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(Research Article)

Efficiency of watermelon rinds, neem seeds and neem leaves as adsorbents in wastewater treatment

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Abstract

The study evaluates the efficiency of some natural materials as low-cost adsorbents in waste water treatment. Watermelon rind, neem leaves and neem seeds were obtained from Federal College of Education, Katsina, while the adsorbate samples are liquid effluents obtained from Katsina Youth Craft Village(KYCV), and Congo Red and Methyl orange dyes purchased from Chemical stores. Adsorption experiments were conducted at optimal conditions (10 ppm dye concentration, 0.6g adsorbent dosage, 333K temperature and 45 minutes of agitation time). The adsorbents were characterized using Fourier Transform Infrared Spectroscopy(FTIR) and Scanning Electron Microscopy (SEM) before and after treatment to assess changes in surface morphology and functional groups. The watermelon rind (WR) had the highest percentage removal for all the samples, Congo red dye (92.5%), Methyl orange (78.3%) and the industrial effluent (83.1%). Neem leaves (NL), followed with a percentage removal of 88.1% for Congo red, 74.2% for methyl orange and 80% for the industrial dye effluent. Neem seeds had the lowest percentage removal values, 84.7% for Congo red, 71.4% for Methyl orange and 76.5% for the industrial dye effluent. All the adsorbents had the highest percentage removal value in Congo red, followed by the industrial dye effluent from KYCV. Comparison using ANOVA revealed a significant difference in the adsorptions of the three adsorbents. The findings highlight the potential of watermelon rind, neem seed, and neem leaves as alternatives for treating dye-contaminated wastewater, especially under optimal conditions. The FTIR and SEM analyses confirmed the involvement of functional groups and surface modifications during the adsorption process.

Keywords: Efficiency; Adsorbents; Adsorbates; Waste water; Treatment

1. Introduction

Industrial wastewater, particularly from the textile sector, is one of the primary sources of water contamination, especially with harmful dyes such as Congo red and methyl orange. These dyes are resistant to conventional treatment methods and can cause severe environmental and health issues if not removed efficiently [1]. Neem (*Azadirachta indica*) leaves have been shown to effectively remove Congo red and Methyl orange dyes from aqueous solutions under varying conditions such as pH, agitation time, dosage, and particle size [2]. Traditional treatments are often expensive, energy-intensive, and environmentally damaging. In contrast, natural waste materials like watermelon rind, neem seed, and neem leaves have emerged as promising, low-cost, and eco-friendly alternatives for dye removal due to their abundant availability and adsorption capacity [3]. Water pollution due to industrial dye effluents is a major global concern, particularly in developing countries with limited access to advanced treatment technologies. Synthetic dyes such as Congo Red and Methyl Orange are non-biodegradable, toxic, and resistant to conventional biological treatment. This study investigates the use of natural, locally available agricultural residues—watermelon rind, neem seed, and neem leaves—as low-cost, eco-friendly, adsorbents for dye removal from wastewater. Anchored in the principles of green

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chemistry and circular economy, it demonstrates how abundant biomass in Katsina can be repurposed to reduce environmental impact, minimize disposal costs and promote local economic empowerment. Watermelon and neem-based materials are abundant in Katsina, and their utilization supports waste valorization and local economic empowerment. Furthermore, the study addresses an urgent need to develop cost-effective, accessible solutions for rural and semi-urban communities, especially in northern Nigeria, where industrial activities such as textile dyeing contribute significantly to surface water pollution. The development of cheaper, effective and novel methods of decontamination is currently an active field in research. [4].

Despite extensive studies on dye removal from wastewater, several limitations remain in the existing literature. One major gap is the reliance on synthetic dye solutions in laboratory experiments, which do not accurately reflect the complexity of actual industrial effluents. This study addresses this by incorporating real wastewater from the KYCV Dye Factory in Katsina, Nigeria, thereby offering a more practical and environmentally relevant assessment of adsorbent performance. Another notable gap is the scarcity of data from northern Nigeria, where industrial pollution from local textile operations poses serious environmental and health concerns. By focusing on this underrepresented region, the study contributes location-specific findings that can inform local environmental policy and wastewater management strategies. Furthermore, most existing studies evaluate the performance of single natural adsorbents in isolation. This limits the ability to compare different materials under uniform conditions. To bridge this gap, the current research conducts a comparative analysis of three different natural adsorbents— watermelon rind, neem seed, and neem leaves, —assessed simultaneously for their efficiency in removing both individual and mixed dyes. Temperature is another critical factor that influences adsorption, yet it is often overlooked or inadequately studied. This research includes experiments conducted at elevated temperature (333K), providing insight into how thermal conditions affect dye removal, which is important for real-world applications where wastewater may be discharged at higher temperature. Lastly, most prior studies focus solely on single dye systems, neglecting the fact that industrial effluents often contain complex mixtures of dyes. The present study includes experiments with industrial effluents with mixtures of dyes, thereby offering a more realistic scenario and filling the gap regarding multi-component adsorption systems.

