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ORIGINAL RESEARCH PAPER

SYNTHESIS, CHARACTERIZATION AND POTENTIAL APPLICATION OF BIOCOMPOSITE MATERIAL BASED ON SAWDUST BIOMASS FOR REMOVAL OF PERSISTENT ORGANIC POLLUTANTS FROM AQUEOUS SOLUTIONS

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Abstract: This study aimed to develop a biocomposite material by immobilizing sawdust in a natural polymer matrix (chitosan) and to evaluate its biosorptive potential for the removal of dyes and pharmaceutical compounds from aqueous solutions. The synthesized biocomposite, designated as C-SD-2.5%, was characterized by scanning-electron-microscopy (SEM), X-ray energy-dispersive spectroscopy (EDS), and Fourier transforms infrared (FT-IR) spectroscopy. Additionally, particle size and the point of zero charge were established. Its biosorption capacity was evaluated for the removal of two dyes, Malachite green (MG) and Brilliant green (BG), and one pharmaceutical compound, Ethacridine lactate (EL), from aqueous media. The results demonstrated that the removal efficiency exceeded 96 % for all tested molecules after 48 hours under the selected experimental conditions. These findings suggest that the synthesized C-SD-2.5% biocomposite has strong potential as a low-cost and effective adsorbent for the removal of MG, BG, and EL from aqueous environment.

Keywords: *adsorption, brilliant green, chitosan, ethacridine lactate, immobilization, malachite green, sawdust*

INTRODUCTION

Global population growth, industrialization, and climate change have significantly impacted water quality, contributing to an escalating freshwater crisis. Furthermore, the extensive use of water resources and the presence of various contaminants have exacerbated the depletion of freshwater supplies. The leading source of aquatic environment contamination is represented by the main effluents of urban and industrial wastewater treatment plants. The presence of emerging pollutants has been reported worldwide in various aquatic environments: lakes, rivers and marine waters [1 – 3].

However, only a limited number of these pollutants have been toxicologically evaluated, and analytical methods capable of detecting residues at very low concentrations, on the order of $ng \cdot L^{-1}$, are available for only a few [4].

Organic dyes represent one of the largest categories of water pollutants and originate from a wide range of industries, including textiles, pulp and paper, paints and varnishes, cosmetics, leather processing, pharmaceuticals, and food production [5, 6].

Special attention has been directed toward pharmaceuticals, a significant category of emerging pollutants that are widely used in both human and veterinary medicine. Their widespread use, improper disposal, and the low efficiency of conventional wastewater treatment plants contribute significantly to water contamination [7, 8].

In recent decades, the scientific community has become increasingly concerned about the impact of these categories of pollutants on ecosystems and human health, in accordance with the "One Health" concept [4, 6]. Therefore, there is an urgent need to explore effective strategies for the removal of emerging pollutants from aqueous environments.

Numerous methods have been developed for the removal of pollutants from water, including chemical precipitation, chemical oxidation or reduction, electrochemical treatment, reverse osmosis, ion exchange, electrocoagulation, and evaporation recovery. However, many of these approaches have become unsustainable due to high operational costs, energy consumption, and secondary pollution by hazardous sludge. Adsorption technology, by contrast, has emerged as a promising method for water treatment, generating increasing interest in the development of practical and low-cost adsorbents for industrial applications [9].

In light of these considerations, we propose the valorization of sawdust, a waste of the wood processing industry that is generated in large quantities and contributes to environmental pollution, as an adsorbent [10]. Furthermore, recent literature indicates that various types of sawdust have already been successfully tested for the retention of specific dyes [11 – 13] and heavy metals [14 – 17].

In this context, the study aimed to develop a biocomposite material by immobilizing sawdust onto a natural polymer (chitosan) and to evaluate its biosorptive potential for removing persistent organic pollutants from water.

This study investigated the biosorption of two triarylmethane dyes, brilliant green and malachite green, in addition to the pharmaceutical compound ethacridine lactate.

Brilliant green (BG) is widely used in the textile industry for dying wool, in the paper industry, biological dyes and dermatological agents. However, it is a hazardous contaminant that causes diarrhea, eye irritation, nausea and vomiting [18].

Basic malachite green (MG) dye has been used extensively to color leather, silk and wool. It is also used as an antiseptic and fungicide in the aquaculture sector to fight fish diseases and parasites [19].

Malachite green is a persistent organic pollutant and acutely toxic to a wide range of aquatic and terrestrial animals, being lethal to freshwater fish. MG is also considered a serious public health hazard, being a multiorgan toxin, which has multiple consequences: it decreases food intake, causes damage to the liver, kidneys, heart and spleen; causes damage to the skin, eyes, lungs, bones and produces teratogenic effects. Malachite green is extremely cytotoxic to mammals [20, 21]. Furthermore, there is a lack of literature available on the use of sawdust to remove triarylmethane dyes.

Ethacridine lactate is an acridine derivative with antiseptic properties, that is recommended for the treatment of Gram-positive bacterial infections. Because it is an excellent antibacterial medication, it is used to treat enteric diseases like shigellosis and diarrhea orally. Despite being beneficial to humans, EL is regarded as a dangerous material that is highly toxic for aquatic life, causing both acute and long-term health consequences [6, 22].

