Adsorption, kinetics, and thermodynamic study of dyeing the Scutellaria Orientalis L as an eco-friendly natural colourant on cotton fabric

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ABSTRACT – REZUMAT

Adsorption, kinetics, and thermodynamic study of dyeing the Scutellaria Orientalis L as an eco-friendly natural colourant on cotton fabric

The adsorption isotherm, thermodynamic parameter, and kinetics study for dyeing without mordanting cotton fabric dyed with natural dye obtained from an aqueous extract of the Scutellaria Orientalis were investigated using, as optimal conditions, at pH of 5 a material to liquor ratio (MLR) of 1:100, an initial dye concentration of 1.0/l and contact time (20–90 min.). The effect of the temperature and dyeing time (from 20–90 min.) on dyeing was evaluated using three different temperatures (from 60, 80, and 90°C). Also, the adsorption isotherms have been analyzed by Langmuir and Freundlich models. It is revealed that the adsorption kinetics was found to follow the pseudo-first-order kinetic model, the obtained adsorption isotherm was found to be suitable for both Langmuir and Freunlich adsorption isotherm, and the dyeing process is exothermic. The rate of dye uptake and thermodynamic parameters have also been calculated and discussed.

Keywords: *Scutellaria orientalist L, cotton, dyeing, adsorption, isotherm, thermodynamic*

Adsorbția, cinetica și studiul termodinamic al vopsirii ţesăturii de bumbac cu colorantul ecologic natural Scutellaria Orientalis L

Studiul izotermei de adsorbție, al parametrului termodinamic și al cineticii pentru vopsirea fără mordansare a țesăturii de bumbac cu colorant natural obținut dintr-un extract apos de Scutellaria Orientalis a fost investigat folosind condițiile optime: la un pH de 5 un raport de flotă (MLR) de 1:100, o concentrație inițială de colorant de 1,0/l și un timp de contact de 20–90 minute. Influența temperaturii și al timpului de vopsire (de la 20–90 min.) asupra vopsirii a fost evaluată folosind trei temperaturi diferite (de la 60, 80 și 90°C). De asemenea, izotermele de adsorbție au fost analizate prin modelele Langmuir și Freundlich. S-a descoperit că cinetica de adsorbție urmează modelul cinetic de pseudo-ordin întâi, izoterma de adsorbție obținută s-a dovedit a fi potrivită atât pentru izoterma de adsorbție Langmuir, cât și pentru Freundlich, iar procesul de vopsire este exoterm. Rata de absorbție a colorantului și parametrii termodinamici au fost, de asemenea, calculaţi și discutaţi.

Cuvinte-cheie: *Scutellaria orientalis L, bumbac, vopsire, adsorbție, izotermă, termodinamic*

INTRODUCTION

The use of natural dyes to colour textiles (silk, wool, cotton, and leather) had been flourishing for thousands of years until the appearance of synthetic dyes in 1856. Since synthetic dyes have apparent advantages such as overall chromatography, good fastness, good colour reproducibility, and low costs, natural dyes almost disappeared after the discovery of synthetic dyes. However, recently there has been a revival of growing interest in the application of natural dyes on natural fibres due to worldwide environmental consciousness [1]. Moreover, compared with synthetic dyes, natural dyes exhibit some functions and better biodegradability and compatibility with the environment [2]. Thus, more and more natural dyes including Scutellaria Orientalis L have been reused in textile dyeing [3]. Scutellaria plants are known to contain large amounts of flavones. The main flavonoids of this genus are baicalein, wogonin, and chrysin [4]. Its chemical structure is shown in table 1 and figure 1. Chrysin (5,7-dihydroxyflavone), a natural flavonoid that is found in many plant extracts, honey, and propolis is reported to possess antioxidant property [5]. Chrysin possesses different biological activities such as antiviral anti-inflammatory and anti-diabetic antioxidant and anticancer properties. Wogonin is another flavour-noid-like chemical compound found in the dried root of Scutellaria. Baicalein, 5,6,7-trihydroxy flavone, is the main bioflavonoid found among other flavonoid derivatives in the roots of S. baicalensis. Numerous studies have demonstrated that it has a broad spectrum of bioactivity, including anti-oxidative [4].

