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Application of Agricultural Industry Wastes in the Dyeing Process of Handwovens

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ABSTRACT

Textile processing industries are one of the major hazardous sources from an ecological point of view that produce large amounts of toxic and dangerous waste containing heavy metals every year. Heavy metal accumulation and contamination in water and soil is a serious problem throughout the world due to their non-biodegradable nature, toxicity, abundant sources, and accumulative behavior in the environment. There is an urgent need to explore biocompatible and safe ways for textile dying industries to use environment benign route. Recently, there has been greater interest in the use of natural products in the dyeing industry due to improving international awareness of waste disposal, water pollution, and the environment. In the present work, Pistacia shell and Amaranth were considered as bio-compatible mordant and dye for the wool dyeing process. The research method is practical in terms of purpose and response surface methodology based on Box-Behnken Design (BBD) was used to design experiments and minimize the amount of consumables and production waste. The effects of three main parameters i. e. dyeing time, dye concentration, and citric acid concentration on the color performance of wool yarns were investigated and the optimum conditions were specified. The validity of the model for optimization and prediction of the process with a low number of experiments was established by experimental results (low difference between adjusted correlation coefficient (0.9832) and predicted coefficient value (0.9307)) and also by a high value of model correlation (0.9927). Also, it was found that all independent factors, the quadratic effect of dyeing concentration, and the interaction terms citric acid-dyeing concentration were significant at a confidence level of 95%. The results show that the Pistacia shell used as a bio-mordant can improve the affinity of wool yarns to the dye extract and obtain acceptable dye fastness properties. The use of Pistacia shell as a biodegradable and new sustainable bio-mordant in the dyeing industry resulted not only in increasing dyeing efficiency but also in minimizing the environmental problem of agricultural waste and byproducts. Hence, the proposed novel approach might serve as an excellent and economical replacement for the common metallic mordants and provide a space for new businesses with value-added at no environmental costs.

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INTRODUCTION

Water and soil pollution are among the most significant environmental problems worldwide, posing a serious threat to the lives of all living creatures, especially humans. To reduce environmental damage by decreasing energy consumption, and waste production, and eliminating hazardous chemicals from textile processes, two main strategies exist. The first solution is optimizing dyeing processes using chemical dyes. The second is replacing chemical materials with natural ones and developing the technology and use of sustainable, biodegradable, renewable, and environmentally friendly materials in textile processes (Li et al., 2022; Baseri, 2022; Macchi et al., 2021; Zhang et al., 2022; Baseri 2022; Zeng et al., 2020).

This research aimed to extract phenolic compounds from pistachio shells and use them as a low-cost and readily available bio-mordant for dyeing wool yarn with *Amaranth* natural dye. This study also investigated the main factors in the wool dyeing process and optimized dyeing conditions through response surface methodology.

DATA AND METHODS

This research is entirely experimental, and the data were obtained through experiments. The powder of Amaranth was soaked in 40%v/v ethanol at ambient temperature with stirring for 48 hours. The mixture was then heated at boiling temperature for 90 min. After the end of the period, it was cooled down and finally accurately filtered. It was then concentrated at 50 °C. The pre-mordanting method was carried out on soaked wool yarns using 20% (of the yarn weight) of pistachio shells at 97 °C for one hour. Then the pre-mordanted yarns were cooled and washed with distilled water, and subjected to a dyeing procedure. The dyeing process was designed by using the Design Expert software based on the Box-Behenken design algorithm. According to the preliminary experimental results, three independent process variables (i. e., dye concentration, citric acid concentration, and time) and their experimental levels were selected.

RESULTS AND DISCUSSIONS

The response values were fitted to several models to check the model adequacy. According to the adjusted R-square (0.9927), predicted R-square (0.9307), and the value of sequential p-value (0.0003), the quadratic model was chosen. The analysis of variance for wool yarns dyed with Amaranth extract showed that all the linear terms, the quadratic effect of dye concentration, and the interaction terms of dye and citric acid concentrations are significant in the wool dyeing process with Amaranth extract, while no such significant effects are observed for the quadratic effects of citric acid concentration and time and the interaction terms of dye concentration-time and citric acid concentration-time (P-value > 0.05). Based on the experimental data and actual factors, the regression model in terms of coded factors may be estimated using below equation:

$$RCS = 11/86 + 3/03A + 0/9742B + 0/6306C + 0/4850AB - 1/35A^2$$

The simultaneous effects of dyeing parameters as well as the effect of each parameter on the relative color strength of the wool yarns are shown in Fig. 1.