By addressing the urgent need for affordable treatment technologies in rural and semi-urban communities of Northern Nigeria, where textile dyeing contributes significantly to water pollution, the findings advance understanding of low-cost, bio-based adsorbents and offer practical solutions for developing countries with limited access to conventional treatment technologies.

This study aims to assess the efficiency of watermelon rind, neem seed, and neem leaves in removing Congo red, methyl orange, and dye effluent from a textile industry in Katsina, Nigeria. The adsorption process was monitored under optimal conditions (10 ppm dye concentration, 0.6g adsorbent dosage, 45 minutes of agitation and relative temperature of 333K), and the percentage removal of dyes was determined. Additionally, the adsorbents were analyzed using FTIR and SEM to understand the adsorption mechanism and surface modifications during the treatment process [5,6].

2. Materials and Methods

2.1. Preparation of adsorbents

The adsorbents used in this study are watermelon rind (WR), neem seeds (NS), and neem leaves (NL), all sourced from Federal College of Education, Katsina and identified at the Department of Plant Biology, Faculty of Life Sciences, Bayero University, Kano. The Water melon rind, Neem seed and Neem leaves were given Accession numbers, ABB88898.5, AAO92027.1 and AAB47640.1 respectively. The materials were washed thoroughly to remove any dirt or external contaminants and then dried under shade. Once dried, the materials were ground into fine powder, and then dried overnight in an oven at a temperature of 65°C . The oven dried samples were sieved and stored in sealed containers for the adsorption experiments [2,7].

2.2. Adsorbates

The adsorbates used for the adsorption tests were collected from the KYC dye factory in Katsina State, Nigeria. Other samples used for comparison are Congo red dye (CR) and Methyl orange (MO) dye bought from chemical stores in Katsina without further treatment. 10ppm solution of the three samples (KYC, CR and MO), were prepared using standard procedures [2]. The pH of the dye solutions was adjusted to 7, which is optimal for adsorption of most pollutants [6].

2.3. Batch Adsorption Procedure

Experiments on the adsorption of CR, MO, and KYC effluents using Water melon rind (WR), Neem seeds (NS) and Neem leaves (NL) as adsorbents was carried out by batch method using the procedure reported by [8]. The influence of contact time (15,30,45,60 and 90 min), adsorbent dosage (0.2,0.4,0.6 and 0.8g), initial adsorbate concentration (10, 20, 30,40,50 and 60 mg/L) and relative temperatures (303,308, 313, 318, 323, 328, and 333K) were studied at a constant agitation speed, at room temperature in triplicates. The optimal contact time, adsorbent dosage, initial adsorbate concentration, relative temperatures, and agitation speed were first determined using standard procedures [8]. The adsorption experiments were then carried out under the following optimal conditions: contact time (45 minutes), Adsorbent dosage: 0.6g of each material (watermelon rind, neem seed, neem leaves) per 100 mL of adsorbate sample solution, Initial adsorbate concentration of 10 ppm and Temperature (333K). The adsorption experiments were conducted by adding 0.6g of each of the adsorbents (WR, NS, NL) in 250 mL beakers containing 100mL each of known concentrations of the adsorbate (CR, MO, KYC) solutions. The mixtures were agitated on a magnetic stirrer for the predetermined contact time of 45 minutes to attain equilibrium, after which the samples were taken out and the supernatant solutions separated from the adsorbents by filtration using Whatman No. 41 filter paper. The filtrates were analysed using UV-Visible spectrophotometer (Perkin Elmer, Hitachi Model 2800) at a maximum absorption (λmax) of 500nm (CR), 464nm (MO) and 553nm (KYC). The data is reported as an average value of the triplicate readings. In each case, the percentage adsorption and substrate's equilibrium adsorption capacity(mg/g) were evaluated.

