Adsorption Behavior of Dye Extract from *Justicia carnea* Leaf on Cotton Fabric

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ABSTRACT

The adsorption behavior of dye extracted from Justicia carnea using aqueous method was studied. The dye extract was used to dye cotton fabric treated with a mordant and cotton fabric without mordant. Dyeing was done at 50^{O}C, 60^{O}C and 70^{O}C with Aluminium Potasium Sulphate as mordant. The effluent after dyeing was characterized using FTIR and UV-VIS spectrophotometer. The result of the UV-VIS spectrophotometer confirmed the presence of emodin, a flavonoid in the dye extract. The adsorption studies showed that the adsorption mechanism fits the pseudo-second order kinetic model with the R^2 of 0.99. The results also showed that increase in temperature favours dyeing without mordant while decrease in temperature favours dyeing with pre-mordanted cotton fabric.

Key words: *Justicia carnea* Leaf, adsorption kinetic, dyeing, mordant

1.0 Introduction

The use of natural colorants, a significant class of non-wood forest products, spans various industries, including food, textiles, cosmetics, medicines, paint, and ink. In recent years, the textile industry has faced mounting environmental challenges due to its reliance on synthetic dyes, which involve extensive chemical use during dyeing and printing processes. These synthetic substances are known to pose significant risks to human health and the environment, with some dyes being banned for their mutagenic and carcinogenic properties [1][2].

Natural dyes are derived from various sources, including plants, insects, and minerals, making them readily available and environmentally friendly. Their resurgence is attributed to multiple factors: the preservation of traditional knowledge, the promotion of sustainable practices, and the revival of local textile industries. The global shift towards green products and sustainable living has further catalyzed the adoption of natural dyes, as societies increasingly prioritize ecological balance and cultural heritage [3][4].

Driven by growing environmental awareness and consumer demand for sustainable products, natural dyes have really gained renewed interest. Unlike synthetic dyes, natural dyes are biodegradable and non-toxic, contributing to a safer and more sustainable textile industry. Research indicates that natural dyes not only offer health and environmental benefits but also exhibit a wide range of color shades, enhancing their appeal for various applications. In addition it has been shown that the shade of colour given by a plant dye extract is affected by age of the plant, condition of growth and type of mordant used during dyeing [5]. Furthermore, natural dyes support local biodiversity by encouraging the cultivation of dye-yielding plants, which in turn helps maintain ecological balance. The integration of natural dyes into the textile industry not only promotes environmental sustainability but also fosters economic development by creating opportunities for local communities engaged in the cultivation and processing of natural dye sources [6][7].

Justicia carnea, commonly known as the Brazilian Plume Flower, is a tropical plant belonging to the Acanthaceae large family [8]. It is known for its vibrant red flowers and has been traditionally used for medicinal purposes to treat various diseases, including anemia, cancer, malaria, sickle cell disease, diabetes, gastrointestinal infections, diarrhea, typhoid, liver diseases, hepatitis, cough and HIV [9]. Studies on the antibacterial efficacy, in-vitro antioxidant and anti-obesity potentials, and antiplasmodial potency of methanol and ethanol extracts from *justicia carnea* leaf have been severally reported [10][11][12][13]. In Nigeria, the shrubs of J. carnea are easy to grow and propagate from stem cuttings by pushing the stems 1 to 2 inches into the soil [14]. Research has shown that *Justicia carnea* has high hemoglobin level [8] which explains why in Nigeria it is commonly known locally as: *ogwu obara* (a drug for gaining blood) [10][12], *Oso-afia* [15]. However, there has been no report on the adsorption behavior of the dye extract on cotton fabric which is the main focus of this research. This paper also compares the adsorption kinetics behaviour of this natural dye extracted in an aqueous medium when used to dye cotton fabrics with and without any mordant.

1. Experimental

2.1 Materials

The *Justicia carnea* and *Camellia assamica* plant leaves samples were sourced from Umuchima Ihiagwa, Owerri West, Imo State Nigeria and identified at the Department of Crop Science, FUTO. Distilled water and Aluminium Potasium Sulphate ($KAl(SO_4)_2.H_2O$) was purchased from Chemisciences Ltd, Owerri

Imo State Nigeria. The cotton fabrics used were sourced from the regular market in Owerri, Nigeria. Dye extraction and fabric dyeing was carried out at the Polymer Engineering Department laboratory of Federal University of Technology, Owerri (FUTO).

