

Application of Fermented Date Seeds for Copper Ion Removal from Wastewater: A Sustainable Adsorption Approach

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Abstract: This research investigates the feasibility of employing fermented date seeds (FDS) as an efficient and environmentally friendly adsorbent for removing copper ions (Cu^{2+}) from wastewater. Date seeds, an abundant by-product in date-producing regions, can be managed sustainably by repurposing them as a heavy metal adsorbent from date vinegar production. The vinegar fermentation process partially activates the seeds, enhancing their adsorptive properties. The surface properties of the FDS were analyzed using techniques such as Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and SEM-EDX. The chemical oxygen demand (COD) test is used to evaluate the stability of organic matter in the adsorbent derived from FDS. Batch adsorption studies were conducted to determine the best conditions for Cu ion removal, including contact time, initial metal concentration, adsorbent dosage, and pH level. The FDS adsorption capacity is 4.76 mg g^{-1} , achieved within an equilibrium time of 90 minutes at pH 5 and $25 \text{ }^\circ\text{C}$. The isotherm and kinetic models were applied to understand the adsorption mechanism, with results indicating a good fit for Freundlich isotherm and pseudo-second-order kinetics. In addition, the FDS shows effectiveness, with a COD value of $150 \text{ mgO}_2/\text{L}$. Fermentation stabilizes organic components, reducing leaching risk and improving water treatment performance.

Keywords: Adsorption, Fermented Date Seeds, Isotherm, Kinetics, Heavy Metal Removal, Copper Ions

Introduction

Water is a vital natural resource for the existence of all living organisms. However, with the global economic revolution and the rapid expansion of modern industrialization, water contamination has become a severe problem (Sulaiman et al, 2021). Heavy metals are persistent pollutants that do not biodegrade and can build up in living organisms, creating serious health risks for humans and other species due to their toxic effects on blood. Specifically, copper(II) ions (Cu^{2+}) from wastewater discharge are among the heavy metals that can enter household water supplies through human activities, posing significant dangers to public health and ecosystems. It is recognized as a common cause of

illness in living organisms, and there is increasing emphasis on identifying and removing these metals from polluted wastewater sources (Masood et al, 2015). Industries such as smelting, electrolysis, electroplating, plumbing, and cable production are notable contributors to copper pollution (Hilal, 2012) (Qasem et al, 2021).

Several chemical and physicochemical techniques are available to eliminate heavy metal ions from effluent. Choosing the suitable method, or a combination of methods, depends on how concentrated the pollutants are in the water (Türkmen et al, 2022). These methods include ion exchange, electrochemical treatment technologies, chemical precipitation, membrane filtration, and reverse osmosis (Türkmen et al, 2022) (Gunatilake, 2015) (Ghanim et al, 2022). Coagulation and precipitation are the most common techniques for removing heavy metal ions, including copper(II) ions. Heavy metals can precipitate as insoluble hydroxides or occasionally sulfides at high pH. Disposing of precipitated waste is a significant issue with this form of treatment (Agrawal et al, 2004). Ion exchange treatment ranks as the second most prevalent method for metal removal. This approach effectively addresses sediment disposal issues while also facilitating metal recovery. Nevertheless, ion exchange is not cost-effective for effluent treatment (Aksu et al, 2005).

The adsorption approach offers several benefits, including accessibility, low expense, high surface area, and less impact on the surrounding ecosystem. As a result, the focus has transitioned towards utilizing new adsorbents featuring a variety of functional groups that can enhance the removal of Cu^{2+} (Sulaiman et al, 2021) (Shafiq et al, 2018). Activated carbon may be a very effective technique to remove numerous trace elements from water, but its high manufacturing costs make it difficult to utilize on a large scale as an adsorbent. (Aksu et al, 2005) (Shafiq et al, 2018). Agricultural wastes possess several distinguishing features, including their abundant supply, cost-effectiveness, environmental compatibility, and notable ability to absorb substantial amounts of heavy metals. Functional groups in these wastes are mostly responsible for their absorption feature, which facilitates the binding of metals and subsequently aids in eliminating heavy metal contaminants from effluent streams (Hilal, 2012). Examples of agricultural waste used to adsorb copper(II) ions are peanut hulls, date pits, lentil shells, rice shells, wheat shells, and cashew nut shells (SenthilKumar, et al, 2010).

Date palms are a crucial crop in the Middle East, Asia, and arid regions of Africa since the date fruit is a staple food in these areas. Date production produces significant waste and by-products, such as palm trees and seeds. Iraq is the world's primary cultivator of date palms, with approximately 21 million trees. Together with other Middle Eastern nations, they dominate global date fruit production. The estimated annual worldwide demand for dates is 10 million. Approximately 14% of the total weight of these date fruits, or approximately 1.4 million tonnes, is rejected as undesirable solid waste annually (Sivarajasekar et al., 2019) . As a result, it is a promising source to consider as a low-cost adsorbent.