There are many research articles described in reviews relevant to the adsorption of dyes, heavy metals and antibiotics. However, to the best of our knowledge, no previous studies have investigated the adsorption of brilliant green dye and ethacridine lactate drug using a sawdust immobilized in chitosan biocomposite as a biosorbent.

MATERIALS AND METHODS

Materials and reagents

Sawdust

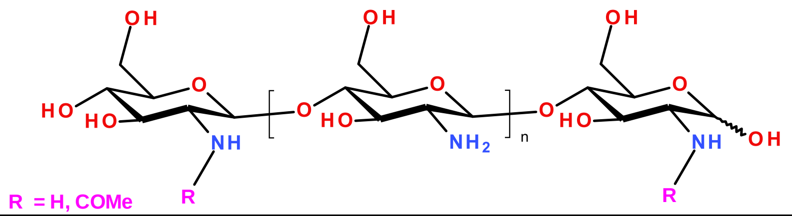
In this study, oak and pine wood sawdust was utilized, sourced from Woodgrade Company, a Romanian manufacturer of wooden furniture. The sawdust originates from various stages of the lumber processing workflow. Notably, the company exclusively processes lumber, which ensures that other wood residues such as bark or wood chips are not present.

Given the presence of multiple sawdust types at the industrial platform, differing in particle size, only the fine sawdust generated during sanding and calibration operations was selected for synthesis. This fine material is collected in filter bags. The sample was subsequently sieved, and particles ranging in size from 0.050 to 0.100 mm were used in the synthesis process.

Chitosan

Chitosan was supplied from Sigma-Aldrich (Germany), and its specifications, as provided by the manufacturer, are detailed in Table 1.

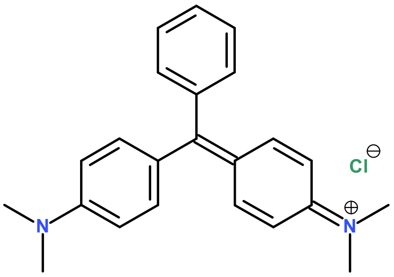
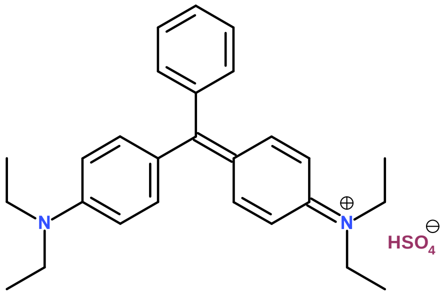
Table 1. *The chitosan characteristics*

Characteristics	**Chitosan**
Structural formula	
Linear formula	$(C_6H_{11}O_4N)_n$
Deacetylation degree	≥ 75 %
Origin of material	Shrimp shells

Target molecules

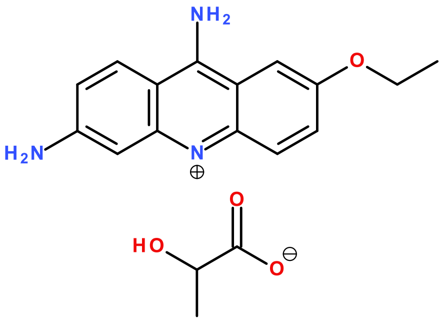
Two dyes and one pharmaceutical compound were chosen as target molecules for testing. Malachite green (MG) and Brilliant green (BG) dyes used in the study were purchased from Merck Company (Darmstadt, Germany) and were of analytical purity. The characteristics of the above dyes are provided in Table 2.

Table 2. *Characteristics of dyes*

Characteristics	**Malachite green (MG)**	**Brilliant green (BG)**
Structural formula		
IUPAC name	4-{[4-(Dimethylamino)phenyl](phenyl)methylidene}-*N*,*N*-dimethylcyclohexa-2,5-dien-1-iminium chloride	4-{[4-(Diethylamino)phenyl](phenyl)methylidene}-*N*,*N*-diethylcyclohexa-2,5-dien-1-iminium bisulphate
Usual names	Aniline green; Basic green 4; Diamond green B; Victoria green B	Malachite green G, Emerald green, Solid green JJO, Diamond green G, Benzaldehyde green, Fast green J
Molecular formula	$C_{23}H_{25}N_2Cl$	$C_{27}H_{34}N_2O_4S$
CAS No.	569-64-2	633-03-4
Molecular weight [g·mol^{-1}]	364.91	482.64
λ_{max} [nm]	618	625

Ethacridine lactate drug used in experiments was purchased from Merck Company (Darmstadt, Germany), and its characteristics are presented in Table 3.