2.4. Adsorption Efficiency Calculation

The adsorption efficiency of the adsorbents was calculated using the following equation:

$$\text{Percentage Removal} = \frac{C_0 - C_f}{C_0} \times 100\%$$

Where: C_0 is the initial concentration of the solution (ppm)

C_f is the final concentration of the solution after treatment (ppm)

2.5. Characterization of Adsorbents

To understand the changes in the surface characteristics of the adsorbents before and after the adsorption process, Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) were used. FT-IR spectra were recorded in the range of 4000–650 cm^{-1} to identify functional groups involved in the adsorption process [5]. SEM images were obtained at various magnifications to examine the surface morphology of the adsorbents before and after treatment [9].

2.6. Statistical Analysis

The results were compared using two-factor ANOVA without replication to see if there is a significant difference in the adsorption efficiencies of the three adsorbents.

3. Results and Discussion

3.1. Dye Removal Efficiency

The percentage removal of Congo red (CR), methyl orange (MO), and dye effluent mixture (KYC) using watermelon rind (WR), neem seeds (NS), and neem leaves (NL) is presented in Figure 1.

The watermelon rind (WR) had the highest percentage removal for all the samples: Congo red dye (92.5%) ,Methyl orange(78.3%) and the industrial effluent (83.1%). Neem leaves (NL), followed with a percentage removal of 88.1% for Congo red, 74.2% for methyl orange and 80% for the industrial dye effluent. Neem seeds had the lowest percentage removal values, 84.7% for Congo red, 71.4% for Methyl orange and 76.5% for the industrial dye effluent. All the adsorbents had the highest percentage removal value in Congo red, followed by the industrial dye effluent from KYCV. The least percentage removal was obtained in Methyl orange dye. The strong adsorption capacity for the two dyes and components in industrial effluent by WR may be due to the high surface area and functional groups such as hydroxyl and carbonyl groups present in the rind's cell walls, which promote dye binding [7]. Adsorption of components in the industrial effluent (KYC) by all the adsorbents were lower than for Congo red. This could be due to the complex mixture of contaminants in the effluent, which may have limited the adsorptive capacity of the materials [1]. The percentage removal values for the effluent were however higher than those of methyl orange dye. ANOVA indicated a significant difference in the adsorption of the three adsorbents. Factors such as adsorbent characteristics, solution properties and environmental factors can influence adsorption of contaminants from water. The analysis was carried out using optimal conditions of solution properties and environmental factors such as concentration, temperature and contact time.

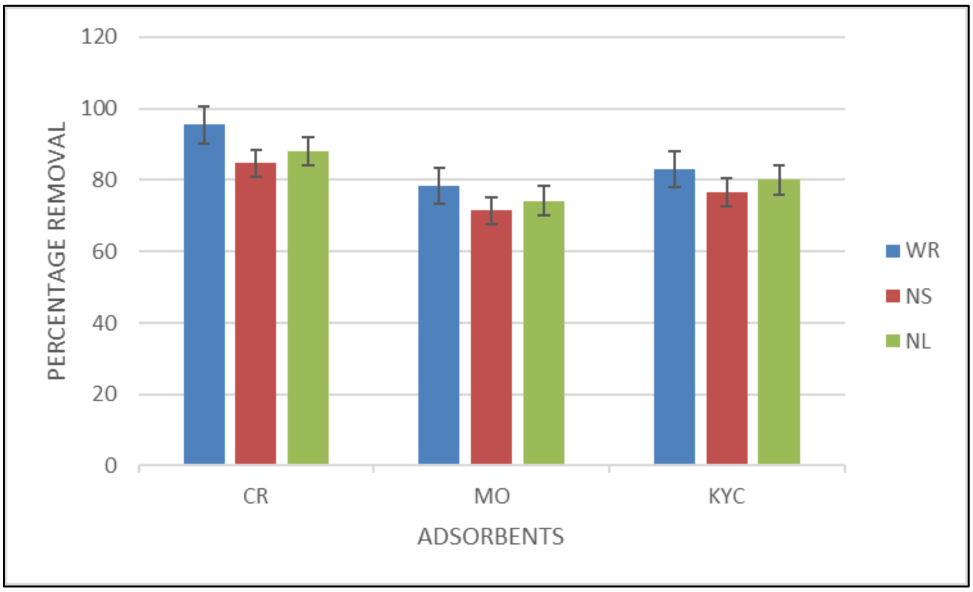

Figure 1 Percentage Removal Efficiency of the Adsorbents for CR, MO and KYC

3.2. FTIR Analysis

The FT-IR analysis before and after the adsorption of CR dye are depicted in figures 2-7.

