



# Article Commercially Biochar Applied for Tartrazine Removal from Aqueous Solutions

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Abstract: Biochar gained attention due to its definite physico-chemical characteristics and because it is a cost-effective and efficient adsorbent. In this paper, commercial biochar was tested for the removal of tartrazine from aqueous solutions. Thus, the optimum experimental conditions were determined for several parameters (pH, temperature, initial concentration of tartrazine, biochar dose, and contact time). The concentration of tartrazine residues was determined using UV-Vis spectrophotometry. The best experimental results were obtained at 1 mg L<sup>-1</sup> concentration of tartrazine, pH 2, 30 °C, 18 min, and 0.9 g L<sup>-1</sup> adsorbent dose. The maximum removal efficiency of tartrazine obtained in optimum conditions was 90.18%. The experimental data were analyzed by the isotherm and kinetic models. The isotherm and kinetics of tartrazine removal on biochar follow the Langmuir isotherm and pseudo-second-order kinetics, respectively. According to the Langmuir isotherm model, the biochar showed a maximum adsorption capacity of 3.28 mg g<sup>-1</sup>. In addition, biochar demonstrated a good reuse potential and therefore can be used for the removal of tartrazine from aqueous solutions.

Keywords: biochar; adsorption; tartrazine; isotherm; kinetic studies

# 1. Introduction

The fact that large amounts of synthetic dyes are released into the environment on a daily basis by industries such as textile, paper, food product, and dyeing makes environmental contamination by these dyes a pressing global concern these days [1]. A significant risk is posed by their diffusion in the environment because the majority of them have detrimental impacts on people, animals, and plants [2,3].

The azo dyes are chemical compounds that contain two hydrocarbon groups joined by two nitrogen atoms. They account for up to 70% of all dyes used in the food, pharmaceutical, and textile industries. Their popularity is a consequence of their higher stability with respect to most natural food dyes and relatively low production costs. Furthermore, they have excellent water solubility and fixation, accounting for 65% of all those used in the industry [4]. Tartrazine, also referred to as Yellow 5, E102, is an azo dye that gives a bright yellow color to the food products in which it is used (candies, soft drinks, breakfast cereals, condiments, etc.), being one of the most widely used dyes. It is produced from compounds extracted from coal tar, which is an asphalt derivative. Like many other synthetic compounds, it has side effects on the human body. Among the known side effects are allergic responses in certain individuals, especially for those suffering of asthma or aspirin intolerance, and loss of concentration or hyperactivity for children when combined with benzoic acid (E210). It might also be associated with blurred vision, itching, rhinitis, fatigue, purple skin patches, etc.; however, these effects need to be confirmed by additional



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**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). studies. Due to these concerns regarding its toxicity and side effects, tartrazine is already banned in some countries. In 1959, Lockey described for the first time tartrazine-induced urticaria [5]. Since then, many other studies were performed in order to elucidate the risks associated with tartrazine consumption. While the studies of Maekawa et al. and Borzelleca and Hallagan, from 1987 and 1988, respectively, show that there is no carcinogenic effect from the use of tartrazine, in a study from 2002, Sasaki et al. claim that it may induce DNA damage in mice colon [6–9].

Although the severity of the side effects of the tartrazine are still under debate, it is clear that limiting its spread and contact with human and living cells will also prevent or minimize the unwanted consequences that it might generate. For this reason, providing low-cost, efficient methods for their removal from the environment could be considered as an achievement.

Effective ways to treat polluted effluents are required since tartrazine's chemical treatment produces harmful chemicals and its breakdown is difficult due to the aromatic rings on both sides of the azo group [4].

Many conventional physical and biological methods were employed for the removal of dyes from water—among these, photodegradation, coagulation, membrane separation, reverse osmosis electrochemical processes, and adsorption [10–13]. Most of these processes require high operational and capital costs, which restricts their application for the removal of contaminants from polluted waters [14]. Adsorption has become one of the most used processes due to its modest costs, simple operating conditions, high flexibility, material regeneration, and environmental friendliness [15,16].

Many adsorbents are frequently used to remove dyes from contaminated water. The benefits of metal-oxide-based, bio-adsorbent, metal-organic framework, polymer-based, and activated-carbon materials include ease of production, high surface area, high reactivity, reusability, cheap cost, and high efficiency [17–23].