Table 3. *The ethacridine lactate characteristics*

Characteristics	**Ethacridine lactate (EL)**
Structural formula	
IUPAC name	2-ethoxy-6,9-diaminoacridine monolactate monohydrate
Usual names	Acrinol, Ethacridine lactate monohidrate, Rivanol
Molecular formula	$C_{18}H_{21}N_3O_4$
CAS No.	1837-57-6
Molecular weight [$g\cdot mol^{-1}$]	343.38
λ_{max} [nm]	431

Sodium hydroxide and glacial acetic acid were obtained from Chempur (Piekary Śląskie, Poland). All solutions were prepared using distilled water. Stock solutions (500 $mg\cdot L^{-1}$) of brilliant green, malachite green and ethacridine lactate were prepared and stored at 4 °C in closed vessel. Working solutions were then prepared by dilution: 1 - 10 $mg\cdot L^{-1}$ for brilliant green and malachite green, and 1 - 70 $mg\cdot L^{-1}$ for ethacridine lactate. Absorbance measurements were performed at specific wavelengths using a UV1280 spectrophotometer (Shimadzu, Tokyo, Japan) to generate calibration curves. All experiments were conducted in triplicate.

Biocomposite material synthesis

To prepare the composite material, a sawdust fraction with particle sizes between 0.050 and 0.100 mm was used, hereafter referred to as P1F6. The technique employed for synthesizing the composite granules was immobilization in a polymeric matrix using chitosan.

The preparation of the sawdust - chitosan composite started with the pre-drying of the P1F6 sawdust fraction at 105 °C for 3 hours. A suspension was then prepared by dispersing the sawdust in a 2 % acetic acid solution, followed by continuous stirring. Chitosan was added to this suspension to reach a final concentration of 2.5 %, and the mixture was stirred until a homogeneous suspension was achieved. After homogenization and a 12-hour resting period for degassing, the mixture was carefully dripped into a 1 M sodium hydroxide (NaOH) solution. The resulting granules were washed with distilled water until the *p*H reached a range of 7.5 to 8.5, and were subsequently stored at 4 °C.

Biocomposite characterization

The biosorbent, namely C-SD-2.5%, was characterized in terms of morphological characteristics, functional groups, particle size, and point of zero charge.

Morphological analysis was conducted using scanning electron microscopy (SEM) with a TESCAN MIRA model S6122 device (TESCAN ORSAY HOLDING, Brno, Czech Republic), coupled with Energy-Dispersive X-ray Spectroscopy (EDS). Prior to the experiment, the biosorbent beads were dried at 60 °C for 2 hours.

Fourier-transform infrared (FTIR) spectra were recorded in the range of 4000 cm^{-1} to 400 cm^{-1} using an IRSpirit-X Series FTIR spectrometer (Shimadzu, Tokyo, Japan) equipped with an attenuated total reflectance (ATR) accessory.

SEM and FTIR analyses were performed both on the synthesized biosorbent and on the granules obtained after the biosorption process.

To determine the point of zero charge (pH_{pzc}), 0.4 g of biosorbent was mixed with 20 mL of 0.1 M NaCl solution at various initial *p*H values ranging from 2 to 12. The mixture was agitated for 24 hours at room temperature using a SK-O180-S Digital Orbital Shaker (DLAB SCIENTIFIC Co., Ltd., Beijing, China). The initial (pH_i) and final (pH_f) values were measured using a portable *p*H meter (Dostmann KLH9.1, Carl Roth, Germany). The resulting data were then used to generate a plot for determining the pH_{pzc}.

Biosorption experiments

The experiment was conducted using the batch adsorption method. In each Erlenmeyer flask, 25 mL of aqueous solutions of MG, BG and EL at specified concentrations were put in contact with 1 g of biosorbent to carry out the biosorption tests. The mixtures were maintained at ambient temperature (22 ± 1 °C) for 72 hours. At 24-hour intervals, the residual concentrations of MG, BG and EL were measured using a UV1280 spectrophotometer (Shimadzu, Tokyo, Japan). These concentrations were determined by measuring the absorbance of the samples at their specific wavelengths, using previously established calibration curves.

The amount of MG, BG and EL adsorbed onto the biosorbent at time (noted as q_e) was calculated using the equation (1) [4]:

$$q_e = \frac{C_0 - C_e}{m} \cdot V \tag{1}$$

where q_e ($mg \cdot g^{-1}$) is the equilibrium biosorption capacity, C_0 is the initial BG, MG, and EL concentrations ($mg \cdot L^{-1}$), *Ce* is the concentration of BG, MG, and EL at equilibrium, *V* is the volume of BG, MG, and EL solutions (L), and *m* is the mass of biosorbent (g).

Furthermore, the BG, MG, and EL removal efficiency (*R*, %), were determined with equation (2).

$$R(\%) = \frac{C_0 - C_e}{C_0} \cdot 100 \tag{2}$$

RESULTS AND DISCUSSION

Biocomposite material synthesis and characterization

The synthesis of the biocomposite material was carried out by immobilizing sawdust (fraction with particle sizes between 0.050 and 0.100 mm) in chitosan. This approach was chosen both to eliminate issues related to supernatant separation and because chitosan is a biocompatible, biodegradable polymer that can be easily transformed into a hydrogel [23, 24].

As a result, the sawdust biomass was uniformly and homogeneously incorporated into the polymeric matrix. The obtained granules exhibited an irregular shape, smooth surfaces, and an opaque appearance (Figure 1), with particle sizes of 3.2060 ± 0.0583 mm.

a **b** **c**

Figure 1. *Images of the synthesized biocomposite granules (C-SD-2.5%)*
(a – native image; b and c – microscopic images)

Microscopic examination revealed the integration of sawdust particles and the presence of certain impurities within the polymeric matrix, likely due to the absence of any pretreatment applied to the sawdust.