2.2.1 Sample Preparation: *Justicia carnea* leaves and Cotton fabric

The *Justicia carnea* leaves were thoroughly washed with double distilled water to remove dirt; oven dried at the temperature of 70 °C to crisp before grinding into fine particles. The cotton fabrics were cut to a square size of 2 x 2 cm^2 having 64 ends and 64picks and weight of 1g. Some fabrics were pre-mordanted before dyeing while some were dyed without mordant application.

2.2.2 Fabric Pre-Mordanting

25% of the mordant on the weight of the fabric (OWF) was dissolved in 30ml of distilled water in a 50 ml beaker at 70^{O}C. The fabric was removed after 30mins and excess water squeezed out before spreading it outside to dry under sun.

2.2.3 Dye Extraction from *Justicia carnea*

5g of pulvurized *Justicia carnea* samples were put into a 500 ml Soxhlet extractor with distilled water as the solvent. Extraction was done at 70˚C for 4 h in two-batch process with material to liquor ratio of 1:100. At the end of the extraction process, the extract was centrifuged and stored in a 500 ml conical flask.

2.2.4 Fabric Dyeing

Already prepared cotton fabric was dyed in a beaker containing the dye extract with material to liquor ratio of 1:20 at time intervals of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 mins, and varied Temperature ranges of 50°C, 60°C and 70°C respectively. After each dyeing time, the fabric was removed and a portion of the dye liquor stored in a test bottle to be used for absorbance test the spectrophotometer.

2.2.5 Characterization of dye extract

FTIR (PerkinElmer spectrum IR 10.7.2 spectrometer) was used to identify the functional groups of the dye while UV–vis spectrophotometer (Vis spectrophotometer 728, wave length range: 320 nm – 1020 nm) was used to check the absorption characteristics of the extracted dyes

3.0 Results and Discussion

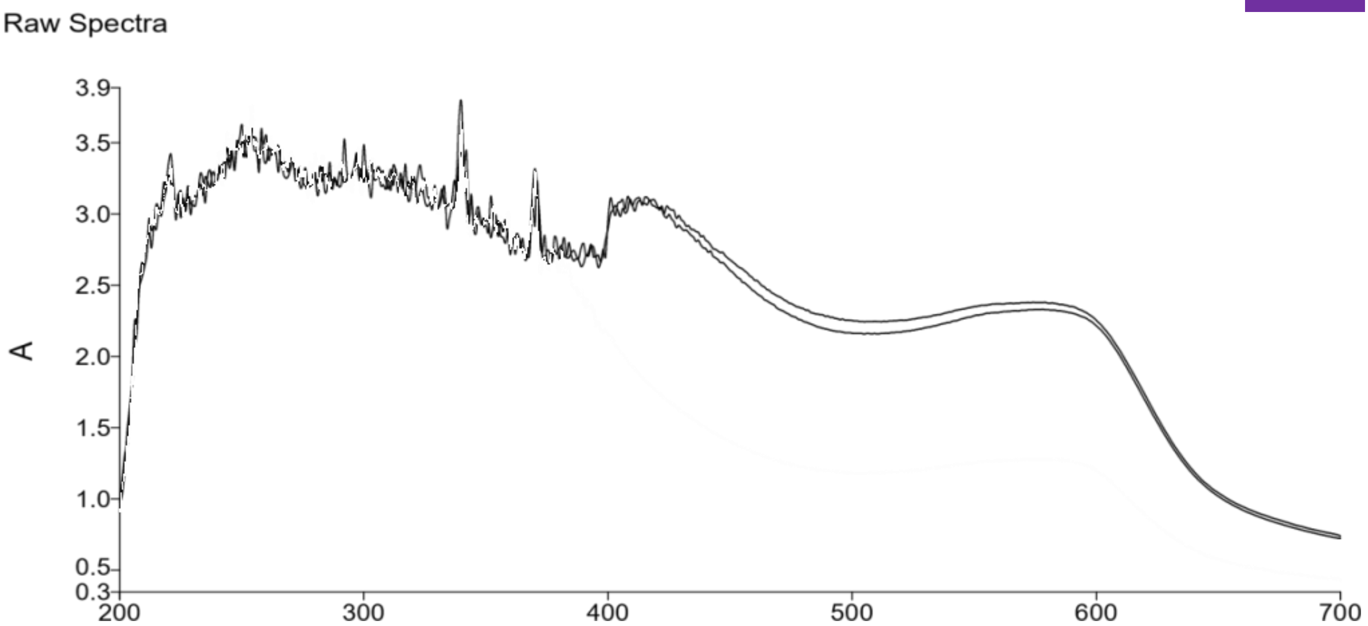

Figure 1. Ultra violet visible infrared spectroscopy (UV-VIS) spectral of Justicia carnea