Scutellaria is a genus of flowering plants belonging to the Lamiaceae family. They are known commonly as skullcaps and include about 350–400 species [5]. Most are annual or perennial herbaceous plants, and more rarely, subshrubs, worldwide, excluding South Africa [5, 6]. It has been widely used in different fields such as food additives, cosmetics, pharmaceuticals, colourants in textiles, and so on. However, it is rare for them to dye Scutellaria plants with cotton, silk,

Table 1

COMPUNDS OF OF SCUTELLARIA ORIENTALIS L.							
Compounds	R_1	R_2	R_3	R_4	R_5	R_6	**The molecular formula and Mol.Wt.**
Baicalein	-	-	-	OH	OH	OH	$C_{15}H_{12}O_5$, 272.25 g
Wogonin	CH_3	-	-	OH	-	OH	$C_{16}H_{14}O_{4,}$ 270.28 g
Chrysin	-	-	-	OH	-	OH	$C_{15}H_{12}O_{4,}$ 256.25 g

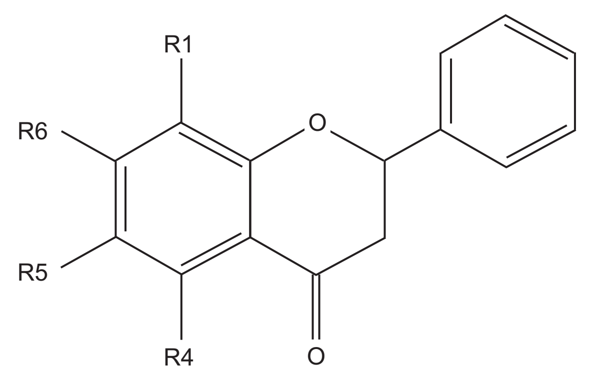

Fig. 1. Chemical structure of Scutellaria Orientalis L.

and wool fibres, they are generally widely used in medicinal fields. Whereas, there are a lot of thermodynamic and kinetics studies on natural dyes in the literature. Samanta and Agarwal investigated the Physicochemical studies on the dyeing of jute and cotton fabrics using jackfruit wood extract, dyeing kinetics, and thermodynamics [7]. Samanta et al reported the dyeing of jute fabric with tesu extract, thermodynamic parameters, and kinetics of dyeing [8]. In another study, thermodynamic and kinetic studies of the adsorption behaviour of the natural dye cochineal on polyamide66 were reported [9]. In another study, kinetics and thermodynamics studies of cationic dye adsorption onto carboxymethyl cotton fabric [10]. However, not much has been reported in the literature about the dyeing kinetics and thermodynamics for the dyeing of cotton fabric using Scutellaria Orientalis L. natural dyes. Hence, the main aim of this present work is to extract aqueous colourants of various shades from Scutellaria Orientalis L and to apply them in cotton fabric dyeing. On the other hand, the adsorption isotherms, kinetics, and thermodynamic parameters were studied in detail.

MATERIALS AND METHODS

Materials

A Commercially scoured, and bleached cotton fabric was received from Kipaş Co., Ltd., Turkey. Scutellaria Orientalist flowers were collected in the season in Van-Turkey. Plants collected were dried under shady and airy conditions, and for the preparation of the solutions Distilled water was used for the preparation of the dyeing solutions.

Methods

Dye extraction

This study used the solid-liquid extraction method, and due to the evaporation of the solvent in the extraction process, the temperature was not increased above the boiling point of the solvent. About 5 g of dried Scutellaria Orientalist L. were weighed taken in the 500 ml beaker and dissolved in 300 ml of solvent (H_2O). After heating the beaker at 70–80°C for 1 h, the extract was filtered, and the solution was stored for later use as an aqueous dye extract.

Dyeing process

The natural dye extracted from Scutellaria Orientalist extracts dye onto cotton fabric was carried out through an exhaustion dyeing process, and the solution containing 100% o.w.f (on the weight of the fabric), and liquor ratio 50:1. The pH of the dye solutions was 7. Next, a steel cup with the dye solution and the fabrics were placed in the YK-12 dyeing machine (Atac Textile Machinery Co., Ltd. Turkey) for dyeing. The dyeing of fabrics was commenced at ambient temperature, and the dye solution was subsequently heated under a heating rate of 2°C/min to 60, 80, and 90°C, and maintained at this temperature for 40 to 90 min. for dyeing time.

Effect of pH on dye extract

The effect of pH on the colour value of the dye extract of Scutellaria orientalist was determined by recording the visible spectra (Optizen 3220 UV/Vis spectrophotometer) of the dye solution at different pHs (5, 7, and 9). Acetic acid buffer was used to maintain pH in range 5, and sodium hydroxide buffer was used to maintain pH 7–9.