Recent research has used biochar and biochar-based adsorbents to remove pollutants from aqueous media because biosorbents are desired for environmental remediation. This can be used in both batch and continuous flow systems and it can be used in combination with other adsorbents to enhance its adsorption capacity [24]. The feedstock, preparation conditions, and modification approaches affect the properties of biochar and are responsible for their adsorptive performances [14,24,25]. The characteristics of the biochar determine the adsorption efficiency. Nonetheless, biochar is thought to be an economical and effective method of eliminating pollutants from water [26].

Testing was performed on the ability of biochar made from different feedstocks to remove various contaminants from aqueous solutions, including organic pollutants and heavy metals [27]. Biochar and biochar-based adsorbents were discovered to be effective in eliminating malachite green [28], crystal violet [28,29], Congo red [28], remazol black B [30], reactive brilliant blue [31], rhodamine B [31,32], methylene blue [29,33], reactive yellow [33], malachite green oxalate [34], safranine T [34], etc.

The AR-18 dye removal capability of N-doped biochar made from birch tree wastes has been demonstrated to be superior [35]. Chen et al. prepared sorghum-straw-based biochar that they activated with peroxydisulfate to enhance the tartrazine degradation [36]. To the best of our knowledge, no articles on tartrazine removal from aqueous solutions on biochar have been found in the literature and there are only a few on modified biochar. Thus, biochar-mediated zirconium ferrite nanocomposite [37] and positively charged triethylenetetramine biochar [38] were used for the adsorption of tartrazine. However, there are quite a few articles regarding the adsorption of tartrazine on different adsorbents. Activated carbon obtained from coconuts and groundnut shells at 450 °C and activated with different concentration of hydrochloric acid was an efficient adsorbent for the removal of sunset yellow and tartrazine from aqueous solutions [39].

The effectiveness of the adsorbent obtained from Moringa oleifera seeds was tested for the removal of tartrazine from aqueous solution, obtaining a removal of 95%. The results

were compared with those obtained for coconut babassu and bone-activated carbon and it was found that the new adsorbent can be an effective alternative to activated carbon [40].

Cellulose obtained from wheat straw residues and cetyltrimethylammonium-chloridemodified cellulose were used for the removal of Congo red and tartrazine from aqueous solution by Villabona-Ortíz et al. [41]. Adsorption capacity increased from 2.31 mg g<sup>-1</sup> obtained for the cellulose to 18.85 mg g<sup>-1</sup> for the modified cellulose in the case of tartrazine removal. In the case of the Congo red, the adsorption capacity increased very slightly from 18.5 mg g<sup>-1</sup> for cellulose to 19.92 mg g<sup>-1</sup> for the modified cellulose.

Albroomi et al. tested the activated carbon from apricot stones for tartrazine removal in a batch and dynamic adsorption system. In batch experiments, the maximum adsorption was found to be 76 mg g<sup>-1</sup> at 100 mg L<sup>-1</sup> of tartrazine, while in fixed-bed column experiments, as flow rate increases, the maximum adsorption capabilities decrease [42].

In this paper, commercial biochar was tested for the removal of tartrazine from aqueous solutions, optimizing several parameters (pH, temperature, adsorbent dose, contact time, and initial dye concentration) that influence the adsorption process. To the best of our knowledge, there is no available information about biochar application in tartrazine removal from wastewater. In addition, the commercial biochar selected for the present study is used as fertilizer in agriculture, and its interaction with pollutants is therefore useful knowledge.

#### 2. Materials and Methods

## 2.1. Materials

For this study, commercial biochar sold as horticultural soil amendment, produced for Dr. Soil GmbH Germany, was procured from the market and used as adsorbent material with no other synthesis steps involved. Tartrazine dye, the pollutant chosen to be investigated in this study, was purchased from Sigma-Aldrich (Schnelldorf, Germany). As pH-adjusting materials, HCl and NaOH solutions procured from Sigma-Aldrich (Schnelldorf, Germany) and VWR Chemicals (Wien, Austria), respectively, were used. Aqueous solutions were prepared using ultrapure water lab source (Direct-Q<sup>®</sup> 3 UV Water Purification System, Merck, Darmstadt, Germany).

The morphological characterization of the commercial biochar was investigated through scanning/transmission electron microscopy (STEM) using a Hitachi HD2700 microscope, operated at 200 kV and in cold field emission.

The specific surface area of biochar was determined from the Brunauer–Emmett–Teller (BET) analysis.