Point of zero charge

The point of zero charge (pH_{pzc}) represents the pH value at which the surface charge of a material is zero. pH_{pzc} is influenced by the material composition, surface functional groups, aqueous solution composition, and temperature.

The point of zero charge (pHpzc) is a key parameter in surface chemistry, especially relevant to adsorption processes. It determines how a material interacts with ions: surfaces are positively charged below the pHpzc, favoring anion adsorption, and negatively charged above it, favoring cation adsorption [25].

For the C-SD-2.5% biocomposite material, the pH_{pzc} was determined to be 7.3 using the salt addition method, as illustrated in Figure 2.

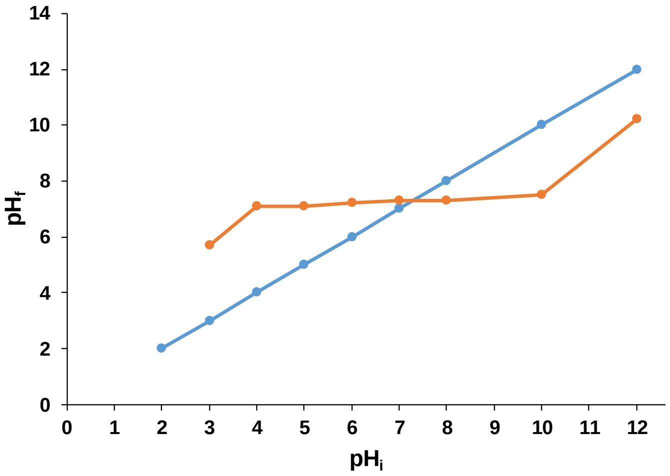


Figure 2. *pH$_{PZC}$ of the synthesized biosorbent (* ▬ *tie line;* ▬ *experimental data)*

A *p*Hpzc value above 7, specifically 7.98, was reported by Szymczyk *et al.* [26], who investigated the sorption characteristics of sawdust immobilized on chitosan in relation to Reactive Black 5 and Basic Violet 10.

FTIR analyses

Significant insights into the biosorption behavior of the tested molecules can be obtained using infrared spectroscopy. For each target molecule, a comparison is made between the biosorbent spectra before and after biosorption, as well as with the spectrum of the target molecule, in order to identify the functional groups involved in the interaction.
The FTIR spectra obtained for each tested target molecule are presented in Figures 3-5.

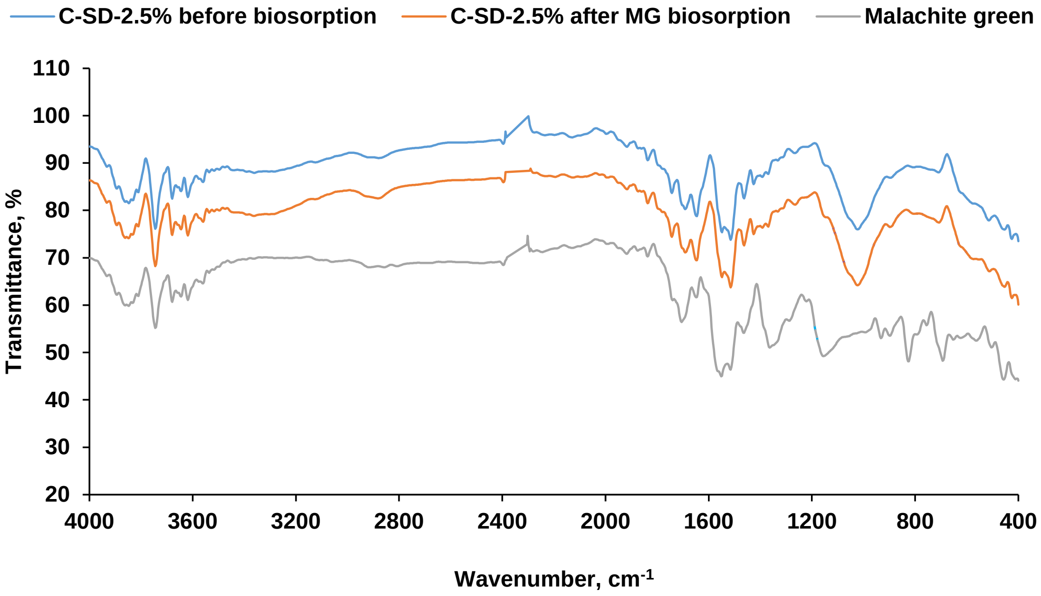


Figure 3. *FTIR spectra of MG dye and C-SD-2.5% biosorbent before and after malachite green biosorption*

The FTIR spectrum of the synthesized C-SD-2.5% beads, shown in Figure 3, primarily reveals the presence of functional groups characteristic of chitosan and sawdust components (cellulose, lignin, and hemicellulose).