Dye exhaustion

Dye exhaustion means the amount of dye adsorbed by the fibres, fabric, etc. Exhaustion percentage (*E*%) is determined by measuring the absorbance of extract Scutellaria Orientalis extracts dyebath before and after dyeing, respectively. After the dyeing process, the absorbance of the dyeing solutions was measured using a (Shimadzu UV-Vis 1240) spectrophotometer set at a wavelength of 410 nm, maximum absorbance. The exhaustion percentage (*E*%) was calculated using equation 1 [11].

$$E\% = \frac{A_0 - A_t}{A_0} \times 100 \qquad (1)$$

where A_0 is the absorbance of Scutellaria Orientalist flower extracts dye solution before dyeing and A_t – the absorbance of Scutellaria Orientalist flower extracts dye solution after dyeing.

The amount of Scutellaria Orientalist flower extracts dye adsorbed $[D]_{f,t}$ (g/g) by per unit weight of the cotton fabric at time t was calculated by using equation 2 [11]:

$$[D]_{f,t} = \frac{[C_0] - [C_t]V}{m} \qquad (2)$$

where C_0 is the initial concentration (g/l) of Scutellaria Orientalist flower extracts dyebath, C_t – the concentration (g/l) of Scutellaria Orientalist L extracts solution after time t (min), V – the volume of the Scutellaria Orientalist flower extracts dye solution (L), and m – the weight of cotton fabric (g) used for dyeing in the dyebath. After completion of dyeing, the residual dye bath liquor was measured on a Shimadzu UV-Vis 1240 absorbance spectrophotometer, subsequently, the concentration of Scutellaria Orientalist flower in the extracts in the dyebath (C_t) was calculated using a linear regression equation of the standard curve. The amount of extracts dye adsorbed by per unit weight of the cotton fabric at equilibrium $[D]_e$ (g/g) was calculated using equation 3 [11, 12]:

$$[D]_e = \frac{(C_0 - C_e)V}{m} \qquad (3)$$

Where D_e is the amount of dye adsorbed (g/g), C_0 and C_e are the initial and equilibrium dyebath concentrations of dye (g/g) respectively.

Fourier Transform Infrared (FTIR) Analysis

Fourier transform infrared (Bruker ALPHA model) dye and dyed cotton fabric were analyzed for dye interactions (with a resolution of 4 cm^{-1}). Bands in the FTIR spectra were analyzed by the literature data.

Colourfastness properties

The ability of the dye to be retained by the fabric during washing and on exposure to light was evaluated by the respective colourfastness tests. These were carried according to, ISO 105 C03, and ISO 105 BO2 for washing, and, light fastness, respectively.

Greyscale was used to rate the colour fastness between one and five.

RESULTS AND DİSCUSSION

Effect of dyeing time on the exhaustion percentage

The effect of dyeing time on the *E*% of Scutellaria Orientalist extract dye into the cotton fabrics at different temperatures (60, 80, and, 90°C) with an applied dosage of 1% o.w.f of dye is shown in figure 2. As can be seen in figure 2, the dyeing uptake of Scutellaria Orientalist dye on cotton fabrics increases with the extension of dyeing time, and the initial dyeing rate is faster. However, with time extension, the increase of the dyeing rate slows down and gradually reaches a stable state after 60 min, and the higher the dyeing temperature is, the higher the dyeing uptake is, and higher temperatures lead to shorter equilibrium time. Also, Scutellaria Orientalist extracts showed a thermal property against higher dyeing temperatures. The thermal stability of Scutellaria Orientalist extracts dye proves that when dyeing cotton fabric at high temperatures does not influence the detection of *E*%. These results showed that the *E*% increased with increasing dyeing time, and dyeing of equilibrium times was found to be 75, 60, and 55 min at 60, 80, and 90°C respectively. It is found that for Scutellaria Orientalist extract dyeing onto cotton fabric, 90°C is the optimal dyebath temperature to promote dye exhaustion into the fibre from the dyebath. This can be explained by the dye solution being more quickly transferred from the dyebath to the fabric [11]. Similar results have also been reported in the previous study [13–15].

The substantivity of Scutellaria orientalist dye on cotton fabric

The substantivity is usually used to determine which dye the fibres prefer to the dye bath. It represents the relationship between substantivity, liquor ratio, and the percentage of exhaustion at equilibrium. The substantivity can be calculated using the following equation [11]:

$$K = \frac{\%E_e\,L}{100 - E_e} \qquad (4)$$

where K is the substantivity, $\%E_e$ – the percentage of exhaustion at equilibrium, and L – the liquor ratio. The K value indicates the efficiency of dye transferred from the dye bath to the substrate. A greater value of K means that the dye is favoured to stay in the fibre. The parameters of substantivity of dyeing are presented in table 2. A higher K value suggests higher substantivity of Scutellaria orientalist extracts

