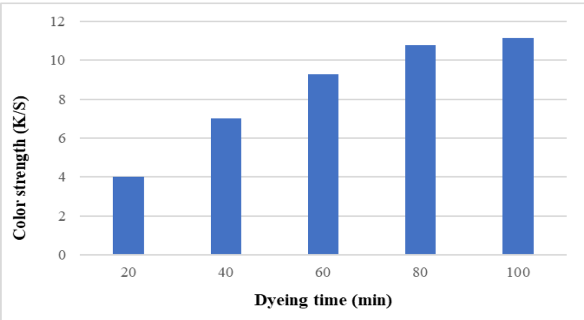


Fig. 6: Effect of dyeing time on the colour strength of silk fabrics dyed with mulberry leaves extract (Dyeing conditions: pH 4, L.R. 1:40, temperature 100°C)

The colorimetric data of the dyed silk fabric is presented in Table 1. Results of this Table clarify that as the dyeing time increased from 15 to 60 min, the dyed fabric gets darker as indicated by the decrease in the "L" values; further increase in the dyeing time to 75 and 90 min has limited effect on the "L" value for the dyed fabric. The data of this table clarifies also that as the dyeing time was prolonged the hue of the fabric got closer towards the red and blue regions and away from the green and yellow, as indicated by the values of "a" and "b", respectively. Figure 6 shows the discrepancy in the colour of the dyed samples at different dyeing times.

Table 1: Colorimetric data of natural silk fabrics dyed with mulberry leaves extract

Time (min)	L	a	b	c	H	ΔE
20	50.97	19.00	2.98	19.79	17.26	1.24
40	43.46	8.99	0.46	11.55	10.56	0.79
60	41.47	11.55	0.11	14.70	12.47	3.99
80	38.94	12.05	-0.38	9.00	12.40	4.74
100	38.91	12.77	-0.84	12.30	16.08	4.29

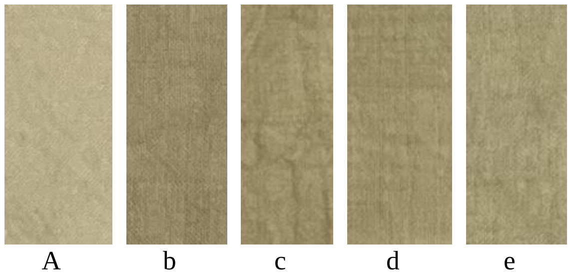


Fig. 7: Some colour samples obtained by dyeing of natural silk with MLE at different dyeing times (a: 20 min, b: 40 min, c: 60 min, d: 80 min, e: 100 min)

3.3. Microwave-assisted dyeing of natural silk

The effect of dyeing pH, microwave (MW) power, and dyeing time during dyeing of silk fabric with MLE under the influence of MW radiation, on its K/S as well as colorimetric data were monitored. The results of this investigation were summarized in Tables 2–4.

The data in Table 2indicates that the optimum pH of dyeing natural silk fabric with MLE is 5. Surprisingly, natural silk exhibited very low dyeability towards MLE at pH 3 or 4, and relatively high dyeability at pH 8 and 10. Compared to the results shown in Figure 4, the optimum pH for dyeing of natural silk with MLE using conventional heating method was 4 and not pH 5 as in MW-assisted dyeing method. It seems that the microwave radiation caused a decrease in the pH of the dyeing bath, most probably due to decomposition of basic groups-containing compounds or formation of new acidic compounds under the influence of MW radiations.

Table 2: Effect of pH on the colour strength and colorimetric data of natural silk fabric dyed with MLE using microwave heating (Dyeing conditions: 80g/L dry mulberry leaves,30 min, L.R 1:40, MW power level 70)

pH of the dye bath	K/S	L	a	b	ΔE
3	0.74	81.86	9.24	9.24	28.58
4	3.80	81.50	2.78	7.12	26.58
5	7.65	66.30	3.42	14.75	45.43
8	3.69	72.94	8.96	40.80	42.86
10	3.43	77.04	7.84	37.25	38.24

The colorimetric data of the dyed fabrics imply that at pH 5 the sample gets darker, redder, and bluer; and the deviation from this pH value resulted in lighter, greener, and yellower hues.

It is obvious from Table 3 that the increase in the MW power during dyeing of natural silk with MLE from 50 Watt up to 70 Watt highly improved the K/S values of the dyed silk fabric. Further increase in the MW power to 80 Watt resulted in limited improvement in the colour intensity of the dyed fabric.