At high frequencies (3619 cm^{-1}), the stretching vibrations of O-H groups were visible. At 2866 cm^{-1}, the aliphatic stretching vibrations of C-H were identified. A strong band at 1742 cm^{-1} indicates the carbonyl absorption and a peak at 1541 cm^{-1} is associated with N-H bending vibrations of the amide group from chitosan. Methyl and methylene bending from chitosan and polysaccharides is detected at 1463 cm^{-1}. The peak that appears at 1426 cm^{-1} is specific to hemicellulose from sawdust. A large signal at 1018 cm^{-1} is attributed to the asymmetric and symmetric stretching vibrations of the C-O bond that are specific for the pyranose ring in natural polymers.

Also, MG signals specific for the stretching of the C_{ar}-N and C-N bonds in tertiary amines can be observed at 1360 cm^{-1} for the aromatic amines and at 1146 cm^{-1} for aliphatic amines group, respectively. The aromatic rings of MG are confirmed by the out-of-plane C-H bending vibration to give substitution patterns below 900 cm^{-1}; *e.g.* 824 cm^{-1} was also detectable for *p*-substituted benzene ring in MG.

As can be seen in the C-SD-2.5% after MG biosorption spectrum, the wavenumbers of the characteristic peaks are slightly modified compared to the initial spectrum, which suggests that the adsorption process of the MG dye has occurred.

Similar outcomes were presented by Hospodarova *et al.* [27], Javier-Astete *et al.* [28] and Tian *et al.* [29] who characterized cellulose and hemicellulose by FTIR spectroscopy, and Meskel *et al.* [30] that reported comparable assignments for spectra of MG.

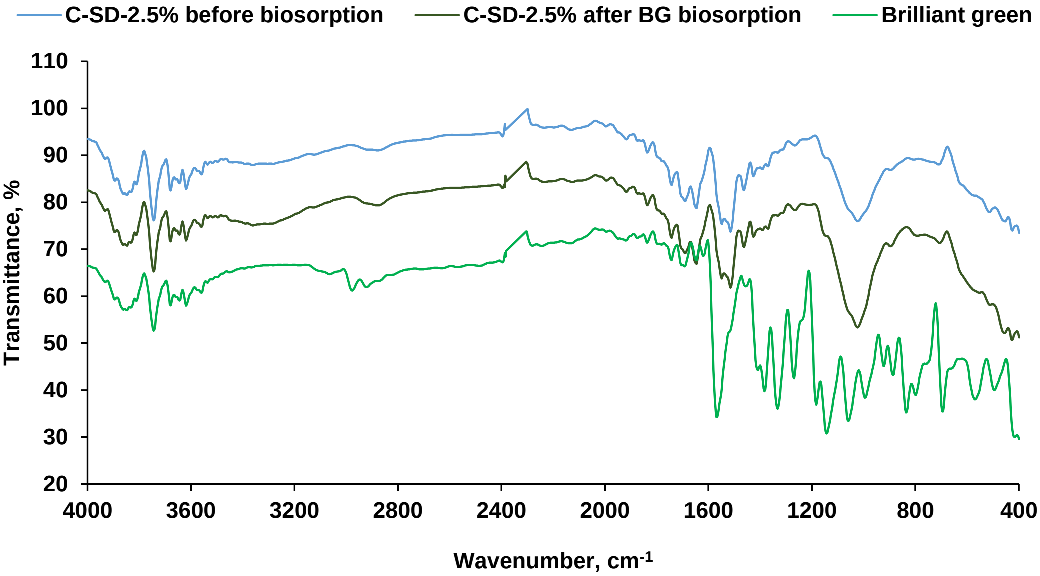


Figure 4. *FTIR spectra of BG dye and C-SD-2.5% biosorbent before and after brilliant green biosorption*

The FTIR spectrum shown in Figure 4 indicates a significant change in the vibrational frequencies of C-SD-2.5% after BG biosorption, in comparison to the spectrum of pure BG.

It is observed that the vibrational peaks at 3051 cm^{-1} specifics for the stretching of C$_{ar}$-H bonds, 2974 - 2920 cm^{-1} specific for C-H stretching and the intense band at 1562 cm^{-1} corresponding to the C$_{ar}$=C$_{ar}$ bond, specific for BG, which tends to vanish in the SD-C-2.5%-BG complex. This indicates strong interactions of C-SD-2.5% with the functional groups of BG and changes to the morphology of the structure in C-SD-2.5% after BG biosorption. Similar behaviors can also be observed at 1406 cm^{-1}, 1383-1329 cm^{-1} and 1266 - 1060 cm^{-1}, confirming that the sawdust-chitosan biocomposite has high adsorption and good interaction with the BG dye [31 – 33].

The presence of characteristic peaks for both dyes (MG and BG) confirms their interaction with cellulose, hemicellulose, lignin and chitosan components of the adsorbent beads.

It can be noted that, compared to the peaks specific to different functions in the FTIR spectra of individual molecular species, the IR spectra of the C-SD-2.5% biocomposite after biosorption of the two dyes show a change in the intensity or position of the corresponding bands compared to the FTIR spectrum before adsorption. This is obviously due to the interactions (such as covalent bonds, hydrogen bonds, electrostatic attractions) that occurred during the adsorption process.