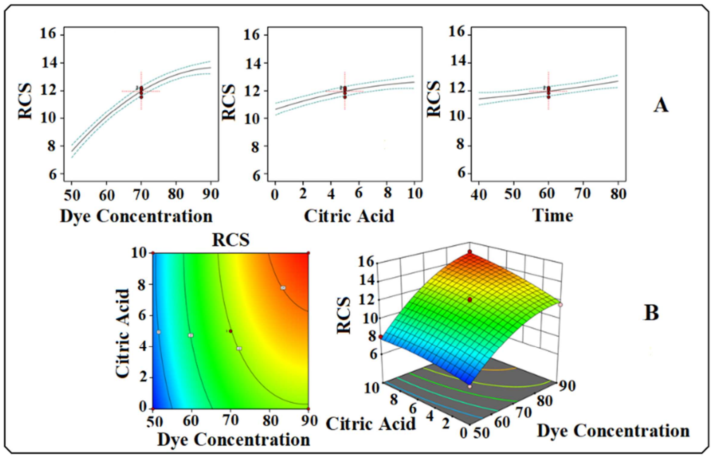

Fig 1. Effects of main dyeing parameters on relative color strength values of dyed wool yarns

Increasing the concentration of Amaranth increased the dye uptake. An increase in dye concentration resulted not only in improving the driving force of the concentration gradient but also helped increase the number of available dye molecules to react with the functional groups of peptide chains. Also, it is seen that a longer dyeing time leads to the dye uptake of wool yarns to improve. This could be explained by the fact that by increasing dyeing time, the required time for color molecules to diffuse into the yarns increased, leading to more interactions with peptide functional groups that enhanced dye uptake.

Fig. 1 shows that the relative color strength values of the dyed wool yarns increase as a result of increasing the concentrations of citric acid. Wool is an animal fiber and consists of repeating amino acid units, which its main pendant groups are NH^{3+} and COO^{-}.I n acidic conditions, the surface of wool chains is positively charged, leading to strong yarn-dye affinity. So, the protonated terminal amino groups of wool samples would interact ionically with the anions of the Amaranth dye molecules and so increasing their dye uptake. On the other hand, citric acid is one of the most important safe polycarboxylic acids with one hydroxyl group and three carboxyl groups. It can break hydrogen bonds between polymer chains and reduce intermolecular interactions and thus can be considered a softener (Miohsin et al., 2014).

Fig. 2 presents the Pareto chart of the standardized effects of the dyeing process. It can be demonstrated the importance of the dyeing factor. It is possible to identify that the dye concentration parameter has the highest coefficient. So, it may be concluded that it has the greatest effect on the dying process with Amaranth extract.

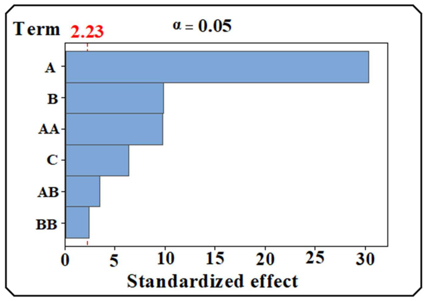

Fig 2. Pareto chart to evaluate the influence of independent factors on the response value

CONCLUSION

In the present work, Pistacia shell and *Amaranth* were used as an eco-friendly mordant and a natural dye, respectively, for dyeing wool yarns. The effect of the main dyeing factors on the process efficiency was investigated and the optimal process conditions to obtain the highest dye uptake were evaluated by the response surface methodology. The results showed that increasing dye concentration, citric acid concentration, and dyeing time increased the color strength value. Also, the established model has a high value of the regression coefficient and is an indicator of a high degree of correlation between the actual data and the empirical model.

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