As shown in Table 4, as the dyeing time of natural silk with MLE under the influence of MW radiation up to 50 min, the colour intensity of the dyed silk fabric increased. No reasonable increase in the colour intensity of the dyed sample was observed when the time was further prolonged to 60 min.

3.4. Ultrasonic-assisted dyeing of natural silk

Ultrasonication is usually used to enhance the dyeing efficiency during dyeing of various textile substrates using their respective dye classes. The effect of different dyeing conditions on the colour intensity and colorimetric data of the dyed natural silk fabric was shown in Tables 5–8. The data in these tables clarify that the most appropriate dyeing conditions for natural silk fabrics with the MLE under the influence of ultrasonic waves are pH 4, 80 °C, and 60min. It has been reported that the induced cavitation and micro-streaming under the influence of ultrasonication accelerates enhances the penetration of the dye molecules into the fiber interior. Concurrently, sonication enhances the rate of chemical combination between dye and fibre [43]

Table 3: Effect of power level on the colour strength and colorimetric data of natural silk fabric dyed with MLE using microwave heating (Dyeing conditions: 80g/L dry mulberry leaves, 30 min, L.R 1:40, and pH 5)

Power (Watt)	K/S	L	a	B	ΔE
50	3.31	67.25	2.38	19.50	21.19
60	3.09	67.87	2.83	19.70	20.96
70	7.65	61.97	3.42	20.57	25.97
80	7.99	65.64	3.09	19.86	22.69

Table 4: Effect of dyeing time on the colour strength and colorimetric data of natural silk fabric dyed with MLE using microwave heating (Dyeing conditions: 80g/L dry mulberry leaves, power 70-Watt, L.R 1:40, and pH 5)

Dyeing time (min)	K/S	L	A	b	ΔE
5	1.84	70.10	1.47	15.69	21.19
10	3.36	63.94	2.65	20..68	28.58
20	4.41	64.92	2.51	21.20	26.58
30	7.65	62.42	2.61	22.92	25.43
40	7.73	61.35	2.63	24.34	22.86
50	8.46	57.03	2.96	27.08	28.24
60	8.57	62.11	2.52	22.14	28.58

Table 5: Effect of pH on the K/S and colorimetric data of natural silk fabrics dyed with MLE assisted by ultrasonic waves (Dyeing conditions: 80g/L dry mulberry leaves, power level 9, L.R 1:40, at 80℃ for 1 h)

pH of dyeing	K/S	L	A	b	ΔE
3	3.20	76.44	8.43	27.71	29.62
4	5.22	79.96	9.73	48.95	30.04
5	1.63	77.18	11.49	44.86	25.03
8	1. 56	76.33	11.63	42.89	29.31
10	1.22	69.83	13.27	48.20	51.65

Table 6: Effect of dyeing time on the K/S and colorimetric data of natural silk fabrics dyed with MLE assisted by ultrasonic waves (Dyeing conditions: 80g/L dry mulberry leaves, power level 9, L.R 1:40, at 80℃ and pH 4)

Time (min)	K/S	L	a	B	ΔE
20	1.17	68.20	11.81	49.85	51.82
40	1.28	66.38	14.78	44.64	53.23
60	5.22	63.10	3.12	16.90	22.92
80	4.40	63.10	3.12	16.90	22.92
100	4.45	63.10	3.12	16.90	22.92

Table 7: Effect of dyeing temperature on the K/S and colorimetric data of natural silk fabrics dyed with MLE assisted by ultrasonic waves (Dyeing conditions: 80g/L dry mulberry leaves, power level 9, L.R 1:40, for 60 min and pH 4)

Temp. (°C)	K/S	L	a	B	ΔE
40℃	2.99	68.42	2.53	17.42	19.53
50℃	3.05	68.64	3.57	18.25	18.95
60℃	5.22	69.41	3.32	17.87	18.69
70℃	6.89	64.44	2.73	17.66	22.19
80℃	8.22	63.10	3.12	16.90	22.92

3.5. Effect of mordant

The effect of mordant (iron II sulphate heptahydrate) on colour strength and the fastness properties of natural silk fabrics dyed with MLE using conventional, microwave-assisted, and ultrasonic-assisted methods was monitored. The results declared in Table 8 reveal that dyeability of natural silk with MLE was enhanced remarkably in presence of iron II sulphate as a mordant whatever the applied method of heating. The colour intensity of the dyed fabric increases in the order: no mordant<post-mordanting<meta-mordanting<pre-mordanting method.

3.6. Fastness properties

The fastness properties of the dyed fabrics towards rubbing, perspiration, washing, and light were assessed. The results of this investigation, shown in Tables 9–11, reveal that the fastness properties of the fabrics dyed using conventional heating, ultrasonic waves, and microwave radiation are in the ranges 2–3, 2–4, and 3–4, respectively. There is significant increase in the fastness properties of samples which were dyed in presence of a mordant, with maximum improvement in case of pre-mordanting methods.