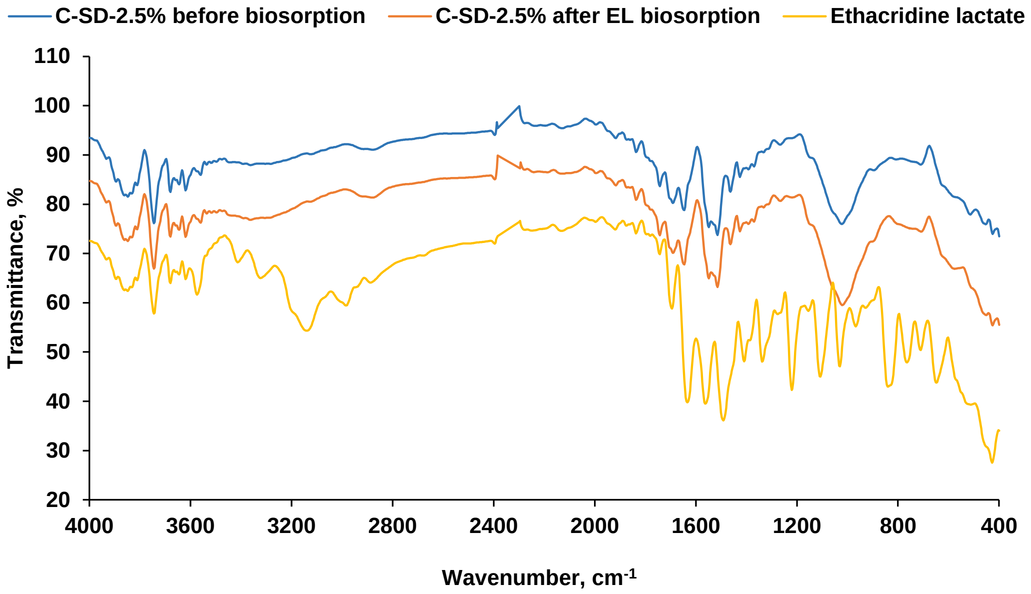


Figure 5. *FTIR spectra of EL drug and C-SD-2.5% biosorbent before and after ethacridine lactate biosorption*

The specific bands of EL (Figure 5) are found at 3405, 3334 and 3128 cm^{-1} due to stretching of the N-H bond, 1637 cm^{-1} for C=N bond of acridine ring, 1340 cm^{-1} for C$_{ar}$-N bond and 1223 cm^{-1} C-O for epoxide. The lactate part of EL is identified by the appearance of peaks at 2977 cm^{-1} characteristic for the stretching of O-H in carboxylic acid, 1691 cm^{-1} stretching of C=O (carboxyl group), 1557 cm^{-1} asymmetric stretching of COO^{-} anionic lactate and 1103 cm^{-1} for C-O in carboxylic. Other authors [6, 34, 35] who studied ethacridine lactate by infrared spectrometry have obtained similar results.

The strong band at 1714 cm^{-1} in C-SD-2.5% after EL biosorption indicates carboxylic acid that confirmed adsorption of EL from the sawdust-chitosan beads.

Therefore, the FTIR spectrum of C-SD-2.5% after EL biosorption showed upward and/or downward band shifts with the appearance or disappearance of other bands, indicating the adsorption of EL.

SEM analyses

Scanning Electron Microscopy (SEM) combined with Energy-Dispersive X-ray Spectroscopy (EDS) was employed to characterize the surface morphology and elemental composition of the C-SD-2.5% biocomposite material, both before to and after the biosorption of the investigated target molecules, as shown in Figures 6-9.

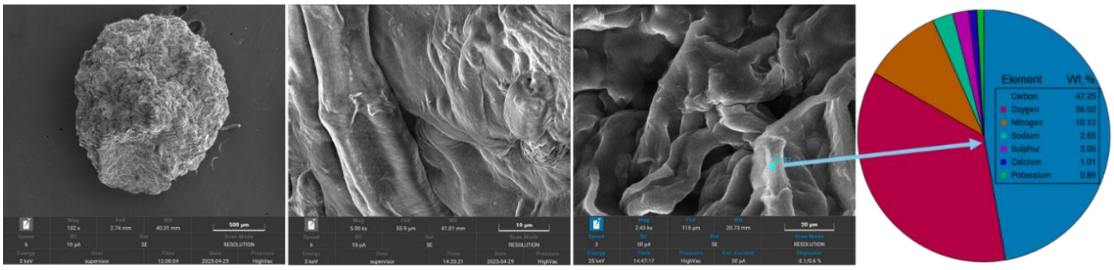


Figure 6. *SEM images of C-SD-2.5% biosorbent synthetized by immobilization of sawdust onto chitosan and EDS elemental analysis before biosorption*

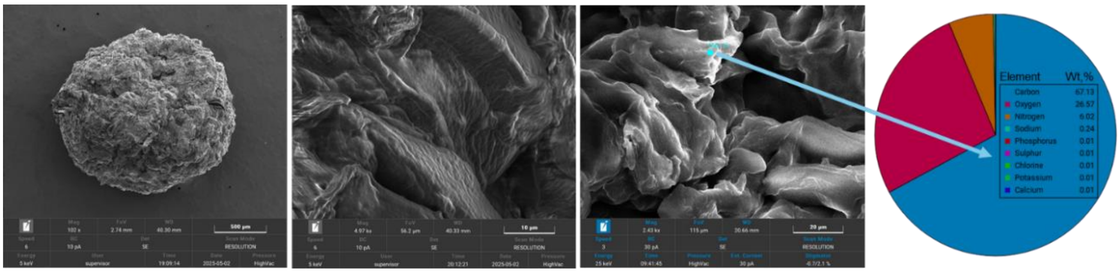


Figure 7. *SEM images and EDS elemental analysis of C-SD-2.5% biosorbent after malachite green biosorption*