Due to its chemical nature, date pits (DP) waste removes heavy metal ions better than other natural wastes, according to most studies (Shafiq et al, 2018). DP is considered a

lignocellulosic material and can potentially be an inexpensive solid adsorbent for various metal ions (Banat, et al, 2003). The three essential components of DP fibers are cellulose (38-41%), hemicellulose (37-40%), and lignin (8.9-13%). The complex three-dimensional polymer known as lignin, composed of phenyl propane units bonded together by C-C or C-O-C connections, is considered one of DP's significant and highly effective components for adsorption applications. Unprocessed lignocellulosic biosorbents were improved through a variety of methods to enhance their sorption capacities because lignocellulosic biosorbents are believed to bind metal ions through chemical functional groups like carboxyl, amino, or phenolic.

This paper offers an alternative way to manage date seed waste by repurposing seeds as a heavy metal adsorbent from date vinegar production. Rather than being discarded, these seeds can serve as an effective adsorbent, as the vinegar fermentation process partially activates them for this purpose. This study examines the viability of utilizing fermented date pits as a Cu^{+2} removal agent in aqueous solutions without pretreatment. Many techniques, such as SEM-EDX, FTIR, and XRD, were employed to describe the adsorbent before this objective was attempted to be met. Stage 2 involved utilizing the one-factor-at-a-time approach to study the impact of adsorbent dosage (0.5-2.0 g/L), initial Cu^{+2} concentration (25-200 mg/L), pH (2-7), and contact duration on adsorption capacity and efficiency. Furthermore, the equilibrium and kinetics of adsorption were studied to comprehend the process.

Methodology

Adsorbent

The collected date pits from local date vinegar were first cleaned and dried in a furnace that circulated air around 100 degrees for approximately 24 hours. The second step is to grind the dry date pits and filter them for three minutes to get a uniform particle size of forty mesh. This is important for adsorption kinetics since the size of the adsorbent particles affects how long it takes for the sorbate to transit through the pore and reach the adsorption sites. Finally, it is preserved in a desiccator until it is utilized as an adsorbent to eliminate copper ions from water.

Chemicals

Copper sulfate was dissolved in deionized water at a suitable concentration for preparing an adsorbate solution of copper ions. To prepare copper(II) solutions from stock, analytical grade $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ (Merck) was mixed with distilled water. Copper (II) solution concentrations vary between 2×10^{-3} and 6×10^{-3} M.

Characterization of the sorbent Analysis

Copper(II) ion concentrations in solutions were measured before and after a state of equilibrium using a Japanese AA6300 Atomic Absorption Spectrometer. A combined glass electrode and a Hanna pH meter were used to test the solution's acidity. The elemental composition and chemical characterization of the adsorbent from the date pits were

examined using the EDS. A different device utilized for investigating the adsorbent's pore structure was a scanning electron microscope (SEM). The date seeds that had fermented had their crystalline structure identified by XRD analysis as well.

Adsorption experiments

The purification of aqueous solutions from copper ions solutions by utilizing a fermented date pit in a batch system was explored in this study utilizing a systematic procedure. Experiments of adsorption were carried out at 25 degrees Celsius, Initial concentration range for Cu(II) (25–200 mg/L) and dosage of adsorbent (0.5–2.0 g/L) for a 90-minute contact. The experiment uses 100 mL of a solution containing metal ions. The mixture was subjected to 90 minutes of stirring using a magnetic stirrer set at 180 revolutions per minute (rpm) after the pH was adjusted and the amount of adsorbent was added. The resulting mixture was next filtrated in order to isolate the adsorbent from the liquid. We assessed the remaining ion concentration using a flame atomic absorption spectrometer. The copper removal efficiency percentage (RE%) for each run was calculated using the below equation:

The equation Eq. (1) is used to calculate adsorption efficiency (RE%)

$$(RE\%) = \frac{C_0 - C_e}{C_0} * 100 \quad \dots\dots\dots(1)$$

The metal adsorptive amount at equilibrium (q_e , milligrams per gram) was calculated utilizing information obtained from batch experiments and is shown in equation (2)

$$q_e = \frac{(C_0 - C_e)V}{m} \quad \dots\dots\dots(2)$$

C_0 and C_e are the initial and equilibrium concentrations, respectively, and both in (mg/L). m is the mass of the dry adsorbent used in the experiments in grams, and V is the volume of the metal aqueous solution in liters.