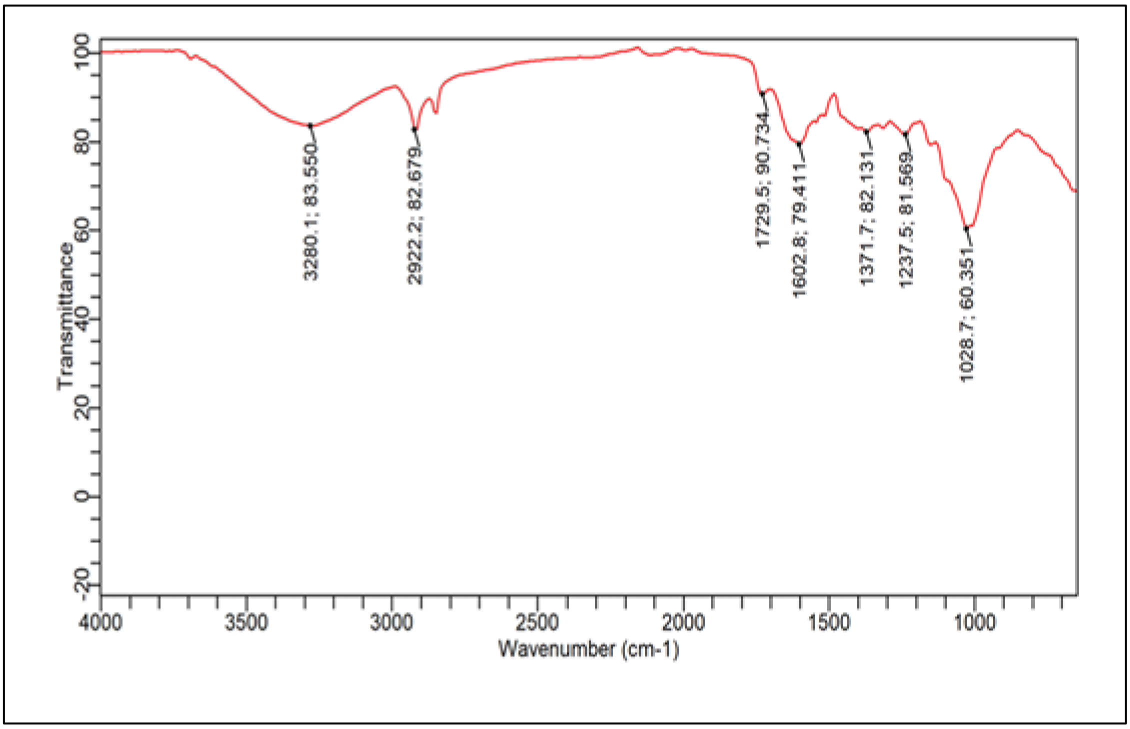

Figure 2 FT-IR Spectrum of WR before Adsorption of CR

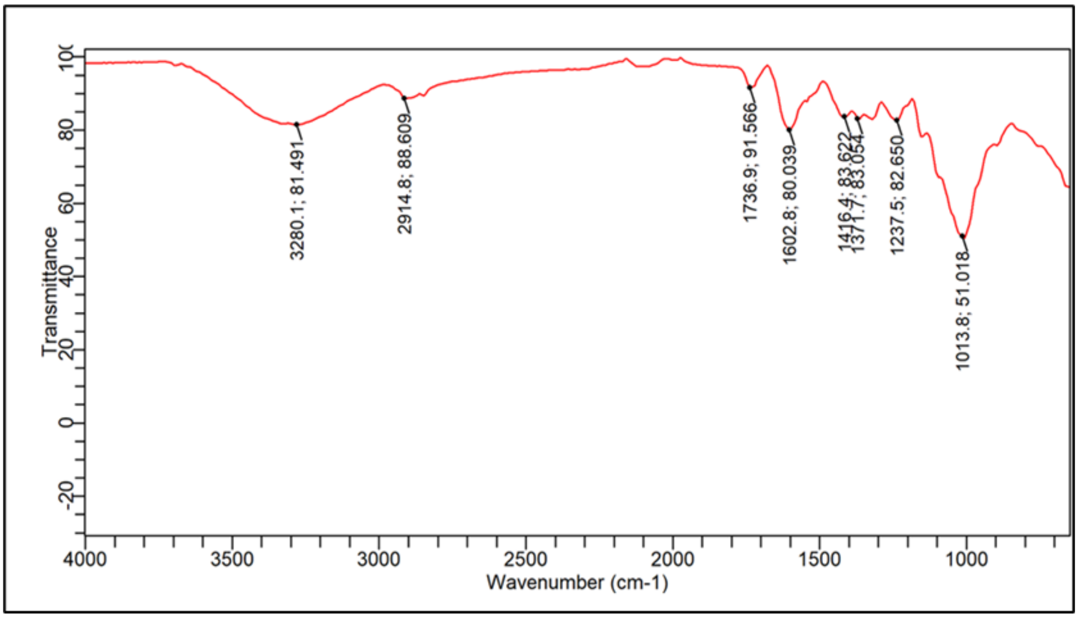

Figure 3 FT-IR Spectrum of WR after Adsorption of CR

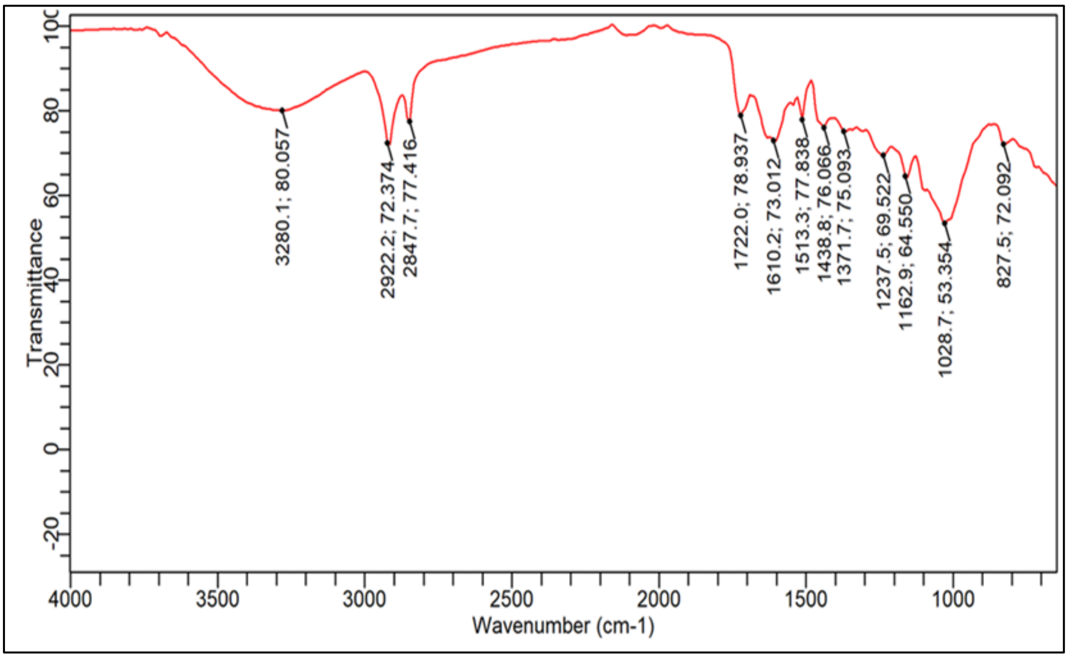

Figure 4 FT-IR Spectrum of NL before Adsorption of CR

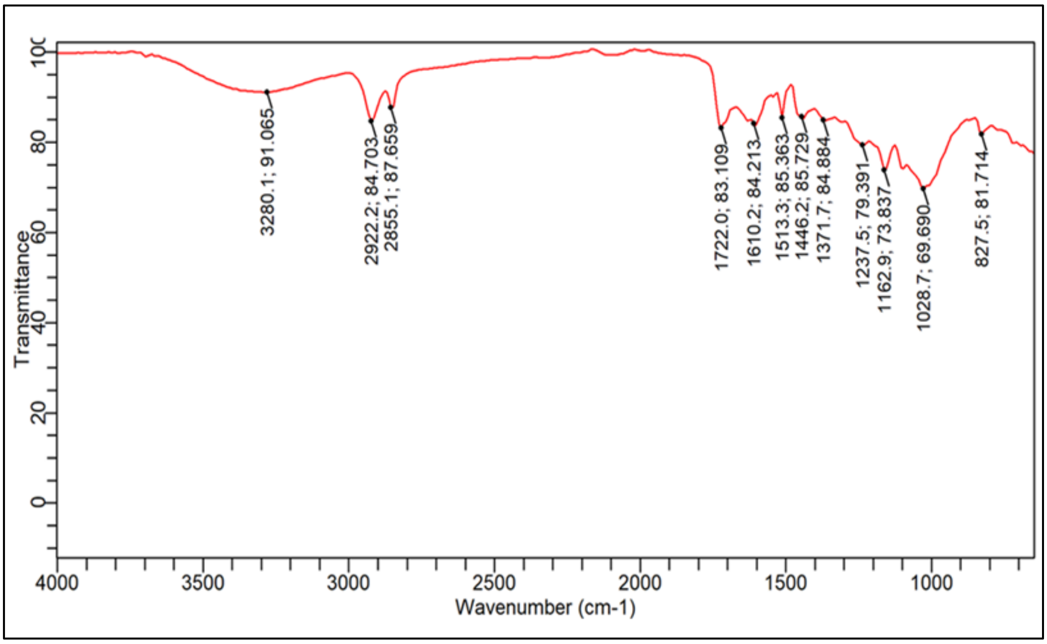

Figure 5 FT-IR Spectrum of NL after Adsorption of CR

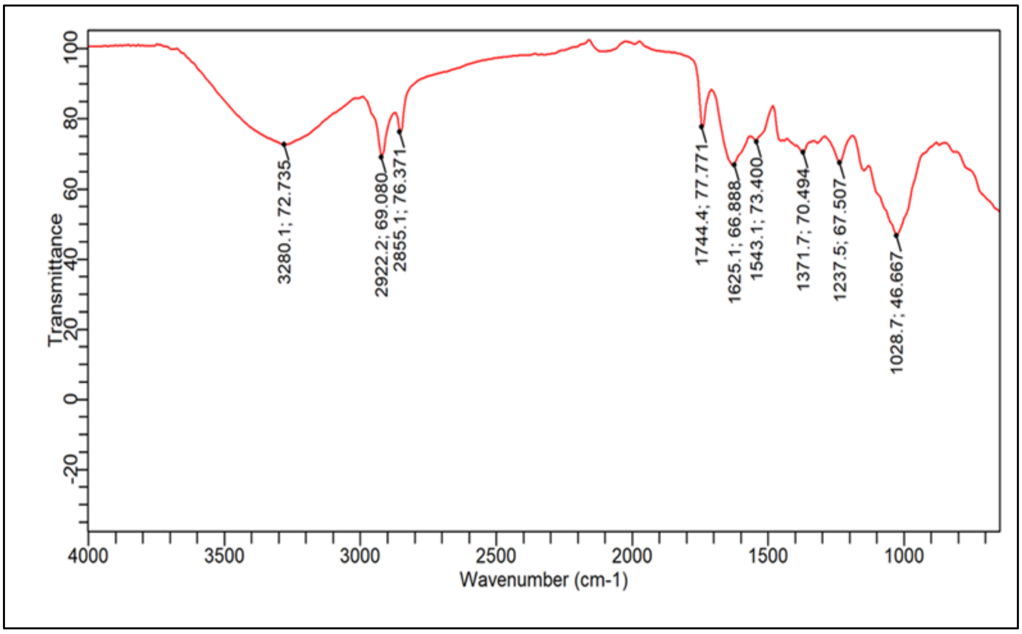

Figure 6 FT-IR Spectrum of NS before Adsorption of CR

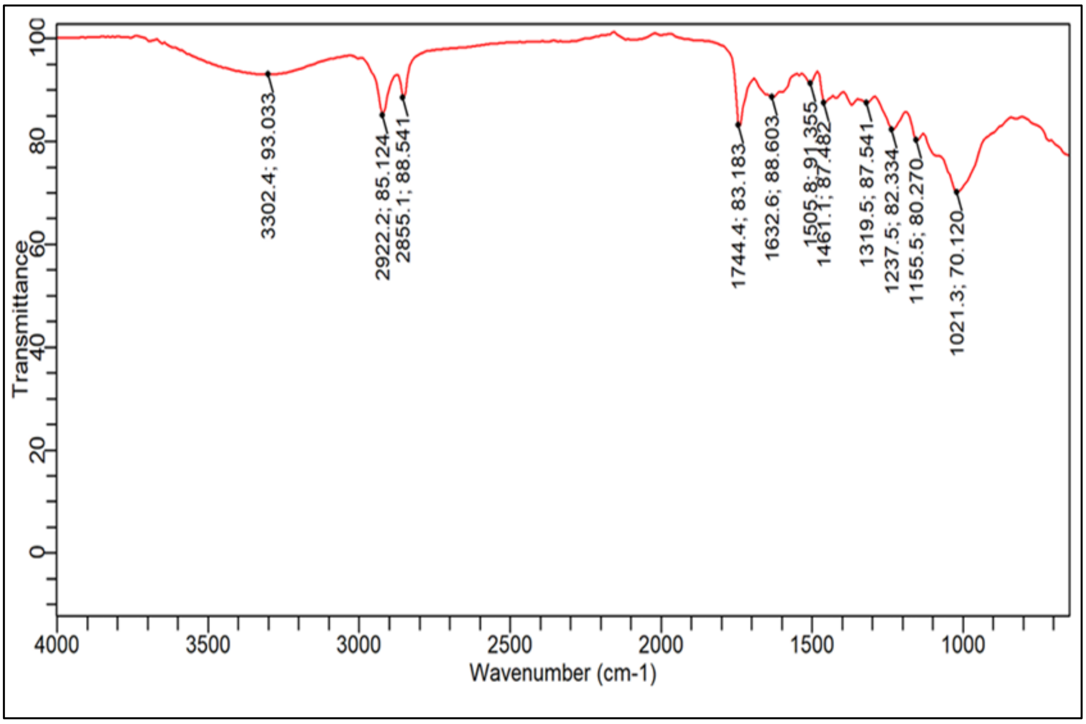