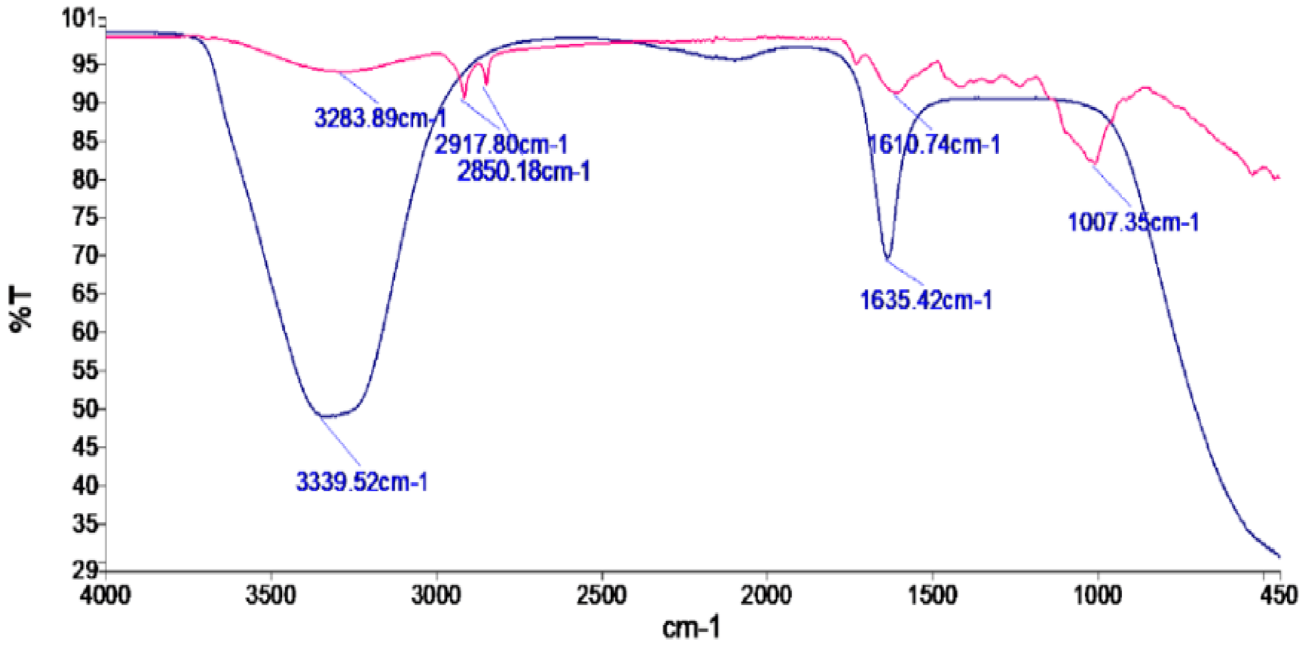

Figure 2. FTIR of ***Justicia carnea* dye extract** (blue colour represents water, medium of extraction while red colour represents dye extract)

3.1 UV-Vis Analysis

Justicia carnea dye has the main maximum absorbance peak at 424nm (Figure 1) which is within the visible light spectrum and hence can serve as a dye. There was an increase at 575nm as the absorbance began to diminish. The peak at 424nm has also been reported in previous studies as the range for flavonoids **[16]**. However, Aslan (2024)[17] was more specific in identify the natural dyes between the peaks 420 – 575nm as emodin which is type of flavonoid. This is also in agreement with the findings of Imohiosen (2023)[9] from the phytochemical studies of justicia carnea leaves extract.

3.2 FTIR Analysis

The FTIR results were obtained with **PerkinElmer spectrum IR 10.7.2 spectrometers in the wavelength range of 450-4000 cm^{-1}.** Result in Figure 2 confirm the possible presence of water with the peak at 1610.74cm^{-1} representing C=C aromatic mode or N-H bending [**18]**[19][20]. The peaks at 1007.35cm^{-1} are due to C-O vibration mode while the peaks at 2917.80cm^{-1} and 2850.18cm^{-1} is attributed to C-H stretch vibrations which indicates the presence of aromatic C – H group in the dye extract [17]. The broad band at 3283.89 is attributed to O-H stretch of alcohols or phenols [17][21]. However, the 3339.52cm^{-1} on the blue spectrum is – OH of the distilled water.