The electrostatic nature of the adsorbent surface was determined with the pH of point zero charge ( $pH_{pzc}$ ) using the so-called pH drift method [43]. The method of determining  $pH_{pzc}$  is according to the one described in a previous article [44].

Using the KBr pellet approach, FT-IR spectra were obtained in the 4000–400 cm<sup>-1</sup> spectral domain with a resolution of 4 cm<sup>-1</sup> on a JASCO 6100 FT-IR spectrometer. After dispersing each sample in roughly 300 mg of anhydrous KBr, the powder was pulverized in an agate mortar. The ground mixture was pressed into an evacuated die to produce the pellet. The software Jasco Spectra Manager v.2 was used to gather and examine the spectra.

#### 2.2. Adsorption Process

The adsorption process was achieved in a Berzelius beaker, under static conditions, bringing the artificial tartrazine aqueous solution in contact with biochar and varying different parameters: temperature, pH, tartrazine content, dose of adsorbent, and duration of contact. At the end, to determine the tartrazine remaining unabsorbed on the biochar, centrifugation was used for 10 min at 9000 rpm in order to separate the solution from the adsorbent. Using the PG Instruments T80 UV-VIS spectrophotometer (Leicestershire, UK), the absorbance at 473 nm was read to conduct the solute analysis.

The following relationships were utilized to determine the effectiveness of the adsorption process and the performance of the nanocomposite as an adsorbent:

$$\eta(\%) = \frac{(C_0 - C_t)}{C_0} 100,\tag{1}$$

$$q_t = (C_0 - C_t) \frac{V}{m'},\tag{2}$$

where  $\eta$  (%) represents the tartrazine removal degree,  $C_0$  and  $C_t$  (mg L<sup>-1</sup>) are the tartrazine concentrations in the solution at the initial moment and at the moment t (min), respectively,  $q_t$  (mg g<sup>-1</sup>) represents the mean of the adsorption capacity, V (mL) is the volume of the dye solution, and m (g) is the amount of biochar.

#### 2.3. Desorption and Recycle Studies

Before desorption, the tartrazine was adsorbed on biochar, the adsorption experiment being performed under the determined optimal conditions. EtOH was investigated for regeneration. Thus, after adsorption on the adsorbent, 5 mL of eluent was added and at room temperature, the mixture was agitated for 20 min at 400 rpm. At the end, the mixture was centrifuged for 10 min at 9000 rpm and the concentration of desorbed tartrazine was determined with UV-Vis.

Tartrazine desorption capacity ( $q_{e,desorption}$ , mg g<sup>-1</sup>) and desorption efficiency (%) were determined from the following relationships:

$$q_{e,desorption} = \frac{Vx C_f}{m}$$
(3)

$$D\% = \left(\frac{q_{e,desorption}}{q_{e,adsorption}}\right) \tag{4}$$

where V is the volume of the eluent solution (L), m is the mass of the tartrazine-saturated nanocomposite biochar, and  $C_f$  is the tartrazine concentration in the desorption solution (mg L<sup>-1</sup>) (g).

Four cycles of adsorption–desorption studies were performed intending to determine the biochar regeneration capacity.

### 3. Results and Discussion

#### 3.1. Biochar Characterization

3.1.1. Morphological Characterization

The TEM analysis conducted to structural characterization of the biochar showing the presence of pores in the material (Figure 1).

The porous structure of the biochar allows the retention of water and other elements (such as nutrients or fertilizers) that are useful for soil and for plants fertilization.

#### 3.1.2. Surface Area

The total surface area of the biochar was calculated from nitrogen adsorption–desorption isotherms registered at the liquid nitrogen temperature. Thus, the BET surface area was  $67.2 \text{ m}^2 \text{ g}^{-1}$ . Two instances of the isotherms, which show the volume of adsorbed–desorbed nitrogen as a function of relative pressure (the ratio between the effective pressure, or p and the saturation pressure, or p<sub>0</sub>), are shown in Figure 2.



Figure 1. TEM images of commercial biochar.



Figure 2. Nitrogen adsorption-desorption isotherms for biochar (blue-adsorption, orange-desorption).

3.1.3. FTIR Analysis

The FTIR spectra for the commercial biochar, tartrazine, and the biochar with adsorbed tartrazine are presented in Figure 3.