Table 2

PARAMETERS OF SUBSTANTIVITY OF DYEING

Temperature (°C)	$\%E_e$	L	K
60	75.4	50	153
80	84.5	50	272
90	88.7	50	392

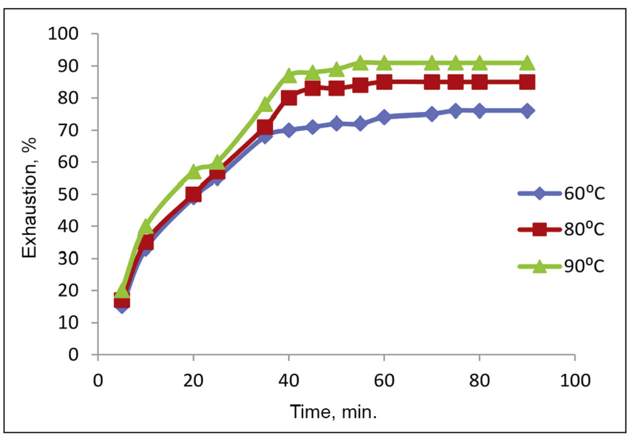

Fig. 2. The effect of of dyeing time on *E*% at different temperatures with 1% o.w.f Scutellaria Orientalist extract and a liquor ratio of 50:1

dye toward cotton fabric and also higher transport of the dye from the dyebath to the fibre. A higher *K* value specifies that more dye could remain inside the fibre than in the dye bath.

Effect of dyeing temperature on the exhaustion percentage

The effect of dyeing temperature on the exhaustion percentage was studied in the range of temperature between 60 to 90°C for Scutellaria Orientalis extracts 1% o.w.f of extract. The obtained results are shown in figure 3. As can be seen from the figure, the exhaustion percentage increased with temperature 60 to 90°C, the exhaustion percentage, but, the increasing rate of the exhaustion began to slow after 80°C which is almost close to that at 90°C.

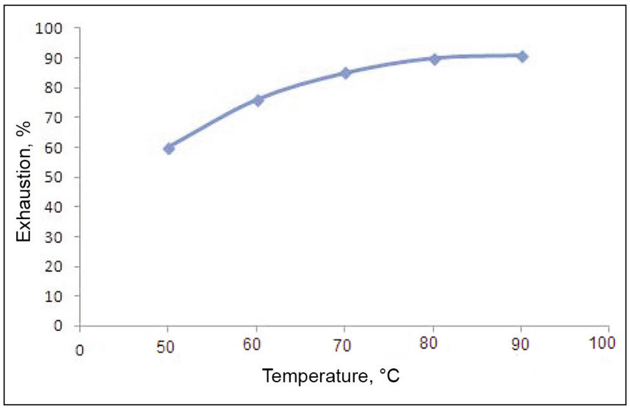

Fig. 3. The effect of dyeing temperature (60–90°C) on *E*% (conditions: with 1% owf of Scutellaria Orientalis extract dye for 90 min. dyeing time, liquor ratio: 50:1)

Effect of pH on dye extract

The visible spectra of the dye extract of Scutellaria Orientalis were measured at pH 5, 7 and 9. The spectra in figure 4 show that the absorbance value is low at pH 7. However, the absorbance value of the dye increases at pH 9, but the maximum absorbance was observed at pH 5, which may be attributed to the increased solubility of polyphenol and flavonoid groups at these values.

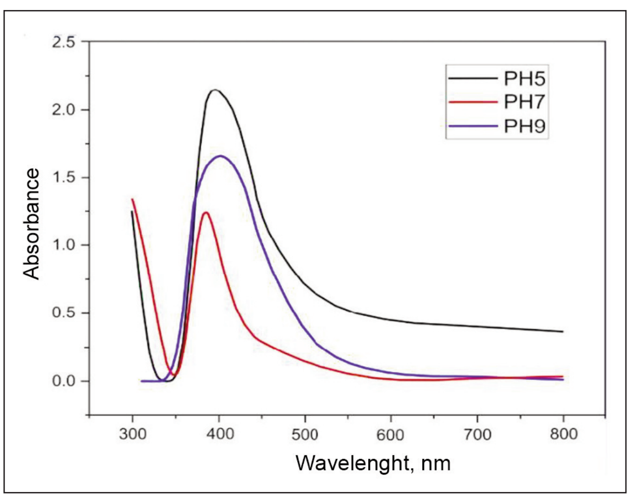

Fig. 4. UV-Vis spectra of the aqueous extracts of Scutellaria Orientalis plant at different pH