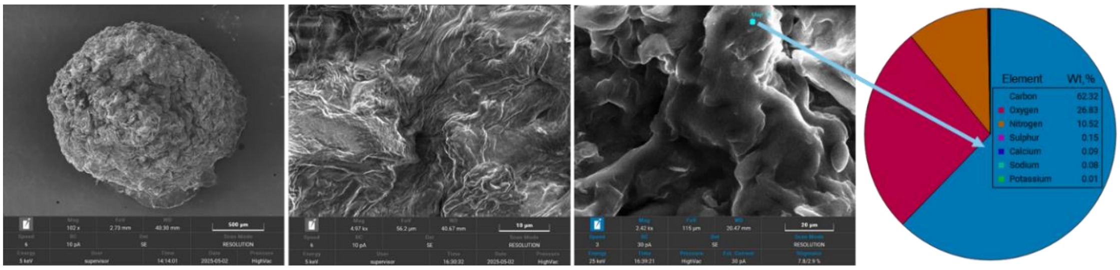


Figure 8. *SEM images and EDS elemental analysis of C-SD-2.5% biosorbent after brilliant green biosorption*

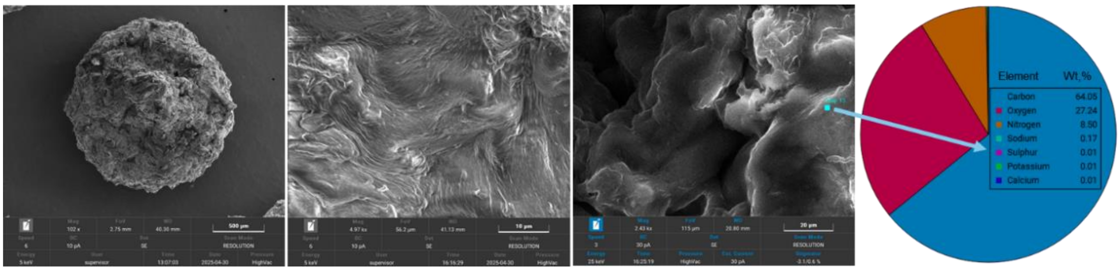


Figure 9. *SEM images and EDS elemental analysis of C-SD-2.5% biosorbent after ethacridine lactate biosorption*

As illustrated in Figure 6, the SEM images reveal that the biocomposite material exhibits a heterogeneous and porous surface texture, with sawdust particles successfully immobilized within the chitosan matrix.

As shown in Figures 6-9, a noticeable shrinkage and alteration in the initial texture of the granules can be observed. These changes are attributed to water removal during the drying process conducted prior to analysis.

Analysis of the SEM images presented in Figures 6 to 9 reveals distinct morphological differences between the granules before and after the biosorption of the target molecules. After biosorption, the surface texture of the C-SD-2.5% granules exhibits increased agglomeration, suggesting interactions with the adsorbed contaminants. These morphological changes indicate successful retention of the tested molecules. Furthermore, the granules maintained structural integrity, demonstrating morphological stability following the biosorption process.

The elemental compositions obtained through EDS analysis indicate that the biosorbents predominantly consist of carbon, oxygen, and nitrogen in comparable proportions. This confirms the presence of key elements associated with sawdust, chitosan, and the adsorbed target molecules.

Application of sawdust biocomposite material to dyes and drug removal from aqueous solution

To evaluate the potential application of the synthesized biosorbent in the removal of persistent organic pollutants, its capacity to retain two categories of contaminants, organic dyes and pharmaceutical compounds, was investigated. Accordingly, two dyes (malachite green and brilliant green) and one pharmaceutical compound (ethacridine lactate) were selected as representative target molecules. The operational parameters for each target molecule were determined based on the results obtained under specific working conditions in batch mode, as reported both in our previous studies [6, 24] and in other studies related to the removal of persistent organic pollutants from aqueous solutions [36 – 38].

Images of the biocomposite material after biosorption of the 3 target molecules are shown in Figures 10-12.

