



Cassava flour bioadsorbent used to remove Cr (VI) from water

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Abstract: The effective removal of metals from water not only helps to preserve the quality of water for human consumption, but also protects aquatic milieus, thereby promoting biodiversity and the proper functioning of ecosystems. In this work, to implement sustainable management practices and continuously monitor sources of contamination, we used cassava flour to remove chromium from water samples. To measure changes in Cr (VI) content in our solutions during the treatment, UV-visible spectroscopy was used, applying the Beer-Lambert formula. Parameters such as pH, absorbent dose, contact time, chromium concentration and temperature were optimized to determine the chromium removal rate. Adsorption kinetics, equilibrium, isotherms and thermodynamic parameters such as ΔG° , ΔH° , and ΔS° , as well as FTIR spectroscopy were studied to better understand the Cr (VI) removal process by cassava flour. The removal rate reached 99.96 mg/g, for an optimum contact time of 90 min at 298 K.

1. Introduction

The pollution of water by heavy metals remains a great concern for industrialists on a daily basis. International standards impose increasingly low levels for these heavy metals. To comply with these standards, high-performance decontamination techniques have been developed to eliminate these pollutants almost completely (Alaqarbeh *et al* 2022; Boutebib *et al* 2023). These elements are present in the aquatic environment at trace levels. Trace elements refer to heavy metals, because they are present at small quantities in wastewater (Jobby 2018) Once in the environment, metals undergo mutations (oxidation, reduction, complexation, etc.) depending on the environment in which they are found. Among these heavy metals, chromium is one of the most widely used in electroplating, metallurgy and tanning industries, hence its massive presence in the waste of these entities (Jobby 2018). Chromium can be found in various oxidation states ranging from Cr (0) to Cr (VI), with a predominance of trivalent (Cr^{3+}) and hexavalent (Cr^{6+}) forms. Hexavalent chromium is 100 times more toxic than other forms of chromium because of its oxidizing power and its ability to penetrate biological membranes (Rosca M., 2023). As a result, its concentration in the environment, and in wastewater in particular, has been very high over the last two decades (Pooja, 2021). Several researchers have tried

to use conventional and non-conventional adsorbents such as carbonized biomaterials, non-carbonized powdered biomaterials and activated carbon to remove chromium from wastewater (Irene, 2020; Vusumzi, 2019; Anh, 2019; Jonas, 2024; Errich, *et al.*, 2021; N'diaye *et al.*, 2022). We therefore used cassava powder to remove chromium from aqueous media. Cassava is a plant native of Central and South America, particularly the south-western. It is a species of dicotyledonous plant in the Euphorbiaceae family. Nigeria is the world's leading cassava producer with 54.832 million tonnes. In Senegal, cassava is available throughout the country, but Cayor (The Region of Thiès) is the main production area. To date, only cassava peel has been used as a bio-sourced material to remove Cr⁶⁺, Cr³⁺ and Co from water (Daniel *et al.*, 2021, Olaoye *et al.*, 2020). There are various varieties of transgenic cassava, including one enriched with vitamin B6 (Fran *et al.*, 2024) or a variety that is resistant to two viruses, mosaic and brown streak disease (Lima & Eduardo, 2024). In our work we have cassava which is very rich in starch. The study of parameters such as concentration, absorbent dose, pH, contact time, temperature and adsorption kinetics gave us satisfactory results compared with other results from research.

2. Materials and methods

2.1 Chemicals

All chemicals used here were purchased from Sigma Aldrich. Hexavalent chromium was obtained by using potassium dichromate (K₂Cr₂O₇, 99.7% w/w) as ion precursor. pH was adjusted by using acidic and basic solutions obtained by diluting concentrated sulphuric acid (H₂SO₄, 98% w/v) and sodium hydroxide (NaOH, 98.8% w/w). Solutions were prepared with ultra-pure water, obtained from a Millipore Milli-Q system (resistivity > 18 MΩ cm at room temperature). The bioadsorbent used in this study was manioc cuttings harvested at Pire in the Thiès Region (Senegal), cut, then chewed and ground to powder using an artisanal mill.

2.2 Apparatus

UV-visible absorption spectrophotometer (Thermo Scientific GENESYS 10S series, France) was used for absorbance measurements and quantification. 250 mL beakers with stirrer and hot plate were used in this study. Adsorbent was characterized using a Fourier transform infrared spectrophotometer (FTIR) (PerkinElmer, France), 8,300-350 cm⁻¹, resolution 0.4 cm⁻¹) to follow the evolution of absorption bands and occupied sites, energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM) (from Bruker Nano GmbH Berlin, Germany) to study the surface morphology before and after contact between Cr (VI) and cassava flour.