Adsorption isotherm

Analyzing adsorption isotherms is vital in understanding the interactions between the dissolved substances and the adsorbent materials. To better understand the adsorption process, the Langmuir and Freundlich isotherm models were used to examine the sorption data acquired for different concentrations of metal ions. Each adsorbed molecule has an identical adsorption activation energy, and the Langmuir isotherm assumes that the adsorbate is covered in a monolayer on a uniform adsorbent surface. In contrast, the Freundlich isotherm model presumes a non-uniform surface with variable adsorption distributed heat and the potential for multilayer adsorption. The equation of Langmuir isotherm is illustrated in Eq.3, and its linearized form is found in Eq.4 (Lima et al, 2015).

$$q_e = (Q_{max} K_L C_e) / (1 + K_L C_e) \quad \dots\dots\dots$$

..... (3)

$$C_e / q_e = (1 / K_L q_m) + C_e / q_m \quad \dots\dots\dots$$

..... (4)

In the given context, q_e and q_m denote the equilibrium and maximum adsorption capacities, measured in milligrams per gram (mg/g), respectively. K_L represents the

Langmuir adsorption constant, measured in liters per milligram (L/mg), and C_e signifies the equilibrium adsorbate concentration, measured in milligrams per liter (mg/L).

The Freundlich model can be represented using Eq. (5) or its linearized variant, Eq. (6):

$$q_e = K_F C_e^{1/n} \dots\dots\dots (5)$$

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \dots\dots\dots (6)$$

The Freundlich adsorption constant (K_F) indicates the capacity of adsorption (mg/g (mg/L)^{-1/n}), whereas n represents the degree of attraction between the adsorbent and adsorbate; for adsorption to occur, n must be more than 1. When n is less than 1, the likelihood of molecules adsorbing to the adsorbent surface is reduced. Elevated values of n signify an effective sorption intensity (De Oliveir et al, 2013).

Adsorption kinetics

The mechanism of adsorption may be determined using the adsorption kinetic studies. The pseudo-second-order and pseudo-first-order kinetic models, often known as Ho's models, are the most commonly utilized options for determining adsorption dynamics [18][20]. The following differential and linearised equations explain the pseudo-first-order kinetic model, which is often used in physical adsorption: Equations 7 and 8:

$$dq_t/dt = k_1 (q_e - q_t) \dots\dots\dots (7)$$

$$\ln (q_e - q_t) = \ln q_e - k_1 t \dots\dots\dots (8)$$

The following differential and linearised equations, Eqs 9 and 10, are utilized in the pseudo-second-order kinetic model, which recognizes chemical adsorption as the rate-limiting step:

$$dq_t/dt = k_2 (q_e - q_t)^2 \dots\dots\dots (9)$$

$$t/q_t = 1/(k_2 q_e^2) + t/q_e \dots\dots\dots (10)$$

where q_e and q_t represent the quantities adsorbed at equilibrium and time t, respectively; k_1 and k_2 represent the pseudo-first-order rate constants (min⁻¹) and the pseudo-second-order rate constants, respectively.

Result and Discussion

Characterization of the adsorbent material

X-ray diffraction (XRD) analysis

The study was conducted to investigate the structural properties of the fermented date seeds (FDS). The diffractogram in Figure 1 displayed that the primary structure of the fermented date seeds was essentially amorphous, with relatively low crystalline content.

The amorphous nature, characterized by a disordered atomic arrangement, is typical of many organic materials. The predominantly amorphous structure is expected to improve adsorption capacity because it offers a larger surface area and a variety of active sites. This analysis gives insight into fermented date seeds as a promising option for adsorption applications.

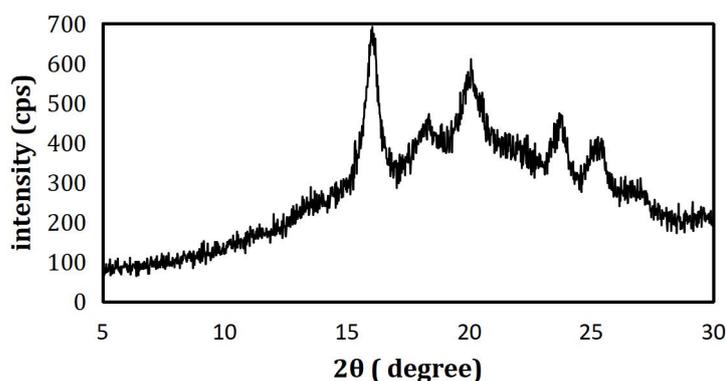


Figure 1: XRD for fermented date seeds (FDS)

Scanning electron microscopy (SEM)

A scanning electron microscope (SEM) was used to examine the raw material's surface. Figure 2 examined the surface morphology of fermented date seeds before and after adsorption. Figure 1-a shows that porosity is associated with a high adsorbent surface, which signifies a good surface area for adsorption. During the fermentation phase, acid degraded organic material, released volatile substances, and formed microporous structures, which increased adsorption capacity (Baccar et al, 2009). Figure 2-b illustrates how the surface configuration changed due to copper ions adsorption into a highly connected fibrillary network with a significant reduction in pores and roughness.