3.3 Absorption characteristics

Absorbance value of the dye extract was checked with the UV-Vis spectrophotometer before dyeing and after each dyeing time and was used to ascertain the equilibrium time. It should be noted that absorbance values are directly proportional to dye concentration at all wavelength hence the absorbance values were used to calculate both the dye uptake and dye concentration at the different time of dyeing and at equilibrium. Uptake of dye was calculated using Equation 1[22] based on the absorbance results measured at a wavelength of maximum absorbance of 424 nm which is the maximum absorbance peak for *Justicia carnea* dye extract. The effect of dyeing time and temperature on dye uptake when fabric was dyed without mordant and when fabric was pre-mordanted is presented in Figure 3 and 4 respectively.

$$\text{Dye uptake } \% = \frac{\text{absorbance before dyeing} - \text{absorbance after dyeing}}{\text{absorbance before dyeing}} \times 100$$

(1)

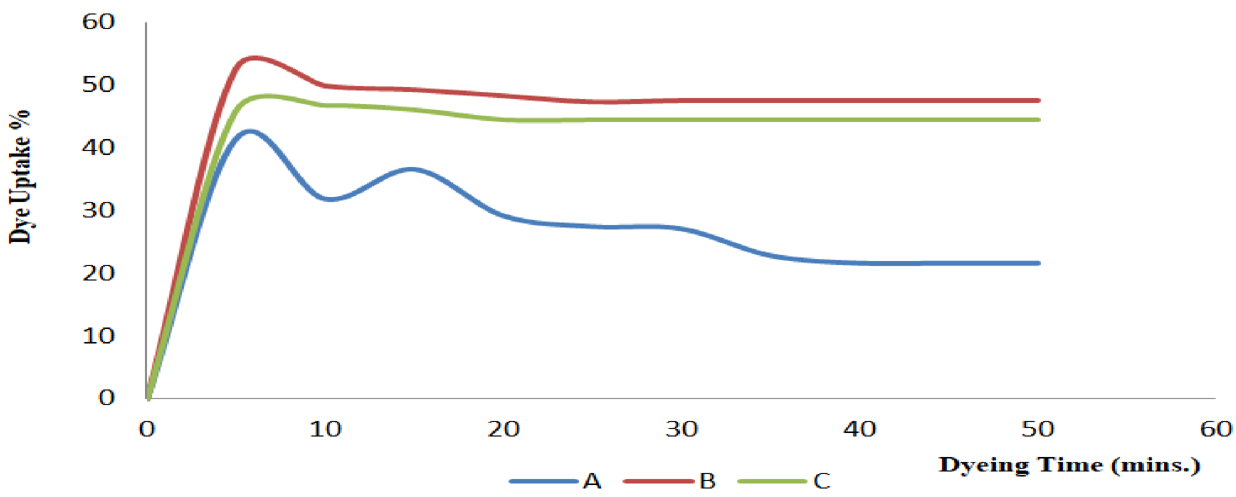

Fig. 3. Effect of time and temperature on J. Carnea dye adsorption on un-mordanted cotton fabric

A (50 °C), B (60 °C) and C (70 °C)