FTIR spectra of biochar shows an amorphous material that contain hydroxyl (3433 cm<sup>-1</sup>), carbonyl (1700, 1125 cm<sup>-1</sup>), aromatic C=C (1623 cm<sup>-1</sup>), aliphatic (2924, 2857, 1369 cm<sup>-1</sup>), and aromatic (1412, 900–700 cm<sup>-1</sup>) C–H groups [45].

The vibrational bands in the FTIR spectrum of tartrazine can be assigned to various functional groups present in the compound as follows:  $3436 \text{ cm}^{-1}$  (OH), 2924 and 2854 cm<sup>-1</sup> (aliphatic C-H), 1744 sh and 1642 cm<sup>-1</sup> (C=O), 1599 and 1192 cm<sup>-1</sup> (COONa), 1562 and 1412 cm<sup>-1</sup> (N=N), 1347 and 1126 cm<sup>-1</sup> (C–H bending and C–H-aromatic ring), 1037 and 1008 cm<sup>-1</sup> (–S=O and C<sub>6</sub>H<sub>5</sub>–SO<sub>2</sub>), 768 cm<sup>-1</sup> (–C<sub>6</sub>H<sub>5</sub>–N=N– bonds), 694 cm<sup>-1</sup> (–CCO), 718 and 648 cm<sup>-1</sup> (the –C–C–, –C=C– and C<sub>6</sub>H<sub>5</sub> out-of-plane stretching), 567 cm<sup>-1</sup> (C<sub>6</sub>H<sub>5</sub>– and R–C<sub>6</sub>H<sub>4</sub>– groups) and 528 cm<sup>-1</sup> (out-of-plane bending of the para-substituted aromatic ring containing a sulphoxyl group) [46,47].



Figure 3. FTIR spectra of initial biochar, tartrazine, and biochar with the adsorbed dye.

After adsorption of tartrazine, some changes were observed on the FTIR spectrum of the biochar, as evidence of the adsorption of the dye from the solution on the surface, such as the following: the band of tartrazine from  $1642 \text{ cm}^{-1}$  shifts and appears as a shoulder at  $1634 \text{ cm}^{-1}$  on the band of biochar from  $1623 \text{ cm}^{-1}$ ; the band of biochar from  $1369 \text{ cm}^{-1}$  shifts to  $1375 \text{ cm}^{-1}$  and appears as a shoulder, the vibrational band of biochar from  $1125 \text{ cm}^{-1}$  and the band of tartrazine from  $1026 \text{ cm}^{-1}$  shift and overlap at  $1129 \text{ cm}^{-1}$ ; the characteristic vibrational bands of tartrazine from 1037, 718, and  $648 \text{ cm}^{-1}$  are founded in the form of a shoulder and shifted to 1046, 726, and  $657 \text{ cm}^{-1}$ , respectively. The vibrational bands of tartrazine from 718 and  $648 \text{ cm}^{-1}$  shift at 726 and  $657 \text{ cm}^{-1}$ , respectively, and appear as a shoulder. The observed shifts of the vibration bands of tartrazine when the biochar adsorbed it are probably caused by the weak intermolecular interactions, possibly of the hydrogen bonds, that arise between the functional groups of tartrazine, namely the C=O and -S=O groups, and the surface of biochar.

## 3.1.4. pH at Point of Zero Charge (pH<sub>pzc</sub>) of Biochar

The  $pH_{pzc}$  of adsorbent biochar is 6.5, as can be seen from Figure 4, which suggests that the adsorbent can be used for the adsorption of cations and anions [48].

#### 3.2. Testing the Biochar Efficiency as Tartrazine Adsorbent from Synthetic Aqueous Solutions

In the adsorption process, the effects of some factors such as solution pH, temperature, adsorbent dose, etc., must be taken into account. Thus, the optimal retention conditions for the tartrazine removal from aqueous solutions, using biochar as adsorbent, were determined following the influence of different parameters. For this reason, the contact time between the biochar adsorbent and the synthetic solution, the initial pH of the aqueous solution, the temperature of the solution during the adsorption process, the adsorbent dose during the adsorption, and the tartrazine initial concentration were varied, and the results are presented in the following sections.



Figure 4. Point zero charge of biochar.