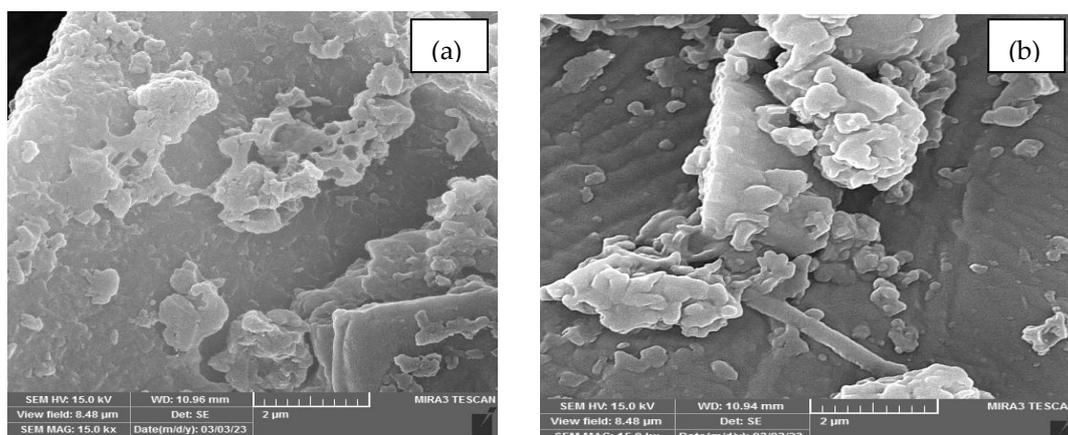


Figure 2. SEM images (a) FDS before adsorption of Cu^{+2} (b) FDS after adsorption of Cu^{+2}

The energy dispersive X-ray spectroscopy analysis (EDX)

The (EDX) of the adsorbent is shown in Figure 3 both before and subsequent to the experiment. While comparing, it is evident that the peak at the top represents the copper

ion and the decrease in carbon and oxygen peak is the direct result of the adsorbant's interaction with the copper ions (Kooti, 2010).

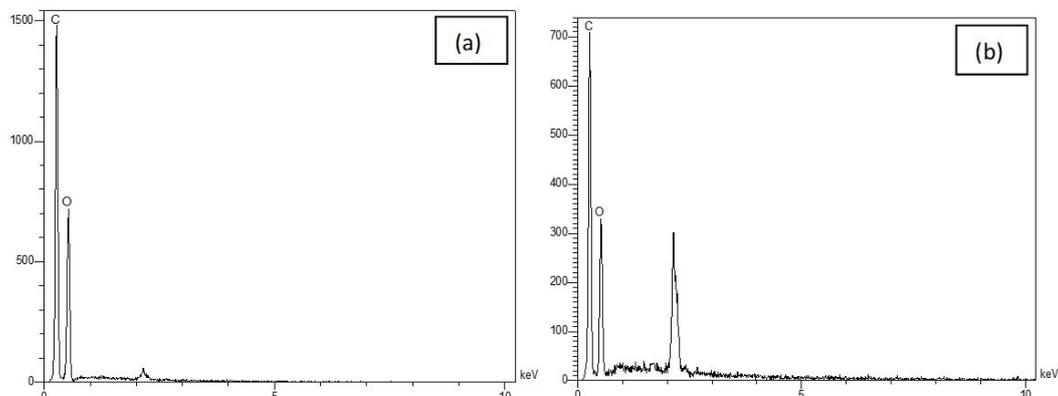


Figure 3. EDX analysis for adsorbent (a) before adsorption of Cu^{+2} (b) after adsorption of Cu^{+2}

Fourier-transform infrared spectroscopy (FTIR)

The FTIR analysis was conducted to gain insights into the adsorption mechanism of the fermented date seed material. Functional group presence on the adsorbent surface and experimental condition effects on these groups may be better understood with the use of Fourier transform infrared spectroscopy (FTIR spectroscopy). Date seeds are mostly protein, cellulose, hemicellulose, and lignin, which make them a lignocellulosic substance. The date seed's hemicellulose and cellulose are full of oxygen-containing functional groups, including carbonyl, hydroxyl, and ether. These functional groups on the FDS surface explain the reason it may efficiently adsorb heavy metal ions.