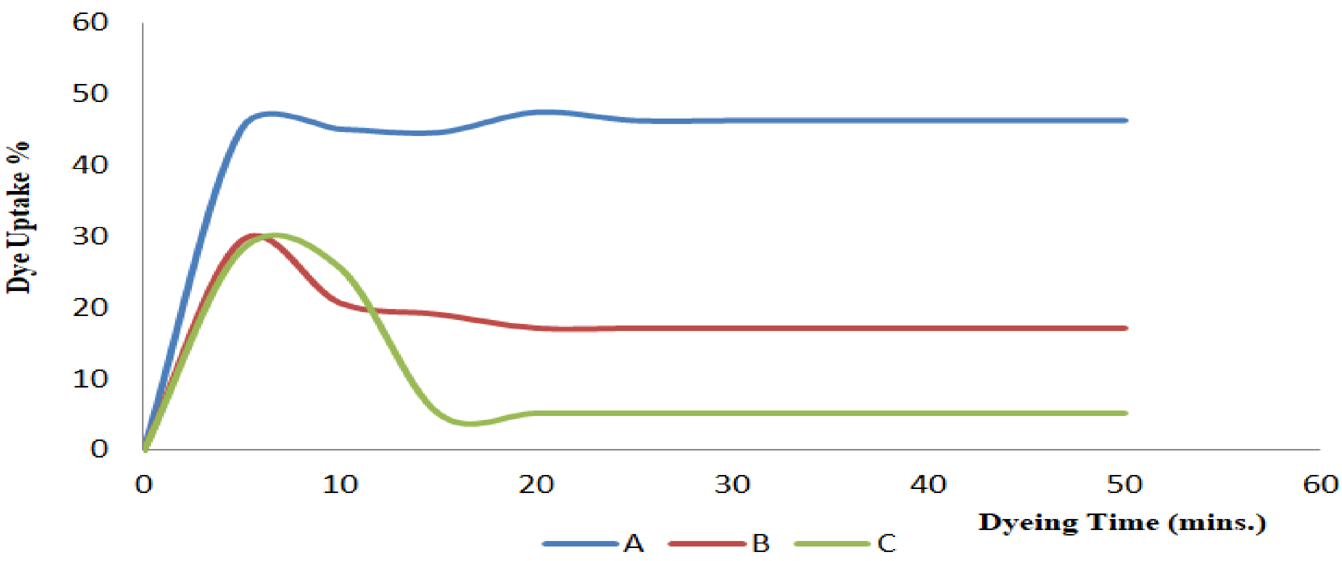

Fig. 4. Effect of Time and Temperature on *J. carnea* dye adsorption on Mordanted Cotton Sample A (50°C), B (60°C) and C (70°C)

3.2.1 Effect of time and temperature on dye uptake

There is usually a sharp high uptake of dye at the first 5 minutes of dyeing which gradually normalizes as time progresses. This is a clear indication that the fabric has high affinity for the natural dye and does not require much time for dye adsorption. Equilibrium was however reached earlier when dyeing with pre-mordanted fabric than without mordant at the respective temperatures. Dye absorption begins with adsorption unto the fabric surface before the dye molecules gradually diffuse into the fabric pores. Hence, equlibruim is reached when the fabric had absorbed enough dye molecules based on its available pore spaces. This phenomenon is clearly seen in fig 3 and 4 with the uptake at the first 5 minutes of dyeing being higher than the dye uptake at equilibrium point. Also, more dyes were absorbed by the fabric without mordant at 60 **°C** and 70 **°C** respectively than the pre-mordanted fabric. This can be attributed to the presence of mordant molecules already occupying some space on the cotton fabric hence reducing the available space for dye adsorption [check one of your journals]. Similarly the dye molecules that formed a complex bond with the mordant desorbs with increase in temperature and time hence at 70 **°C** equilibrium point only 5% of dye uptake was achieved against 44.43 % at same temperature and time of dyeing without mordant on the fabric.

The highest dye uptake was recorded with fabric without mordant at 60 **°C** while with pre-mordant fabric it was recorded at 50 **°C.** This is an indication that dyeing without mordant at a temperature above 50 °C will improve cotton fabric uptake of *Justicia carnea* dyes while dyeing a pre-mordanted cotton fabric at temperature below 50 ^{o}**C** will improve dye uptake. For pre-mordanted fabric, increase in temperature increases the rate of dye desorption as equilibrium time is approached (Figure 4).

3.3 Kinetics of dye adsorption

This study was done at a constant temperature of 60 ^{o}C at the different temperature ranges for both fabric types. We used Equation 2 and 3 [22] to calculate quantity of dye adsorbed at equilibrium Q_e (mg/g) and at different time of dyeing Q_t (mg/g)

$$Q_e = \frac{C_i - C_e}{W} V \quad (2)$$

$$Q_e = \frac{C_i - C_t}{W} V \quad (3)$$

Where C_i, C_t, C_e, W and V represent the initial dye concentration, concentration at different dyeing time, concentration at equilibrium (mg/ml), weight of fabric and dye liquor volume. The values were used for the two adsorption kinetic models used in this research – pseudo first order and pseudo second order kinetic models of adsorption. The Langergren's Equation (as shown in Equation 4) [22] was used to fit the pseudo-first order model as represented in Figure 5 and 6 respectively, while Equation 5 [22] was used for the pseudo-second-order as shown in Figure 7 and 8 respectively

$$\text{In}\,(Q_e - Q_t) = \text{In}Q_e - K_1 t \quad (4)$$

$$\frac{t}{Q_t} = \frac{1}{K_2 Q_e^2} + \frac{1}{Q_e} t \quad (5)$$

Where $K_{1,}$ K_2 and t represent the rate constants of the pseudo first, second order kinetic models and time of adsorption