2.3 Methods

2.3.1 Adsorbate preparation and monitoring

A stock solution of concentration 1 g/L was prepared by dissolving a mass of 500 mg of potassium dichromate in 500 mL of acidified distilled water (pH 2) with a view to the potential formation of hexavalent chromium. Then, by diluting this stock solution with distilled water (pH 2), we obtain a range of solutions with concentrations from 0 to 1 mg/L. Each of these solutions is then run through a UV-visible spectrophotometer to measure the absorbances that will be used to establish the calibration line. With a correlation coefficient (R²) close to unity, we were able to accurately determine the concentration of the corresponding Cr (VI) ion after filtration. The maximum absorption was measured at a wavelength of 350 nm, corresponding to the most resolved absorption.

2.3.2 Optimization of analytical parameters

Analytical parameters such as adsorbent dose, pH, temperature and contact time were optimised. Different masses of cassava flour (1 to 8 g) were used to determine the optimum mass of adsorbent and the pH was varied from 1 to 10. The contact time between the adsorbent and the chromium was varied at 10-minute intervals, from 10 to 90 minutes. Finally, the effect of the initial chromium concentration between 10 and 180 mg/L was studied under an optimum pH (pH 2) favoring the formation of Cr(VI). After stirring, the solutions were left to stand before being filtered and their absorbance was measured using the calibration curve (Figure 1). Calculations were also made to determine the percentage removal (%R) of Cr (VI) ions using Eqn. 1.

$$\%R = \frac{(C_0 - C_t)}{C_0} \times 100 \quad \text{Eqn. 1}$$

where C_0 is the initial chromium concentration (mg/L); C_t is the chromium concentration at time t (mg/L).

2.3.3 Study of the kinetic parameters

After determining the optimum experimental conditions, such as the initial concentration of Cr (VI) ions in the solution, the mass of adsorbent, the pH and the stirring time, we studied the kinetic parameters. Using the first-order, second-order, Elovich kinetic and Intra-particle diffusion models represented by Eqns (2) and (3), respectively, we were able to plot time t as a function of $\log(q_e - q_t)$.

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad \text{Eqn. 2}$$

$$\frac{1}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad \text{Eqn. 3}$$

$$q_t = k_{id} \times t^{\frac{1}{2}} + C \quad \text{Eqn. 4}$$

$$q_t = \frac{1}{\beta} \ln(\alpha\beta + \ln t) \quad \text{Eqn. 5}$$

where q_e and q_t (mg/g) are the quantities of Cr (VI) adsorbed at equilibrium and at time t (h), respectively, and k_1 (h^{-1}) and k_2 (g/mg/h) are the first and second order kinetic rate constants.

K_{id} is the intra-articular diffusion velocity constant (mg/(g.mn^{1/2})) and C is a constant that gives information about the thickness of the boundary layer (in mg/g), α is the initial adsorption percentage (in mg/g.mn) and β is the desorption constant (in g/mg), related to the extent of the adsorbent layer and the activation energy for chemisorption.

2.3.4 Study of isothermal adsorption

The distribution of ions on the surface of the adsorbent at equilibrium at a given temperature is indicated by the isotherm. By applying the empirical formulas of the linear isotherm models of Langmuir, Freundlich and Temkin, we were able to study the adsorption isotherm.

$$\text{Langmuir : } \frac{C_e}{q_e} = \frac{1}{q_m k_L} + \frac{C_e}{q_m} \quad \text{Eqn. 6}$$

$$\text{Freundlich: } \log q_e = \log k_f + \frac{1}{n} \log C_e \quad \text{Eqn. 7}$$

$$\text{Temkin : } q_e = \frac{RT}{b_t} \ln(a_t C_e) \quad \text{Eqn. 8}$$

where q_e (mg/g) and C_e (mgL⁻¹) represent the adsorption capacity and aqueous phase concentration of the adsorbate at equilibrium respectively; q_m (mg/g) and k_L (L/mg) correspond to the monolayer capacity and Langmuir equilibrium related to the free energy of adsorption; the constants k_f (L/mg) and $1/n$ represent the capacity and intensity of Freundlich adsorption; a_t (L/g) and b_t (kJ/mol) are Temkin's isothermal constants; R is the universal gas constant (8.314 J/K/mol) and T is the temperature in Kelvin.