The FTIR spectra of fermented date seeds shown in Figure 4a display a broad spectrum of functional groups. The hydroxyl (OH) functional group is represented with broad peaks between 3860 cm^{-1} and 3350 cm^{-1} . The 2923 and 2852 cm^{-1} peaks indicate C-H stretching in organic molecules and show higher intensity than the raw date seed Figure 4b, indicating fermentation's effect. The FTIR spectrum of the fermented date seed adsorbent reveals a new peak at 2346.38 cm^{-1} , matching to a $\text{C}\equiv\text{C}$ triple bond, which was absent in the raw date seed sample Figure 4b. This peak indicates that alkyne groups were introduced during the fermentation process, potentially enhancing the adsorbent's surface reactivity and increasing its potential for effective adsorption compared to the raw version. From 1712 to 1375 , carbonyl groups stretch, whereas from 1300 to 1176 , C=N stretching, C=C stretching, C-H bending, and C-O bond. These functional groups have anion binding, which improves the adsorbent's adsorption ability.

Chemical Oxygen Demand (COD)

Date seeds and other lignocellulosic materials contain mostly cellulose, hemicellulose, and lignin, along with additional extractives. These substances can take part in adsorption processes because of their abundance of cellulose hydroxyl groups and

lignin, which include a variety of polar functional groups such as acids, phenolic hydroxyls, ethers, aldehydes, ketones, and alcohols (Besbes et al, 2004). However, the extractives in these lignocellulosic materials can leach out when in contact with water during adsorption, potentially increasing the organic content in the effluents. This can limit the usage of adsorbents solely for wastewater treatment (Šćiban et al, 2008). To address this issue, some form of pretreatment may be necessary, such as modifying adsorbents with acid to prevent leaching (Šćiban et al, 2008). However, in this study, the fermentation of date seeds appears effective, as indicated by the low COD value of 150 mg O₂/L observed when using FDS. This suggests that the fermentation process can stabilize the organic components well, reducing the risk of leaching and improving the overall water treatment performance.

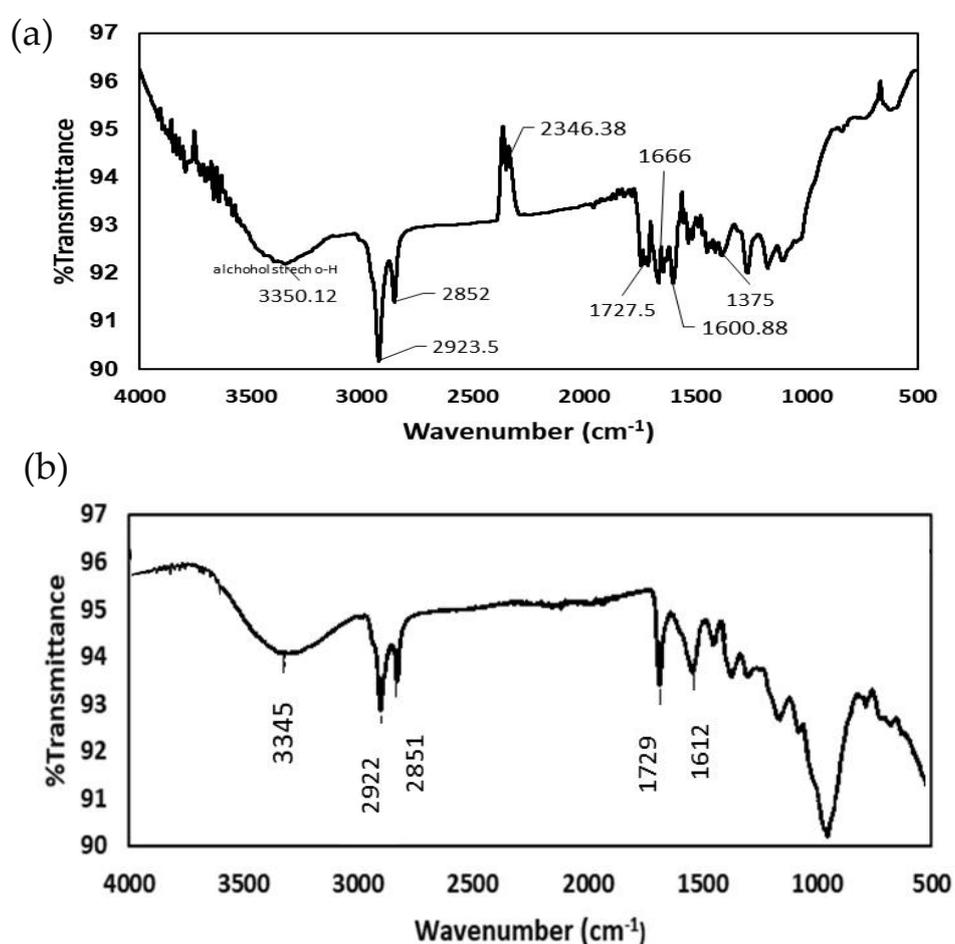


Figure 4. The FTIR test for (a) fermented date seeds and (b) raw date seeds before fermentation

PH effect on copper (II) removal

According to research, pH may be crucial in removing heavy metal ions. As a result, the pH investigation was conducted throughout a range of 2 to 7. Metal ions are being adsorbed more readily. The maximum Cu(II) adsorption percentage was detected at a pH of 5. However, as the pH decreased, the adsorption decreased. This can be explained by

the high concentration of H^+ ions in the solution. H^+ ions occupy the binding sites of the date seed adsorbent, competing with copper ions for biosorption (Hossain et al, 2012). This is due to the fact that the binding site might not be activated at pH levels over six since copper began to precipitate as $Cu(OH)^{2+}$, indicating that its removal was not only due to adsorption (Hossain et al, 2012).