3.2.1. The Influence of the Initial pH of the Aqueous Solution on the Adsorption Process

First, 5 mg of biochar was stirred at 400 rpm with 5 mL of tartrazine aqueous solution with concentration of 5 mg L<sup>-1</sup>, varying the pH of the solution from 2 to 12, for establishing the optimal pH for the tartrazine removal. The adsorption process was performed at room temperature for 20 min for each sample. The two phases were separated at the end of the process by filtration and the solute was analyzed. The results presented in Figure 5 are showing a very low adsorption at pH values of 4 and above (only 5% or less), while for lower pH values, there is a significant increase in removal degree up to almost 50% at pH 2. Since pH < pH<sub>pzc</sub>, the adsorbent surface is positively charged and absorbs the negatively charged dye.

The aqueous tartrazine solutions used in all subsequent tests were prepared at pH 2 in accordance with the findings of this particular example.

## 3.2.2. The Influence of the Temperature of the Solution on the Adsorption Process

In order to investigate the influence of the temperature on the adsorption process, 5 mL tartrazine solution of 5 mg L<sup>-1</sup> was mixed with 5 mg of biochar and stirred at 400 rpm for 20 min at temperatures ranging from 25 to 45 °C. The results depicted in Figure 5 highlight a clear increase in removal efficiency with a temperature of up to about 35 °C, followed by a decrease in the efficiency at higher temperatures. The efficiency increases along the mentioned temperature range from about 49% at 25 °C to above 88% at around 35 °C and then decreases with the temperature.

According to the literature, chemisorption increases with an increase in temperature at first as the requirement of the activation energy for the reaction is fulfilled by an increase in temperature. Then, it decreases due to the exothermic nature of adsorption.

In our case, the pseudo-second-order kinetic model is applicable for the removal of tartrazine on biochar, suggesting that chemisorption is the process that controls the adsorption rate.

For economic reasons and taking into account the fact that, on a large scale, temperatures higher than ambient temperature are difficult to obtain, for the subsequent experiments, a temperature of 30  $^{\circ}$ C was chosen.



**Figure 5.** The influence of the pH, temperature, adsorbent dose, contact time, and the initial concentrations of tartrazine adsorption onto commercial biochar.

3.2.3. The Influence of the Adsorbent Dose on the Adsorption Process

In order to characterize the adsorption process as a function of the adsorbent dose, the degree of tartrazine removal was monitored while the adsorbent dose was increased from  $0.2 \text{ mg L}^{-1}$  to  $1.0 \text{ mg L}^{-1}$ . The measurements were conducted at 30 °C temperature, stirring the mixture of 5 mL tartrazine solution of 5 mg L<sup>-1</sup> concentration and the corresponding amount of adsorbent at 400 rpm for 20 min for each sample. In Figure 5, which shows the removal efficiency with the adsorbent dose, can be observed a rather oscillatory trend in the removal degree.

In order to obtain a good removal efficiency using the smallest possible amount of adsorbent, further studies were carried out using 0.9 mg  $L^{-1}$  adsorbent dose.

3.2.4. The Influence of the Tartrazine Initial Concentration on the Adsorption Process

As expected, the initial concentration of the tartrazine solution should have an effect on the tartrazine removal degree. In order to test it, the removal efficiency was measured at 30 °C stirring for 20 min at 400 rpm a mixture of 5 mg biochar with 5 mL tartrazine solution of different concentrations from 1 to 20 mg  $L^{-1}$ . From the results depicted in Figure 5, it can be concluded that the maximum removal degree was obtained at low tartrazine concentrations.

## 3.2.5. The Influence of the Contact Time on the Adsorption Process

In order to determine the dependence of the removal degree as a function of contact time, 5 mL of tartrazine aqueous solution with initial concentration of 3 mg  $L^{-1}$  was brought in contact with 5 mg of biochar for time periods between 3 and 30 min, at 30 °C. The tartrazine removal degree as a function of contact time between the synthetic solution of tartrazine and the biochar is shown in Figure 5. As one can see in the mentioned figure, the maximum removal efficiency is achieved at contact times of about 18 min, with a removal degree of 90.18%.

#### 3.3. Adsorption Isotherm

Adsorption isotherms are used to illustrate the relationship between the material's capability for removal and the concentration of the contaminated solution, as well as to characterize the pollutant-sorbent interaction [49].

The adsorption isotherm studies were carried out by agitating 5 mg of biochar with 5 mL of tartrazine solutions at 30 °C for 20 min at 400 rpm. The starting concentrations of the tartrazine solutions ranged from 1 to 20 mg  $L^{-1}$ .

The experimental data obtained were evaluated using the linearized forms of Langmuir, Freundlich, and Temkin isotherm models from Table 1.