3.3.1 Pseudo-first order kinetic model

The correlation coefficient R^2 value of 0.1409 was calculated from the plot of In(Q_e – Q_t) against t shown in Figure 5 and Q_e (1.833mg/g) and K_1 (0.0435) were calculated from the intercept and slope respectively. The calculated value of Q_e agrees with experimental value of very low dye uptake just before the point of equilibrium between 25 and 30 minutes of dyeing shown in Figure 3. Same plot for pre-mordanted fabric in Figure 6 gave an R^2 of 0.4521, K_1 of 0.1234 and Q_e of -0.2034 mg/g. Again the calculated Q_e which is negative agrees with the experimental value indicating dye desorption close to equilibrium point that is, between 15 and 20 minutes of dyeing as shown in Figure 4.

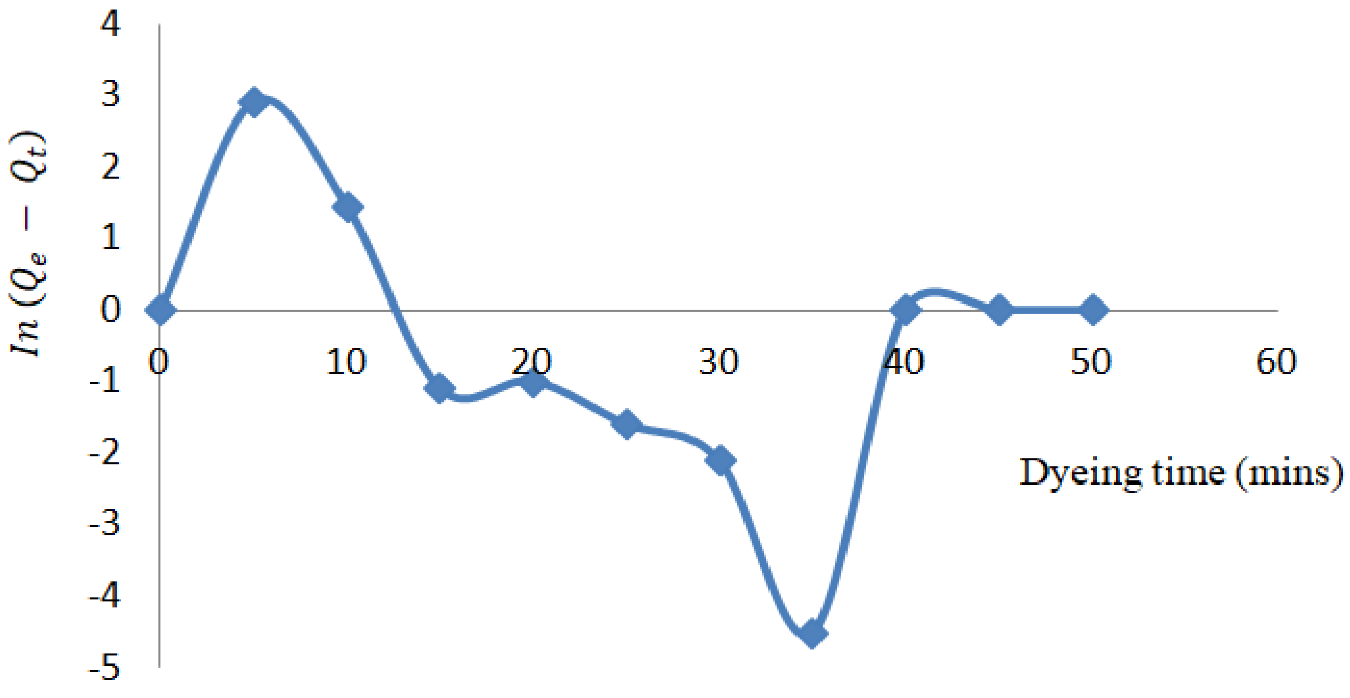

Fig 5: Graph of Pseudo-first Order Adsorption kinetics of *J. carnea* dyes on unmordanted cotton fabric sample