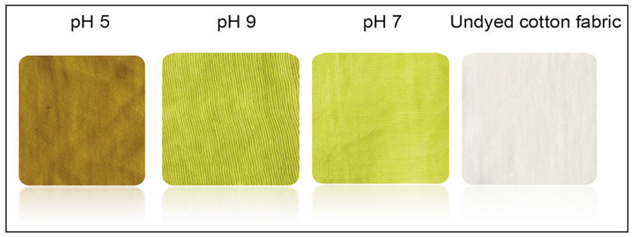

Fig. 5. Photos of cotton fabrics dyed with Scutellaria Orientalis Plant at different pH

It was observed that cotton is significantly attracted by the three different pH extracts This indicates the availability of studying the optimum condition of dyeing and the effect of different mordants

Colourfastness properties

The fastness properties of fabrics dyed with Scutellaria Orientalis with different pH were evaluated in terms of the fastness of washing, and fastness of the light colour alteration as shown in table 3. In the test for colour fastness to artificial light, it was found that all the samples showed a good light fastness rating of 4 and 5 on grayscale. Considering the fastness and properties of the cotton fabrics dyed with different pH extracts of the natural dye, it was observed that the pH 5 extract showed the best fastness properties compared to the other dye extract. This can be attributed to the fact the pH 5 dye extract was purified during the sequential extraction process which reduces the concentration of non-dye substances present in the extracted matrix allowing the dye molecules to bond with the cellulose on the fabric [16]. Similar results have been also observed in previous studies [17–19].

Table 3

COLOUR FASTNESS FOR THE FABRİC DYED WİTH PH DİFFERENT DYE EXTRACT

Samples code	Light fastness	Wash fastness CC	Wash fastness CS
(a)	5	4–5	4–5
(b)	4	4	4
(c)	4	4	4

Note: *CC – colour change of the dyed fabric, CS – colour staining of the adjacent cotton fabric.

Fourier Transform Infrared (FTIR) Analysis

In figure 6, *a*, the FT-IR spectra showed a band at 2918 cm^{-1} corresponding to the O–H bond stretching mode for carboxylic acid. The bands at 2300 cm^{-1}, 1700 cm^{-1}, 1600 cm^{-1},1229 cm^{-1}, and 1026 cm^{-1} correspond to C=C stretching mode, C–O–H bending mode, C=O bending mode, C–O stretching mode, and C–H out of plane bending mode for the aromatic ring, respectively. These observed peaks showed that the extracted dye contained polyphenols and flavonoids. According to Figure 5, *b*, the characteristic cellulose broad peak at 3334 cm^{-1} is for the O–H

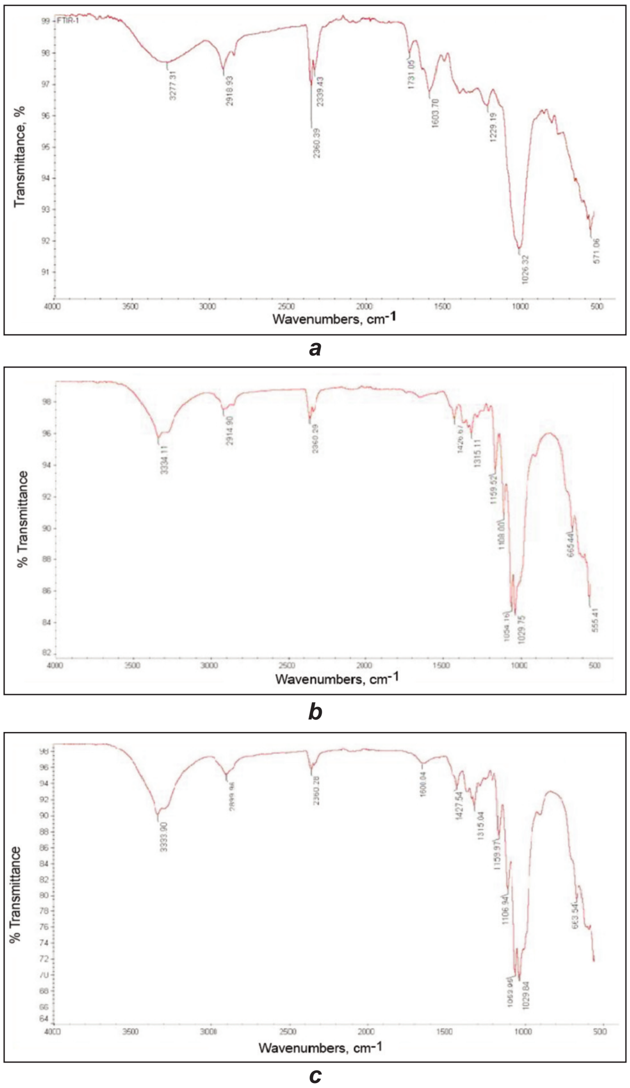

Fig. 6. FTIR spectra of: *a* – dye; *b* – cotton fabric; *c* – dyed cotton fabric