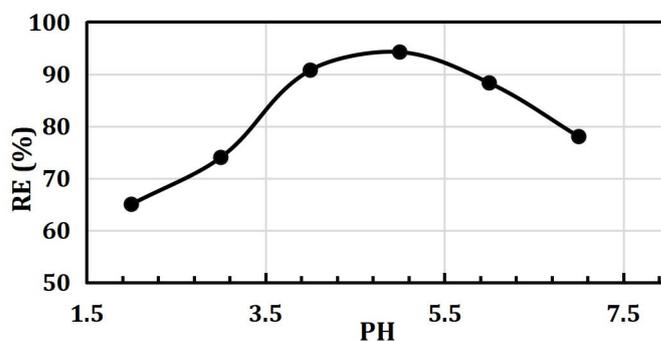


Figure 5. PH and removal efficiency percentage for $C_i=25$ mg , $t=50$ min, $C_{FDS}=1$ mg

Contact time

The initial copper ion and FDS concentrations were 25 mg L^{-1} and 0.5 mg L^{-1} , respectively. The contact time experiments were conducted at a temperature of 293 K. The results show that adsorption increases with contact duration, reaching equilibrium after 90 minutes. The first twenty minutes of contact time for the sorption of copper (II) onto FDS exhibited a high adsorption rate, which subsequently diminished due to a decrease in the availability of active sites. Following this exponential rise, the quantity of copper adsorbed from the solution is minimal since the removal efficiency remains consistently steady. Equilibrium in biosorption was reached within ninety minutes as the binding sites on the biosorbent became saturated. Identical conclusions were seen for multiple bio-sorbent. Similar experiments were conducted using the same adsorbent dose of 0.5 g/L and a 100 mg/L initial concentration. The experiments demonstrated a consistent pattern of rapid adsorption in the initial stages, reaching equilibrium within approximately one hour see Figure 4. Increasing the starting copper concentration to 100 mg/L resulted in a 6.1% drop in equilibrium adsorption efficiency, but the equilibrium time stayed at one hour.

Moreover, the equilibrium time seems to be unaffected by the initial metal concentration, a behavior also noted in earlier research. Other biosorbents demonstrated elevated adsorption rates during the initial minutes, attributed to the adsorption mechanism. At the initial stage of adsorption, a considerable portion of the adsorbent surface is available, and the concentration of the unadsorbed metal is high, which promotes mass transfer. The adsorbent surface becomes increasingly saturated as adsorption progresses, leading to less accessible active sites. As the concentration gradient declines, the driving force for adsorption diminishes, leading to a more gradual increase in the metal removal rate until the equilibrium is attained.

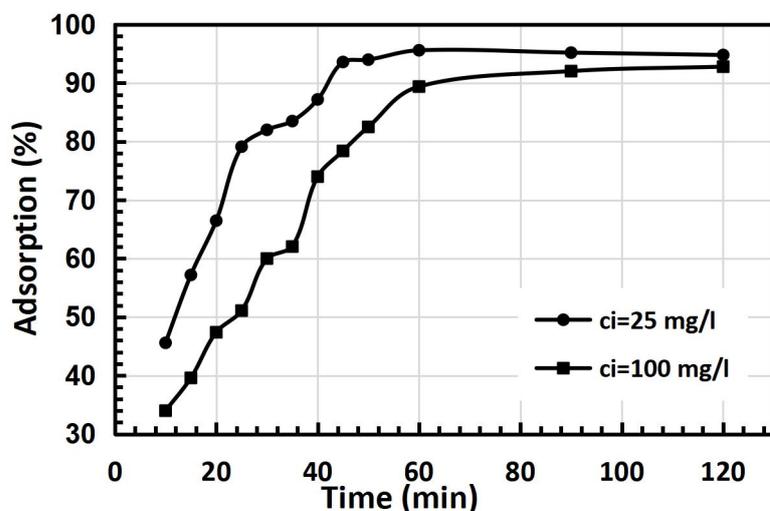


Figure 6. Adsorption efficiency with time for different concentrations of copper ion with 0.5 gr FDS

Initial ion concentration and adsorption isotherms

To further understand the behavior of Cu^{2+} adsorption on fermented date seed, adsorption equilibrium studies were carried out at 293 K with 100 ml of different concentrations of copper ion and 0.5 g of FDS. These studies were carried out to explore the influence of initial copper concentration, and the findings are presented in Figure 5, which reveal that the removal effectiveness reduced as the concentration increased. This is most likely due to insufficient active sites to accommodate the increasing number of ions.