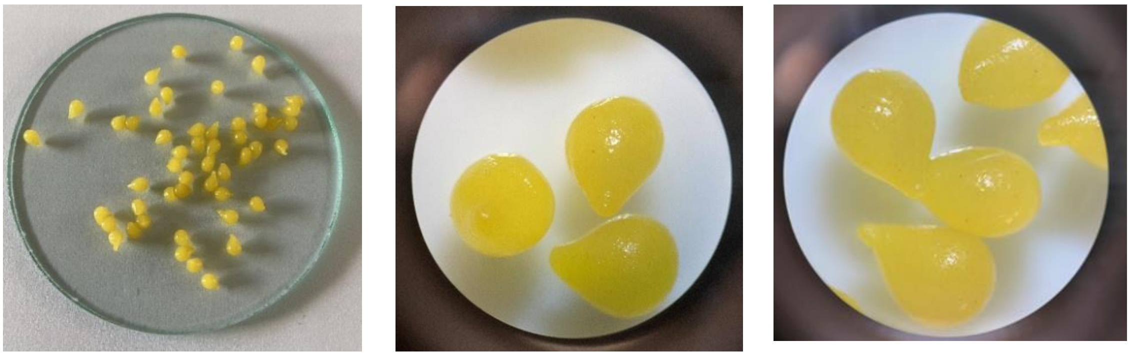
From the analysis of the images obtained under the microscope it appears that the three molecules were retained by the biocomposite granules.

a **b** **c**

Figure 10. *Images of the biocomposite granules (C-SD-2.5%) after MG biosorption (a – native image; b and c – microscopic images)*

a **b** **c**

Figure 11. *Images of the biocomposite granules (C-SD-2.5%) after BG biosorption (a – native image; b and c – microscopic images)*



a **b** **c**

Figure 12. *Images of the biocomposite granules (C-SD-2.5%) after EL biosorption (a – native image; b and c – microscopic images)*

The results for removal efficiency and biosorption capacity of the tested molecules are summarized in Table 4.

Table 4. *Evaluation of the biosorptive capacity of the C-SD-2.5% biocomposite for tested target molecules under static operating conditions*

Target molecule / category	**Operational parameters**	**Removal efficiency R [%]**			**Biosorption capacity q [mg·g^{-1}]**		
		Time			**Time**		
		24 h	**48 h**	**72 h**	**24 h**	**48 h**	**72 h**
Malachite green (MG) / organic dye	C_0 (MG) = 20 mg·L^{-1}; *p*H = 5.0; biosorbent dose = 40 g·L^{-1}	95.03	98.10	98.57	18.80	19.41	19.50
Brilliant green (BG) / organic dye	C_0 (BG) = 20 mg·L^{-1}; *p*H = 5.6; biosorbent dose = 40 g·L^{-1}	86.71	94.15	96.17	17.34	18.83	19.23
Ethacridine lactate (EL) / pharmaceutical compound	C_0 (EL) = 40 mg·L^{-1}; *p*H = 7.0; biosorbent dose = 40 g·L^{-1}	87.50	97.06	98.74	35.00	38.83	39.50

C_0 – initial concentration of the test solution

For the C-SD-2.5% biocomposite, the removal efficiency exceeded 86 % for all tested molecules after 24 hours, with a further increase to over 96 % observed after 48 hours. The highest biosorption capacity was recorded for EL, which may be attributed to the fact that the adsorption mechanism occurs both through physical adsorption in pores and through chemisorption. In contrast, the larger molecular sizes of MG and BG likely hinder their ability to undergo physical adsorption within the pore structure.

The efficiency of the synthesized composite material in adsorption/biosorption processes was evaluated through a comparative analysis with materials previously studied for the same types of pollutants. Thus, a similar result for MG removal was obtained by Sartape *et al.* [37], who obtained a MG dye removal efficiency of 98.87 % using apple wood shell as an adsorbent. Moreno-Ríos et al. [38] investigated the potential of coral rock, specifically oyster shell-derived material, as a bioadsorbent for the removal of brilliant green dye from textile wastewater. They achieved a removal efficiency of 90 % within 15 to 20 minutes at a *p*H of 7.8.

In a previous study conducted by our research group, which also investigated the pharmaceutical compound ethacridine lactate (EL), *Lactococcus lactis* immobilized in a calcium alginate matrix was employed as a biosorbent [39]. The results revealed an EL removal efficiency of up to 80 % for all tested initial concentrations (20 - 60 mg·L^{-1}), under conditions of an initial *p*H of 3.0 and a biosorbent dosage of 2 g·L^{-1}.

CONCLUSIONS

In this study, the C-SD-2.5% biocomposite material was synthesized by immobilizing sawdust in chitosan matrix and evaluated for its potential application in biosorption processes aimed at removing three persistent organic pollutants from aqueous solutions.

The obtained biocomposite material was characterized by FTIR, SEM, and EDS techniques. The beads sizes and point of zero charge were also determined.

The biosorption capacities obtained under the presented test conditions were between 18.83 mg·g^{-1} and 19.41 mg·g^{-1} for dyes and 38.83 mg·g^{-1} for the pharmaceutical compound. These values indicate a good biosorption capacity if the amounts of pollutants present in different water matrices are considered.

The mentioned results demonstrate that the synthesized biocomposite exhibits high efficiency in removing both organic dyes and pharmaceutical compounds from aqueous solutions. Moreover, the use of sawdust immobilization within natural polymers offers dual advantages: it eliminates the problems of separating the adsorbent from the supernatant and promotes the valorization of sawdust by converting it into advanced materials.

Further research is needed to optimize the biosorption process, including investigations into the effects of key operational parameters such as *p*H, initial pollutant concentration, biosorbent dosage, and temperature. Additionally, kinetic modeling and equilibrium studies are essential to better understand the adsorption mechanisms and enhance process performance.

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