bond stretching mode, and that at 2914 cm^{-1} corresponds to C–H bond stretching. C–O stretching mode and C–O–H bending mode was shown by the peaks at 1426 cm^{-1}, and 1315 cm^{-1}, respectively. All these peaks are in relation to the chemical structure of the cellulosic pure cotton fabric. In figure 6, *a* and *b*, comparing the FTIR spectra of dyed cotton fabric with that of undyed cotton fabric there was a new peak at 1600 cm^{-1} corresponding to C=C stretching mode for the aromatic ring confirming the attachment of the aromatic dye molecules to the cellulose structure. Moreover, the characteristic cellulose band at 3334 cm^{-1} is for O–H shifted to the lower region of 3333 cm^{-1} which could be attributed to stronger hydrogen bonds between dye and cellulose than those between cellulose molecules. Similar results have also been reported in previous studies [20–22].

Adsorption isotherm study

The Langmuir adsorption isotherm has been successfully applied to many other real sorption processes. A basic assumption of the Langmuir theory is that sorption takes place at specific homogeneous sites within the adsorbent. It is then assumed that once a dye molecule occupies a site, no further adsorption can take place at that site. Theoretically, therefore, a saturation value is reached beyond which no further sorption can take place [18]. The Langmuir and Freundich adsorption parameters were determined in linear forms as follows [23, 24]:

$$\text{Langmuir isotherm: } \frac{1}{q_e} = \frac{1}{Q} + \frac{1}{Q\,b\,C_e} \qquad (5)$$

$$\text{Freudlich isotherm: } \ln q_e = \ln K_f + \left(\frac{1}{n}\right) \ln C_e \qquad (6)$$

where Q is the maximum amount of the dye per unit weight of cotton fabric to form a complete monolayer coverage on the surface-bound at high equilibrium dye concentration C_e, q_e – the amount of dye adsorbed per gram of cotton fabric at equilibrium, and b – the Langmuir constant related to the affinity of binding sites. The value of Q represents a practical limiting adsorption capacity when the surface is fully covered with dye molecules and assists in the comparison of adsorption performance (table 4) [25]. The linear plot of $1/q_e$ versus $1/C_e$ is obtained from this model as shown in figure 7.

The values of R_L indicate the type of isotherm to be irreversible (R_L = 0), favourable (0 < R_L < 1), linear (R_L = 1) or unfavourable (R_L > 1):

$$R_L = \frac{1}{1 + K_L C_0} \qquad (7)$$

where R_L can be 0 < R_L < 1. The less than unity R_L value supported a favourable adsorption [26–28], as seen in table 4.

The fit is good for the adsorption data of Scutellaria Orientalist flower extract dye onto cotton fabric at 60, 80, and 90°C (correlation coefficient, R > 0.99). In the range of 60–90°C, an increase in the temperature does not affect the adsorption of Scutellaria

Table 4

THE CHARACTERISTIC PARAMETERS OF DYEING PROCESS OF SCUTELLARIA ORIENTALIST FLOWER EXTRACT DYE ON TO COTTON FABRIC

Langmuir isotherm			Freundlich isotherm				
Temperature (°C)	b	Q(g/g)	R^2	R_L	K_f	n	R^2
60	1.12	0.932	0.998	0.485	0.486	2.0538	0.9795
80	1.11	0.802	0.999	0.472	0.478	2.0881	0.9887
90	1.06	0.797	0.998	0.476	0.440	2.2691	0.9989

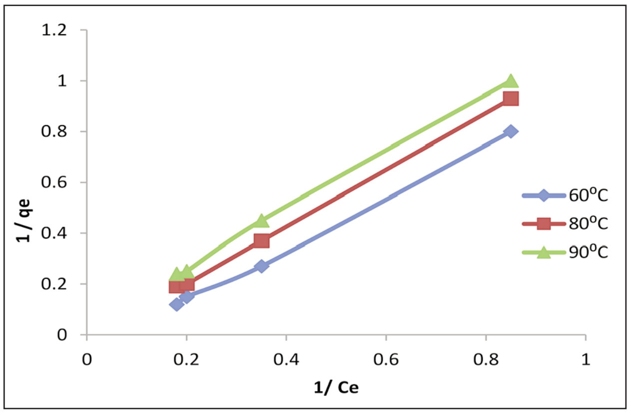

Fig. 7. Langmuir plots for the Scutellaria Orientalist flower extract dye adsorption on to cotton fabric for different temperature

Orientalist flower extract dye onto cotton fabric significantly. This can be explained by physical adsorption decreases with increasing temperature [24]. Also, indicates that the dyeing process is exothermic, and the *Q* values decreased with increasing temperature. The *b* values indicated that the cotton fabric has a maximum affinity for Scutellaria Orientalist flower extract dye almost the same at all temperatures, but slightly higher at 60°C. Similar results have also been reported in the previous study [24, 25, 29]. The values of R_L (table 4) were observed to be in the range of 0–1, indicating that the adsorption of Scutellaria Orientalist flower extract dye on to cotton fabric was favourable for this study.