Figure 6 depicts the amount of Cu ions adsorbed on fermented date seed as a function of the solution's equilibrium metal ion concentration. Over a fixed time, enhanced adsorption resulted from raising the initial Cu^{2+} concentration from 25 to 200 mg/L. The higher driving force from the solution to the adsorbent resulted in more Cu^{2+} contacts with the active sites on the FDS. The porous structure of FDS provides several adsorption sites on its surface, making it easier for the adsorbate to access them and achieve equilibrium quickly.

By fitting the data to the Langmuir and Freundlich isotherm models, the equilibrium adsorption data for copper removal utilizing fermented date seed as the adsorbent were examined. Table 1 displays the correlation coefficients and isotherm parameters that were obtained. The experimental data was adequately described by the Langmuir and Freundlich isotherm models, but the second one demonstrated a superior fit, according to the results. The results show that the metal adsorbed amount can be accurately predicted at a temperature of 25°C using the Freundlich model and its associated constants. The results show that the adsorbent surface was subjected to multilayer adsorption. Adsorption intensity, denoted by n , indicates the affinity between the adsorbent and adsorbate. It is proposed that adsorption is unfavorable when n is less than 1 [20]. Table 1 indicates that the n is greater than 1, confirming that the fermented date seed adsorbed copper. The highest adsorption capacity was determined at 4.76 mg/g, consistent with the

biosorption capacities of other unmodified biosorbents listed in Table 2. This table illustrates the biosorption capacities of copper ions in various biosorbent materials from the literature, with values that are consistent within the same range. The findings of this study indicate that fermented date seed can function as an effective adsorbent for removing copper ions from aqueous solutions.

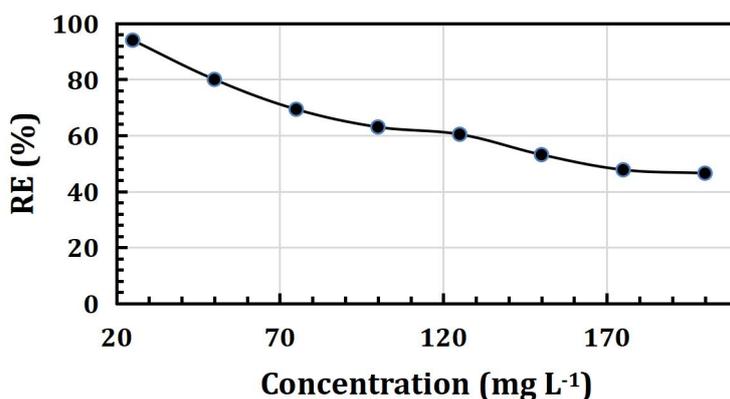


Figure 7. The correlation between the initial concentration of Cu^{+2} and the removal efficiency

Table 1. constants of isotherm models for Cu (II) adsorption on fermented date seed

Adsorbent	Langmuir			Freundlich		
	q_m (mg g ⁻¹)	K_L (Lmg ⁻¹)	R^2	K_F (mg g ⁻¹)	n	R^2
FDS	19.942	0.066	0.976	3.972	3.084	0.991

Table 2. The biosorption capacity of copper ions for various biosorbents mentioned in the published research

Adsorbent	q_m (mg g ⁻¹)	Parameter		References
		pH	T (K)	
Pinus radiata sawdust	2.23	5.4	298	[32]
Wheat shell	10.8	5	298	[34]
Rice hulls	3.92	5.3	293	[35]
Coconut tree sawdust	3.89	6	---	[36]
Orange peel	4.75	5.5	303	[37]
Banana peel	3.65	5.5	---	[37]
Raw date	4.036	3	---	[24]

seed				
Date pits	3.27	2-7	≈ 293.15	[38]
Fermented date seed (FDS)	4.76	5	298	This study