Table 8: Effect of using mordant on the color strength of silk fabric dyed with MLE using conventional, ultrasonic and microwave methods (at 80 °C) at the respective optimum conditions

Method	K/S		
	Conventional	Ultrasonic	Microwave
No mordant	8.04	8.22	8.46
Pre-mordanting	10.10	10.50	10.12
Meta-mordanting	9.67	9.90	9.67
Post-mordanting	9.20	9.80	9.35

Table 9: Fastness properties of natural silk fabrics dyed with MLE in presence of a mordant using (pre-, meta-, and post-mordanting) using conventional heating method.

Method	Crocking	Acidic perspiration	Alkaline perspiration	Washing	Light
No mordant	2	2	2	2	3
Pre-mordanting	3-4	3-4	3-4	3-4	4
Meta-mordanting	3	3-4	3	3	3-4
Post-mordanting	2-3	3	3	2-3	3

Table 10: Fastness properties of natural silk fabrics dyed with MLE in presence of a mordant (pre-, meta-, and post-mordanting) using ultrasonic waves.

Method	Crocking	Acidic perspiration	Alkaline perspiration	Washing	Light
No mordant	2-3	3	3	3	3-4
Pre-mordanting	4	4	4	3-4	5
Meta-mordanting	3-4	3-4	3-4	3-4	4-5
Post-mordanting	3	3	3	3	3-4

Table 11: Fastness properties of natural silk fabrics dyed with MLE in presence of a mordant (pre-, meta-, and post-mordanting) using microwave radiation

Method	Crocking	Acidic perspiration	Alkaline perspiration	Washing	Light
No mordant	3-4	3-4	3-4	4	4
Pre-mordanting	4-5	4-5	4-5	5	5
Meta-mordanting	4	4	4	4-5	4
Post-mordanting	3-4	3-4	4	4	4

3.7. Antimicrobial properties

Functional finishing of fabrics is usually used to enhance the performance, appearance, and comfort attributes of the textile product [44, 45]. Enhancing the resistance of natural silk against microbes and UV rays would prevent its deterioration and increase its life time. Table 12 summarizes the resistance of natural silk fabric dyed with MLE in presence and absence of a mordant against Gram –ve bacteria (*Escherichia Coli* and *Pseudomonas aeruginosa*), Gram +ve bacteria (*Staphylococcus aureus* and *Bacillus cereus*), and the pathogenic fungus *Candida albicans*, as well as the UV rays (expressed as UPF).

Data in Table 12 revealed the inadequacy of the resistance of undyed natural silk fabric against Gram +ve, Gram –ve, and pathogenic fungus. The resistance of silk fabric towards the aforementioned microbes was highly improved when dyed with MLE. It has been reported that mulberry leaves have antimicrobial activity by virtue of the presence of some phenolic acids which have antimicrobial property [46].

On the other hand, the UPF of natural silk fabrics were changed from 34.05 (good protection) in case of undyed fabric to higher than 48 (excellent protection) in case of dyed fabrics in presence or absence of a mordant. The presence of aromatic compounds in the MLE could be the main reason for the induced ultraviolet protection. It was concluded by many authors that the phenolic compounds are capable of scavenging free radicals created under the influence of UV radiation and bringing about anti-ultraviolet radiation property [41].

Table 12: Antimicrobial properties and ultraviolet resistance of natural silk fabric dyed with MLE in presence and absence of mordant

Sample	Reduction in Colony Count (%)			UPF
	E. Coli	*S. aureus*	*C. albicans*	
Undyed	13.4	15.5	11.2	34.05
Dyed without mordant	82.7	80.44	84.57	48.60
Pre-mordanting	91.6	94.8	91.3	49.81
Meta-mordanting	95.0	93.7	94.6	52.22
Post-mordanting	88.9	94.1	93.5	51.73

Conclusion

Based on the above results, mulberry leaves' extract (MLE) was found to be suitable candidate for dyeing of natural silk fibre in presence and absence of iron II sulphate heptahydrate as a mordant. The dyeability of natural silk fabric with MLE was even enhanced under the influence of ultrasonic waves and microwave radiations. The fastness properties of the dyed fabric towards light, washing, rubbing and perspiration ranged between poor to excellent depending on the dyeing and mordanting methods. It was concluded also that the MLF can impart antimicrobial property and excellent resistance to UV radiation to the dyed natural silk fabrics.

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