The plots of $\ln q_e$ versus $\ln C_e$ for the Scutellaria Orientalist flower extract dye adsorption onto cotton fabric for different temperatures according to the linear forms of the Freundlich isotherms are shown in figure 5. The values of the Freundlich constants were determined from the linear plot of $\ln q_e$ versus $\ln C_e$. The values are presented in table 2. The values of *n* were found to be 2.05, 2.08, and 2.26 for 60, 80, and 90°C respectively, indicating that the adsorption was favourable. On the other hand, the values of *n* between 2 and 10 show good adsorption [30]. The K_f

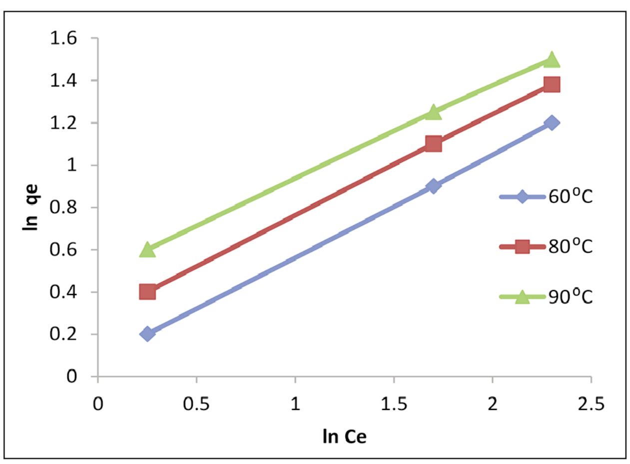

Fig. 8. Freundlich plots for the Scutellaria Orientalist flower extract dye adsorption on to cotton fabric for different temperature

values decreased with increasing temperature which again supported an exothermic process. From table 4, the Freundlich equation can be applied to fit the experimental data as well as the Langmuir equation because it gave a high correlation coefficient $R^2 > 0.99$. Similar adsorption isotherms results have been reported previously in work [24, 25, 31].

Kinetics study

The experimental data relating to absoprtion of Scutellaria Orientalist flower extract dye onto cotton fabric was investigated using the Lagergren pseudo-first and pseudo-second order (equations 8 and 9):

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \quad (8)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q e^2} + \frac{t}{q_e} \quad (9)$$

where, q_e is the amount of adsorption amount at equilibrium, q_t – the amount of Scutellaria Orientalist flower extract dye adsorbed at various times, *t* – time of adsorption duration and k_1 – the pseudo first-order adsorption rate constant. Equilibrium adsorption amount q_e (cal) is determined by employing the linear plot of log $q_e - q_t$ versus the adsorption time (*t*).

Table 5

KINETIC PARAMETERS OF PSEUDO FIRST-ORDER AND PSEUDO SECOND-ORDER KINETIC MODELS FOR SCUTELLARIA ORIENTALIST FLOWER EXTRACT ADSORPTION ON COTTON FABRIC AT DIFFERENT TEMPERATURES

Temperature	60°C	80°C	90°C
Pseudo-first order			
$q_{e\ (Exp.)}$	0.0052	0.0080	0.0120
$q_{e\ (Cal)}$	0.0099	0.0115	0.0119
k_1	2.27×10^{-2}	2.64×10^{-2}	2.74×10^{-2}
R^2	0,960	0.986	0.995
Pseudo-second order			
$q_{e\ (Cal)}$	5.52	13.85	8.59
k_2	7.8×10^{-3}	8.1×10^{-3}	8.4×10^{-3}
R^2	0.910	0.946	0.965

The experimental kinetic data were adjusted according to the indicated models (figure 6, *a* and *b*) and the coefficients of correlation as well as the kinetic parameters of pseudo-first-order and pseudo-second-order kinetic models are given in table 3. The results of table 3 and figure 6, *a* and *b* showed that the pseudo-first-order model provided the best correlation with experimental results. This fact indicates that the adsorption of Scutellaria Orientalist flower extract dye on cotton fabric follows the pseudo-first-order kinetic model. Similar kinetic results have been recorded previously study [32–34].