Figure 7 FT-IR Spectrum of NS after Adsorption of CR

3.2.1. Water Melon Rind (WR)

The clean baseline (Figure 2) indicates pure adsorbent material with characteristic peaks showing presence of functional groups including hydroxyl (-OH), carbonyl (C=O), and aromatic compounds. The peaks shifts and intensity changes in figure 3 indicate successful adsorbate adsorption. New peaks or modified existing peaks suggest interaction between adsorbate molecules and adsorbent surface. Changes in the fingerprint region confirm adsorbate binding.

3.2.2. Neem Leaves (NL)

The spectra (figure 4) show characteristic cellulose, lignin, and other functional groups with a strong O-H stretching vibrations around 3200-3600 cm^{-1}, C-H stretching and bending vibrations. Spectral changes after adsorption (Figure 5), indicate adsorbate molecules have interacted with NL surface. Possible hydrogen bonding and electrostatic interactions between adsorbates and functional groups. Peak broadening or splitting may indicate multiple binding sites.

3.2.3. Neem seeds (NS)

The spectra before adsorption (figure 6) are similar to that of NL but, NL are more complex with additional peaks, possibly from Leaf specific compounds.. Clear evidence of adsorbate adsorption through spectral modifications was shown in figure 7. Changes suggest both physical and chemical interactions during the adsorption process.

3.3. SEM Analysis

The SEM image of the mixture of adsorbents before and after are shown in figures 8 and 9.