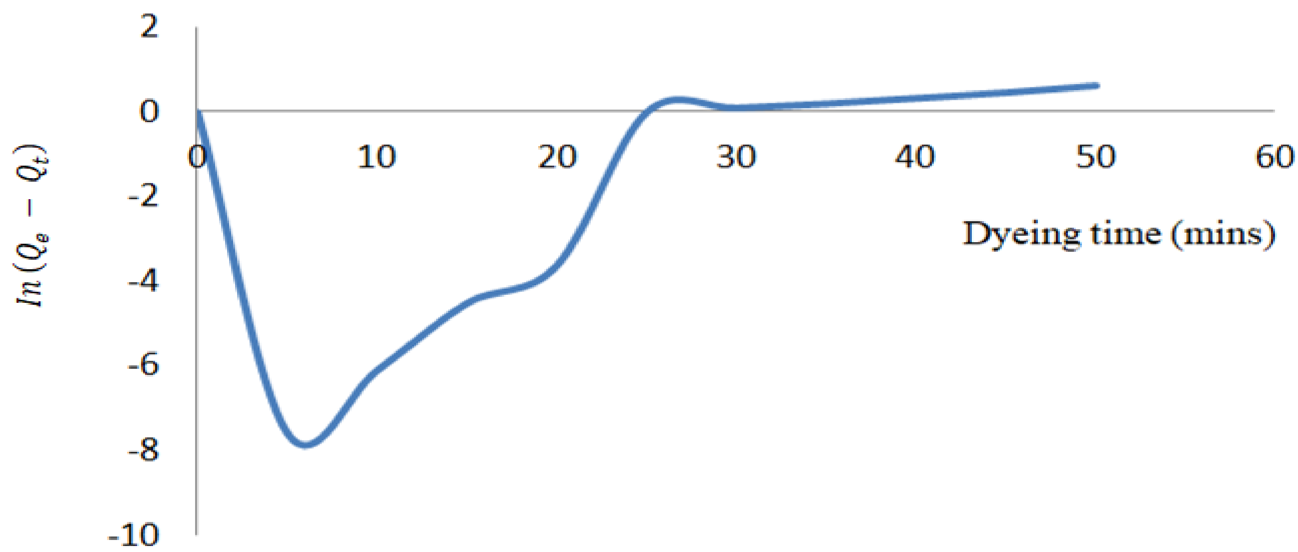

Figure 6: Graph of pseudo-first order adsorption kinetics of J. carnea dyes on pre-mordanted cotton fabric sample

3.3.2 Pseudo-second order adsorption kinetic model

A plot of t/Q_t versus t in Figure 7 was used to calculate the value of R^2 as 0.9932, Q_e as 0.03 mg/g and K_2 as -0.03. The Q_e value still agreed with experimental value of a very low dye uptake at the point before equilibrium. When mordant was applied on the fabric (Fig.8) the R^2 value was calculated as 0.998, with a Q_e of 0.03mg/g and K_2 of -147.