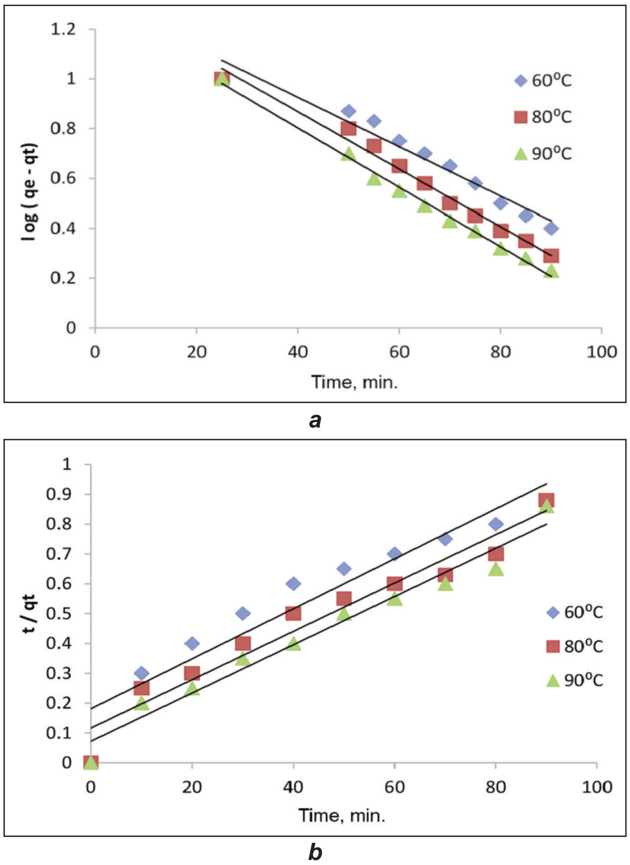

Fig. 9. The applicability of the: *a* – Pseudo first-order kinetic model; *b* – pseudo second-order kinetic model to Scutellaria Orientalist flower extract adsorption on cotton fabric

Adsorption thermodynamic study

The various thermodynamic parameters standard free energy (ΔG), standard enthalpy (ΔH), and standard entropy (ΔS) associated with the adsorption of Scutellaria Orientalist dye onto cotton fabric were calculated by using the following equations [27, 21]:

$$\Delta G = -RT \ln K_c \tag{10}$$

$$\ln K_c = \frac{-\Delta H}{RT} + \frac{\Delta S}{R} \tag{11}$$

$$K_c = \frac{C_{Ae}}{C_{Se}} \tag{12}$$

In the above equations, R is the universal gas constant (8.314 J/mol K), T – the temperature (K), K_c – the equilibrium constant, and C_{Ae} and C_{Se} are the dye concentration adsorbed at equilibrium (mg/l) and the concentration of dye left in the dye bath at equilibrium (mg/L), respectively. The enthalpy (ΔH) and entropy (ΔS) are calculated from the slope and intercept of a plot of ln K_c versus 1/T. The results are given in table 3. It is clear from table 3 that the value of ΔH is positive, indicating adsorption processes endothermic. The positive value of ΔS showed the affinity of cotton fabric to Scutellaria Orientalist flower extract dye and the increasing randomness at the solid-solution interface during the adsorption. The negative values of ΔG show that the Scutellaria Orientalist flower extract dye adsorption on cotton fabric was favourable and spontaneous with a high affinity of the adsorbate to the surface of the adsorbent. Similar thermodynamic results have been recorded on the cacao husk extract dye adsorption on cotton fabric, lac dyeing on silk, and coconut husk, and onto Raphia hookerie fruit epicarp [24, 32, 33].

CONCLUSION

The adsorption behaviour of Scutellaria Orientalist flower extracts dye on cotton fabric was studied to understand the dyeing mechanism of natural dye. The study results demonstrate that a high dye uptake was achieved almost 90% of the Scutellaria Orientalist flower extracts were adsorbed into the cotton fabric. The adsorption equilibrium isotherm fitted for Langmuir and Frenundich but the adsorption equilibrium isotherm was best fitted to the Langmuir isotherm model. The positive value of ΔS showed the randomness of the solid-liquid interface during Scutellaria Orientalist flower extract dye adsorption onto cotton fabric. The negative values of ΔG indicated the spontaneous nature of adsorption, while the positive values of ΔH showed that the adsorption reaction was endothermic. The study results show that cotton fabric dyeing has good dyebath exhaustion by using the Scutellaria Orientalist flower extract dye conventional dyeing method. Also, the findings of the present study indicate that the Scutellaria Orientalist plant can be a good source of natural dye for eco-friendly textile industries.

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