Table 1. The	e linearized	forms o	of isotherm	models.
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Isotherm Model	Linear Form	Reference
Langmuir	$\frac{C_e}{a_e} = \frac{1}{K_L a_m} + \frac{C_e}{a_m}$	[50]
Freundlich	$log q_e = log K_F + \frac{1}{n} log C_e$	[51]
Temkin	$q_e = BlnK_T + BlnC_e$	[52]

The most popular isotherm for physisorption data is the Langmuir isotherm [53], nonideal sorption on heterogeneous surfaces can be addressed with the Freundlich isotherm model [54], and abnormal adsorbate/adsorbate communication during adsorption is taken into consideration by the Temkin model [55].

The best model is the one in which the difference between the experimental and theoretical estimates are the smallest. For this purpose, the coefficient of determination  $R^2$  is used; the closer its value is to unity, the more suitable the model.

Table 2 summarizes the parameters derived from the isotherms models that might shed light on the adsorption mechanism, surface characteristics, and adsorbent affinity.

Table 2. Isotherm constants for the adsorption of tartrazine on biochar.

Isotherm Model	Constants	Values
Langmuir	$\begin{array}{c} q_{m}  [mg  g^{-1}] \\ K_{L}  [L  g^{-1}] \\ R^{2} \end{array}$	3.2841 17.4000 0.9936
Freundlich	K <sub>F</sub> [L mg <sup>-1</sup> ] 1/n R <sup>2</sup>	2.6878 0.1207 0.9451
Temkin	${f K_T}  [L  mg^{-1}] \ {f b_T}  [J  mol^{-1}] \ R^2$	1.0486 1046.5724 0.3315

Furthermore, it is evident from the comparison of the three models with the experimental results (Figure 6) that the Langmuir isotherm best describes the tartrazine adsorption on biochar. Similar results in which the Langmuir isotherm was adapted to the adsorption of tartrazine on bentonite modified with octa-decyltrimethylammonium bromide [56], raw sawdust and activated sawdust [10], and microcline/MWCNTs nanocomposite [57] were also obtained by other authors.



Figure 6. Isotherms of tartrazine adsorption on biochar.

We evaluated the tartrazine adsorption ability of commercial biochar by comparation with other adsorbent reports. Table 3 provides a summary of the maximal adsorption capacity of this and other adsorbents used to remove tartrazine.

Adsorbent	$q [mgg^{-1}]$	References
positively charged triethylenetetramine biochar	85.47	[38]
octadecyltrimethylammonium	43.20, 145.80,	
bromide-modified bentonite	175.80, and 201.00	[00]
raw sawdust	0.80	[10]
activated sawdust	127.00	[10]
microcline	37.96	[57]
microcline/MWCNTs	67.17	[57]
chitosan/polyaniline	584.00	[58]
activated red mud	136.98	[59]
activated carbon derived from cassava sievate	20.83	[60]
activated carbon from Ziziphus Spina-Christi	160.00	[61]
commercial biochar	3.28	present study

Table 3. Comparison of several adsorbents' adsorption capacities with charcoal for tartrazine removal.

## 3.4. Kinetic Studies of the Adsorption Process

In order to understand the rate of adsorption and mechanism, kinetic studies are conducted, pseudo-first-order, pseudo-second-order, and intra-particle-diffusion models being most widely used. The best-fitted model is selected considering the correlation coefficient  $R^2$  [62].

The investigation of tartrazine adsorption kinetics on biochar was carried out at 30 °C with an initial concentration of 3 mg mL<sup>-1</sup> brought to pH 2, for various durations, ranging from 3 to 30 min.

The rate of adsorption and potential adsorption mechanism of tartrazine adsorption on biochar were examined using a number of kinetics models. The kinetic models applied in this study and their linearized form are presented in Table 4.

Table 4. The linearized forms of kinetic models.

Kinetic Model	Linear Form	Reference
Pseudo-first-order kinetic	$log(q_e - q_t) = logq_e - \left(\frac{k_1 t}{2.303}\right)$	[63]
Pseudo-second-order kinetic	$\frac{1}{q_e} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$	[64]
Intraparticle diffusion	$q_t = k_{id} t^{0.5} + C$	[65]

The pseudo-first-order model (Lagergren model) establishes the relationship between the change in time and the adsorption capacity with order of one, the pseudo-second-order kinetic model (Ho and Mckay model) shows the relationship of the adsorption capacity and concentration with second order, and the intraparticle diffusion model (Webber and Morris model) determines the rate-controlling factor for the adsorption process [66].