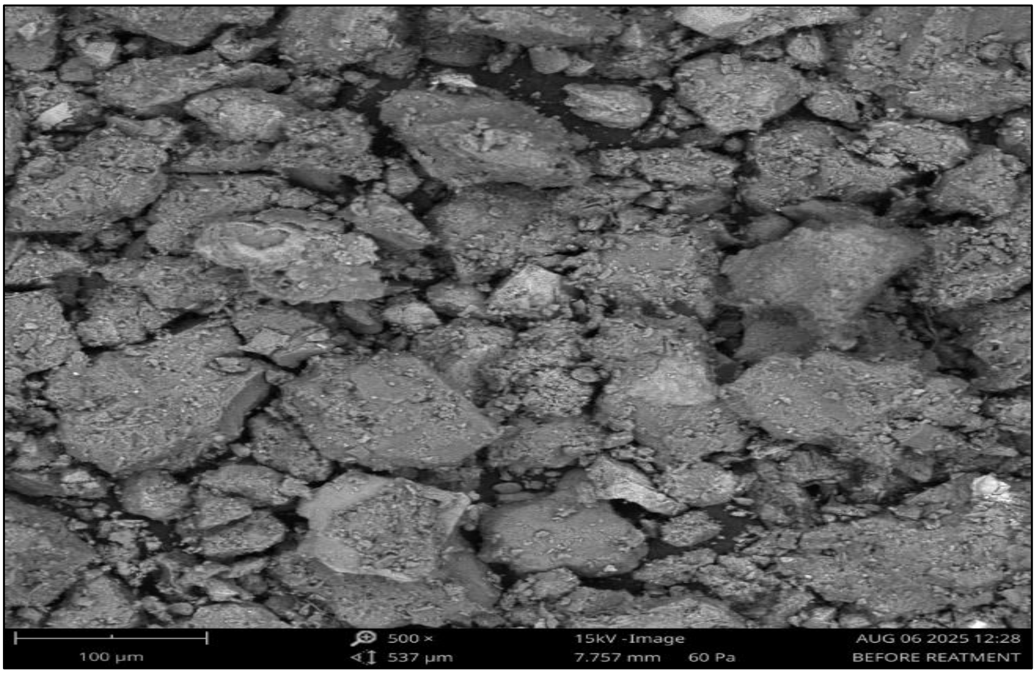

Figure 8 SEM Analysis on the Mixture Adsorbents before Dye Uptake

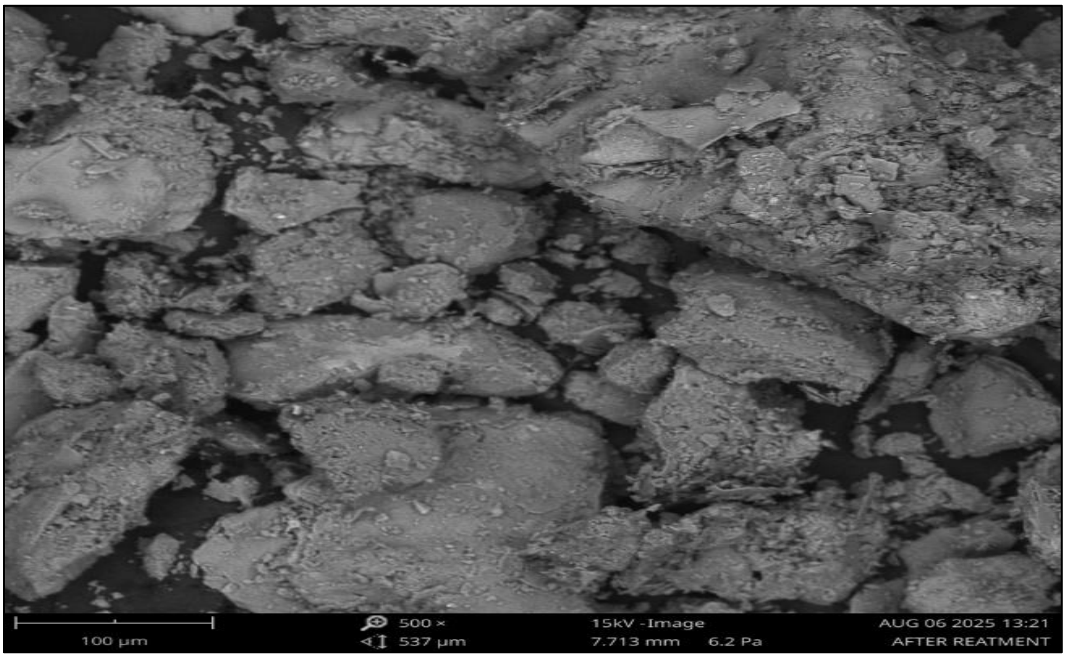

Figure 9 SEM Analysis on the Mixture Adsorbents after Dye Uptake

3.3.1. SEM Analysis

There were clear differences between before (figure 8) and after adsorbate uptake (Figure 9). Before adsorption, surface morphology shows the original structure of the adsorbents. Surface area appears to have good porosity and surface texture suitable for adsorption. After adsorption, the adsorbate molecules altered the surface characteristics, with some degree of structural modification due to adsorbate loading. There was non-uniform dye distribution across the adsorbent surface.

4. Conclusion

This study found that the three natural materials (watermelon rind, neem seed, and neem leaves) effectively remove synthetic dyes from wastewater. Watermelon rind performed best, especially for Congo red dye removal, under optimal conditions of 10 ppm adsorbate concentration, 0.6g adsorbent dosage, 45 minutes agitation time and a temperature of 333K. FTIR and SEM analyses confirmed the adsorption mechanism through functional groups and surface changes. These materials offer sustainable, low-cost solutions for mixed dye wastewater treatment. Future research should focus on adsorbent regeneration/reuse and industrial scaling. Further optimization could enhance the adsorption capacity and selectivity.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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