Effect of the adsorbent concentration

At a particular initial concentration of the adsorbate, the adsorbent's capacity highly depends on the adsorbent dose. While maintaining all other experimental conditions constant, varying quantities of adsorbent were used to remove Cu^{2+} in different samples. Copper ions (25 mg/l) were added to a 100-ml solution, and then 0.5, 1.0, 1.5, 2, and 2.5 grams of sorbent were added with the specified experimental conditions. The efficiency of copper ion removal is demonstrated in Figure 8, which represents the different quantities of fermented date seeds sorbent. The finding shows that the initial removal efficiency of copper is substantially enhanced as the quantity of biosorbent increases, and the biosorbent mass gradually increases until optimal removal occurs at 2 g. Increasing the biosorbent-to-copper ion ratio in the solution enhances removal efficiency due to the improved total surface area and the increased number of possible binding sites for biosorption. Despite this, the sorption capacity is significantly affected as the biomass concentration increases. An increase in the fermented date seed adsorbent dosage may cause it to aggregate, reducing its total surface area. As a result, the adsorption capacity can be reduced. A decrease in adsorption capacity may be caused, in part, by aggregation, which reduces the adsorbent's overall surface area while increasing the adsorbate's diffusion path length. Using a dosage of 0.5 grams of adsorbent results in the maximum biosorption capacity being recorded. The biosorption capacity curve and removal efficiency for different dosages of biosorbent are shown in Figure 8.

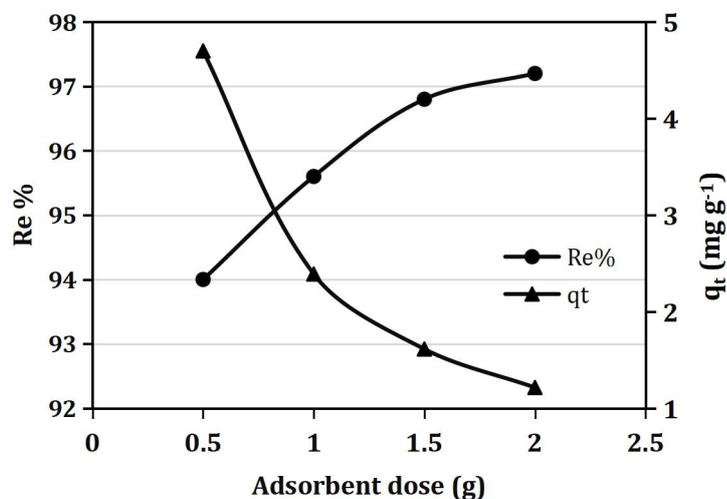


Figure 8: The biosorption capacity curve (q_t) and removal efficiency (Re) for various doses of FDS with 25 mg/L as Cu^{2+} initial concentration

Adsorption Kinetics models

The adsorption mechanism can be determined using the adsorption kinetic studies. The parameters and correlation coefficients for kinetic models are displayed in Table 3, which shows the results of fitting the data for copper removal by fermented date seed to the pseudo-first-order and pseudo-second-order kinetic models. The pseudo-second-order model more accurately represented the data, and the predicted adsorption capacities were comparable to the observed values. Thus, chemical sorption can characterize Cu^{2+} adsorption onto FDS. The sorption is more accurately depicted by the pseudo-second-order kinetic model, which considers the possibility that the rate-limiting step incorporates chemisorption with valence forces, which occurs when the adsorbent and adsorbate share or exchange electrons.

Table 3. The data of Kinetic Models

q_e (mg g ⁻¹) (Experimental)	Pseudo-first order			Pseudo-second order		
	q_e (mg g ⁻¹)	K_1 (min ⁻¹)	R^2	q_e (mg g ⁻¹)	K_2 (g mg ⁻¹ min ⁻¹)	R^2
4.76	6.832	0.0823	0.9072	5.059	0.0263	0.993

Conclusion

This study's findings show the potential of fermented date seeds FDS as an efficient adsorbent for removing Cu^{+2} ions from aqueous solutions. The study found that copper ion adsorption on FDS increases with contact time, reaching equilibrium after 60 minutes. The initial rate of adsorption is rapid; however, it slows down as a result of the reduced number of active sites. Regardless of the initial ion concentration, the equilibrium time and removal efficiency are both unaffected. The research results showed that the adsorption process was accurately described by the Freundlich isotherm model, which showed that heterogeneous adsorption occurred throughout the surface of the adsorbent. The adsorption kinetics were determined to be consistent with a pseudo-second-order model, which stated that chemical adsorption processes could potentially play a role in the rate-limiting step. Adsorbent quantity affects active site and surface area availability, which affects adsorption capacity. However, higher adsorbent dosages can lead to increased surface contact and agglomeration, reducing the free specific area and contact with the adsorbate. This can lead to a decrease in removal efficiency and adsorption capacity caused by copper ion saturation in the solution and the reduced surface area of the adsorbent due to aggregation. Although this mild acidic treatment does not reach the same adsorption capacity as full chemical or thermal activation, it does increase the pits' adsorptive surface area to a measurable extent compared to raw pits, improving their ability to adsorb organic molecules and select heavy metal ions. In addition, the

fermentation process contributed to stabilizing the adsorbent, with a Chemical Oxygen Demand (COD) test indicating low organic leaching.

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