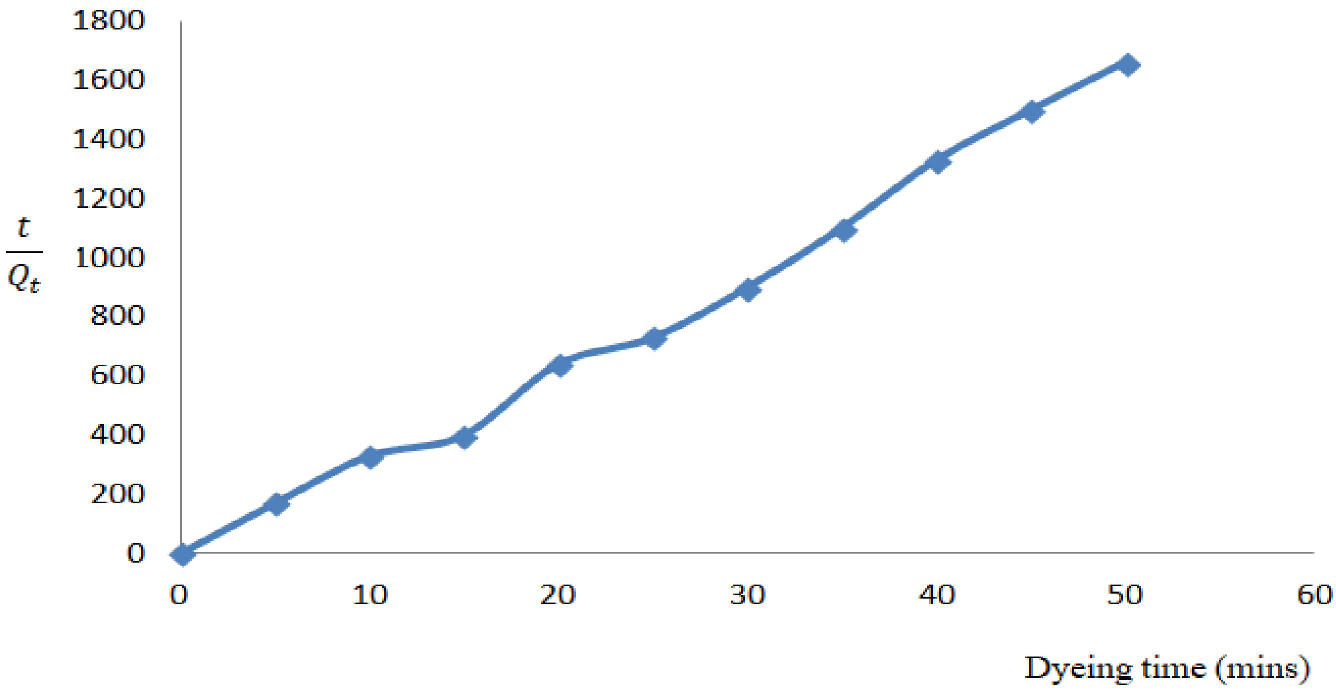

Figure 7: Graph of pseudo-second order adsorption kinetics of *Justicia carnea* dyes on unmordanted cotton fabric sample

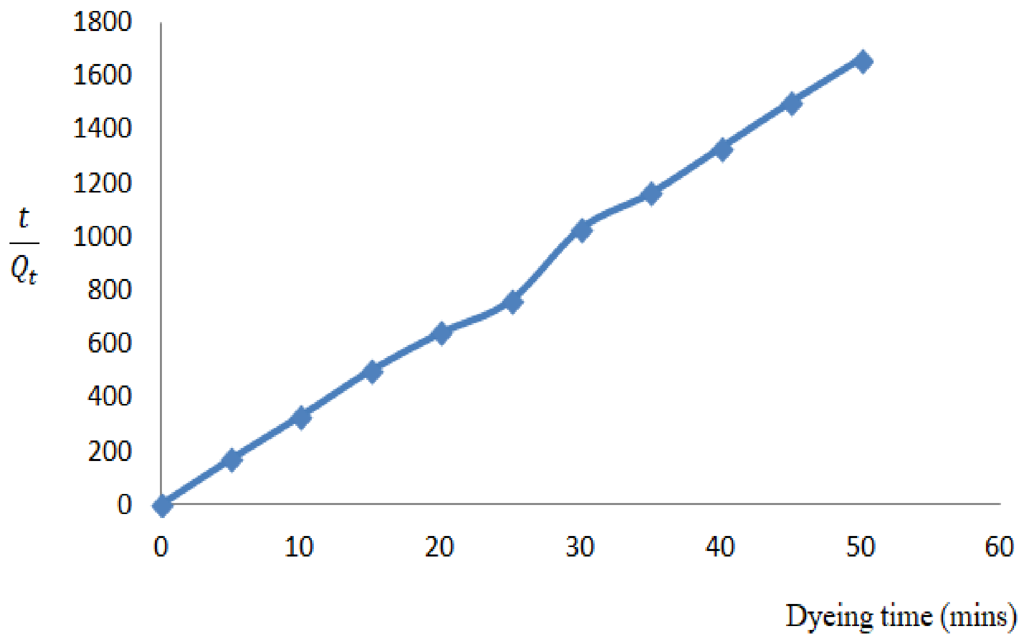

Figure 8: Graph of pseudo-second-order adsorption of *Justicia carnea* on mordanted cotton fabric sample

The R^2 values from the pseudo-second order kinetic models are higher and closer to 1 than that of the pseudo first order models for both dyeing with pre-mordanted cotton fabric and cotton fabric without fabric. It should be noted that the adsorption system is best described by the model with highest regression coefficient [23]. This indicates that the adsorption mechanism of *Justicia carnea* dye extract fits the pseudo-second order kinetic model and hence is used to describe it. This implies that chemical adsorption controlled the process [24]. It has also been reported that a correlation coefficient of 1 indicates a positive linear correlation [25].

Conclusion

This study has shown that *Justicia carnea* dye extract can be used to dye cotton fabric either with mordant or without mordant. Temperature affects the dye uptake with 60 ^oC being the most favourable for dyeing without mordant on the fabric and 50 ^oC being the most favourable for dyeing a pre-mordanted fabric. The increase in temperature also leads to more dye desorption as it approaches equilibrium time while dyeing with pre-mordanted cotton fabric. We therefore posit from our study that increase in temperature favours dyeing without mordant while decrease in temperature favours dyeing with pre-mordanted cotton fabric. The adsorption kinetic behavior was found to fit the pseudo second order kinetic mechanism.

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