The kinetics parameters obtained for the adsorption of tartrazine on biochar are available in Table 5.

By examining the appropriate values of  $\mathbb{R}^2$ , it was discovered that the removal of tartrazine on biochar can be accomplished using the pseudo-second-order kinetic model. This suggests that the mechanism governing the rate of its adsorption was chemisorption. The pseudo-second-order model fit with the results obtained for adsorption of tartrazine on biochar-mediated ZrFe<sub>2</sub>O<sub>5</sub> nanocomposites [37] and on positively charged triethylenete-tramine biochar [38].

Table 5. Kinetic constants for the adsorption of tartrazine on biochar.

Kinetic Model	Constants	Values
	$q_e [mg g^{-1}]$	0.1313
Pseudo-first-order kinetic	$k_1  [min^{-1}]$	0.0355
	$\mathbb{R}^2$	0.1867
	$q_e [mg g^{-1}]$	2.7579
Development of the line (in	h [mg g <sup><math>-1</math></sup> min <sup><math>-1</math></sup> ]	2.1245
Pseudo-second-order Kinetic	$k_2 [g mg^{-1} min^{-1}]$	1.0603
	$\mathbb{R}^2$	0.9889
	$k_{id} [mg g^{-1} min^{1/2}]$	0.0630
Intraparticle diffusion	C	2.4296
	R <sup>2</sup>	0.1912

Additionally, Figure 7 shows that the plots are divided into two linear zones and were not linear across the whole time range. According to the literature, if the line passes through the origin point (0, 0), the adsorption is dominated by the intraparticle diffusion, while if not, it is a multiple adsorption process. Because the line does not pass through the origin, this indicates that the intraparticle diffusion is not the controlling stage of the adsorption rate of tartrazine on biochar and it is complex.



Figure 7. Intraparticle diffusion adsorption kinetics of tartrazine adsorption on biochar.

Numerous writers have also reported on the effective use of the pseudo-secondorder model to reflect the experimental kinetic data of tartrazine adsorption on different adsorbents; these reports are shown in Table 6.

 Table 6. Correlation of the pseudo-second-order kinetic model for tartrazine adsorption on different adsorbents.

Adsorbent	References
raw sawdust	[10]
activated sawdust	[10]
octadecyltrimethylammonium bromide-modified bentonite	[38]
cellulose from wheat straw residues	[41]
cetyltrimethylammonium chloride-modified cellulose	[41]
microcline/MWCNTs nanocomposite	[57]
chitosan/polyaniline	[58]
activated red mud	[59]
activated carbon derived from cassava sievate	[60]
crosslinked chitosan-coated bentonite	[67]
commercial biochar	this study

## 3.5. Reusability of Biochar

The reusability of biochar was investigated by adsorption–desorption cycles using EtOH as desorption eluent. The degree of dye elimination is displayed in the Figure 8 after these cycles were completed four times.



Figure 8. Adsorption of tartrazine on biochar in four consecutive cycles.

The adsorbent can be employed in a number of treatment cycles since, as the figure shows, there was no discernible drop in the amount of dye removed after the four cycles.

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# 4. Conclusions

This study examines the effectiveness of commercial biochar in eliminating tartrazine from aqueous solutions. The ideal parameters for extracting tartrazine from aqueous solutions were determined by this study to be pH 2, 30 °C working temperature, 0.9 g L<sup>-1</sup> adsorbent dosage, 18 min contact duration, and 1 mg L<sup>-1</sup> beginning dye concentration.

The equilibrium data for adsorption of tartrazine on the biochar were evaluated using Langmuir, Freundlich, and Temkin isotherms. Of the three isotherms used, the Langmuir isotherm was most suited to explain the process of adsorption; the maximal monolayer uptake capacity was 3.28 mg g<sup>-1</sup>. The uptake kinetics demonstrate that the tartrazine adsorption onto biochar was well-fitted by the pseudo-second-order model.

Biochar can be reused after regeneration because its adsorption capacity does not decrease significantly after four adsorption–desorption cycles.

According to the obtained results and taking into account the fact that commercia biochar is an efficient and cost-effective material which can be employed for practical engineering applications on an industrial scale, this can be used to remove the tartrazine from the aqueous solutions.

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