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ORIGINAL ARTICLE

An eco-friendly dyeing of woolen yarn by *Terminalia chebula* extract with evaluations of kinetic and adsorption characteristics

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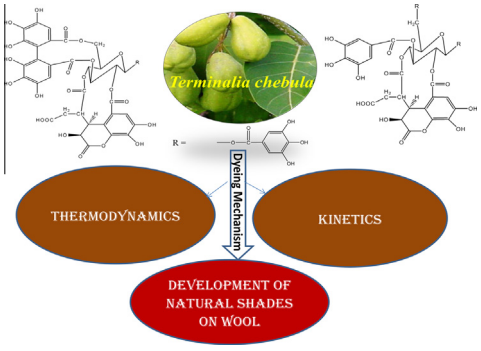
GRAPHICAL ABSTRACT



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ABSTRACT

In the present study *Terminalia chebula* was used as an eco-friendly natural colorant for sustainable textile coloration of woolen yarn with primary emphasis on thermodynamic and kinetic adsorption aspects of dyeing processes. Polyphenols and ellagitannins are the main coloring components of the dye extract. Assessment of the effect of pH on dye adsorption showed an increase in adsorption capacity with decreasing pH. Effect of temperature on dye adsorption

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showed 80 °C as optimum temperature for wool dyeing with *T. chebula* dye extract. Two kinetic equations, namely pseudo first-order and pseudo second-order equations, were employed to investigate the adsorption rates. Pseudo second-order model provided the best fit (R^2 = 0.9908) to the experimental data. The equilibrium adsorption data were fitted by Freundlich and Langmuir isotherm models. The adsorption behavior accorded well (R^2 = 0.9937) with Langmuir isotherm model. Variety of eco-friendly and sustainable shades were developed in combination with small amount of metallic mordants and assessed in terms of colorimetric (CIEL$^*a^*b^*$ and K/S) properties measured using spectrophotometer under D65 illuminant (10° standard observer). The fastness properties of dyed woolen yarn against light, washing, dry and wet rubbing were also evaluated.

Introduction

Natural dyes have been used for coloration of synthetic as well as natural textile materials such as wool, cotton, silk, nylon, fur and leather since prehistoric times. With the advent of synthetic dyes in the middle of nineteenth century, use of natural dyes declined to great extent and practically becomes unused in the beginning of 20th century [1,2]. An international awareness about environment, ecology and pollution control creates an upsurge in the use of natural dyes in the middle of 20th century. During the last few decades, increasing attention has been paid by the researchers all over the globe towards various aspects of natural dye applications [2,3].

Natural dyes/colorants derived from flora and fauna are believed to be an eco-friendly, safe and viable substitute to synthetic colorants because of their non-toxic, non-carcinogenic and biodegradable nature [4,5]. Moreover, natural dyes do not cause pollution and waste water problems. As per present trend of meeting peoples demand keeping in view ecological concerns of synthetic colorants, natural dyes are used for textile functional treatments with antimicrobial, UV-protection, de-odorizing, anti-allergic, anti-feedants, fluorescence and some other functional finishing properties [6–12]. Therefore, constantly increasing demand and new source of natural dyes are to be explored suitably and systematically for sustainable coloration of synthetic and natural textile material.

Terminalia chebula, commonly called as chebulic myrobalan/harda, belongs to family *Combretaceae* of genus *Terminalia* grown in Asian continent. *T. chebula* is a popular traditional medicine not only used in India but also in other countries of Asia and Africa. It possesses laxative, diuretic, cardiotonics, hypoglycemic, anti-bacterial [13], anti-fungal [14], antioxidant [15,16] and anticancer [17] properties. Hydrolysable tannins, chebulagic acid, chebulinic acid, gallic acid, and ellagic acid are the major tannin constituents present in myrobalans [18]. Besides the complex tannin mixture of myrobalans is also known to yield a dye C.I. Natural Red 5. Yellow dye obtained from *T. chebula* fruits can be applied to textile substrate with or without mordants to get a large range of shades of reasonable colorimetric (CIEL$^*a^*b^*$ and K/S) and fastness properties [19]. To achieve present day sophisticated demands of people, lot of research has been undertaken in the field of natural dyes for obtaining colorful and eco-friendly shades on textile materials [3,12,20]; but the fastness properties and reproducibility to give consistency in production are still to be solved. As a part of the approach to handle these problems, fundamental physical studies are important to understand the dyeing mechanism and improving the dyeing performance of natural dyes on variety of synthetic and natural textile materials.

Recently several investigations on dyeing properties of natural dyed textile materials have been undertaken using various functional finishing agents along with the evaluations of thermodynamic and kinetic parameters. Adsorption and kinetic aspects of honeysuckle extract on wool, tea polyphenols on wool, silk, and nylon, sodium copper chlorophyllin on silk, etc., have been investigated to understand the dyeing mechanism of natural dyes on textile materials [21–25]. The purpose of this research was to understand the dyeing mechanism of *T. chebula* natural dye onto woolen yarn with effective and sustainable coloration in combination with small amount of metallic mordants.

Experimental

Materials and chemicals

100% semi worsted woolen yarn (60 counts) was purchased from MAMB Woollens Ltd., Bhadohi, India. Commercial sample of extracted *T. chebula* dye in powder form was obtained from Sir Biotech India Ltd., Kanpur, India, and used without any further purification. Alum ($K_2Al_2(SO_4)_4$ś24H_2O), ferrous sulfate ($FeSO_4$ś5H_2O), and stannous chloride ($SnCl_2$-ś2H_2O) used as mordant were of laboratory grade. Sodium hydrogen carbonate, phosphate, and sodium acetate buffer were purchased from Merck, Mumbai, India.

Methods

FT-IR spectroscopic investigations

Fourier Transform infrared (FT-IR) spectroscopy was performed using "Perkin Elmer Spectrum RXI FT-IR System" in order to investigate and observe fiber–dye interactions with a resolution of 2 cm^{-1}. Disks were prepared by cutting dyed and undyed woolen yarn samples into fine pieces and ground with KBr, used as internal standard. Analysis of recorded FT-IR spectrum was done in accordance with the resolution of Amide I, II and III bands.