2.3.5 Study of thermodynamic parameters

The study of these parameters was carried out in a temperature range from 298 to 328 K and the thermodynamic variables such as the Gibbs free energy and the activation energy are given by the following relationships:

$$k_c = \frac{C_{ad}}{C_e} \quad \text{Eqn. 9}$$

$$\Delta G^\circ = -RT \ln k_c \quad \text{Eqn. 10}$$

$$\ln k_c = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad \text{Eqn. 11}$$

$$k_2 = Ae^{\left(-\frac{E_a}{RT}\right)} \quad \text{Eqn. 12}$$

where k_c is the equilibrium adsorption constant, C_e and C_{ad} (mg L⁻¹) represent the equilibrium and Cr (VI) concentrations adsorbed by the adsorbent respectively, R is the universal gas constant (8.3145 J/mol/K) and T is the temperature in Kelvin.

The rate constants of the model are used to estimate the activation energy E_a using Arrhenius **Eqn. 12**.

3. Results and Discussion

3.1 Optimization of the adsorption parameters

3.1.1 Adsorbent dose

The dose of adsorbent is among the most important parameters in the study of Cr (VI) ion adsorption in aqueous media (Rajapaksha *et al.*, 2022). To study this parameter, cassava doses from 1 to 8 g under pH 2 and constant concentration ($C_o=40$ mg L⁻¹) of Cr (VI) ions were used (Figure 2). The percentage of elimination (%R) increased with the increase in the dose of cassava up to a limit value of 99.8%. This maximum elimination rate is obtained for a dose of cassava equal to 6 g, which is the maximum dose. This means that at low adsorbent levels, all available sites are occupied by Cr (VI) ions. However, an increase in the dose of sorbent would cause the excess chromium in solution to be eliminated by generating new binding sites (Ukhurebor *et al.*, 2021) The increase in percentage recovery may be due to the fact that the concentration of Cr (VI) in solution remains constant while the number of binding sites increases with the addition of an extra dose of sorbent (Irene *et al.*, 2020). This optimized dose (6 g L⁻¹) will be used to study the other parameters.

3.1.2 Initial chromium concentration

The initial chromium concentration was varied between 20 and 150 mg L⁻¹ while the mass of cassava powder was fixed at 6 g L⁻¹ for a contact time of 115 min. We noted that the percentage of Cr (VI) removal increased rapidly from 95 to 99.7% when initial concentration passed from 20 to 25 mg L⁻¹ (Figure 3). The Cr (VI) recovery rate then decreased before stabilizing at 20% for a concentration of

125 mg L⁻¹ (Figure 3), which could correspond to saturation of all the available sites. The way in which the removal rate varies according to the concentration of chromium in solution is similar to that for the use of biomaterials in the recovery of hexavalent chromium in aqueous media (Rajapaksha *et al.*, 2022), (Belcaid *et al.*, 2021), (Ukhurebor *et al.*, 2021). These results provide information about the concentration at which all the sites will be occupied and the excess of chromium will remain in solution. The elimination rate of Cr (VI) in water by cassava flour (99.7%) for an optimum concentration of 25 mg L⁻¹ is clearly comparable to that of other materials used from biomass, (Rajapaksha *et al.*, 2022), (Belcaid *et al.*, 2021). This means that water contaminated with chromium and then treated with cassava flour can be reused with total safety, as it meets international standards (Ukhurebor *et al.*, 2021).

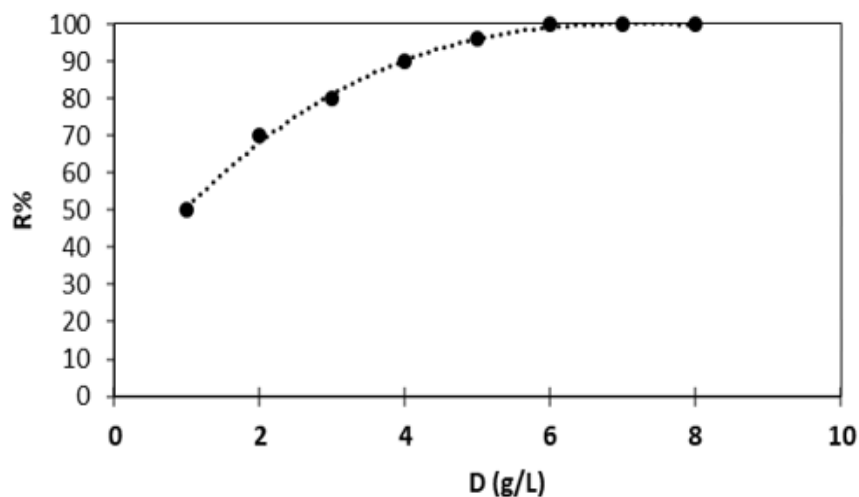


Figure 2. percentage of chromium elimination as a function of cassava mass

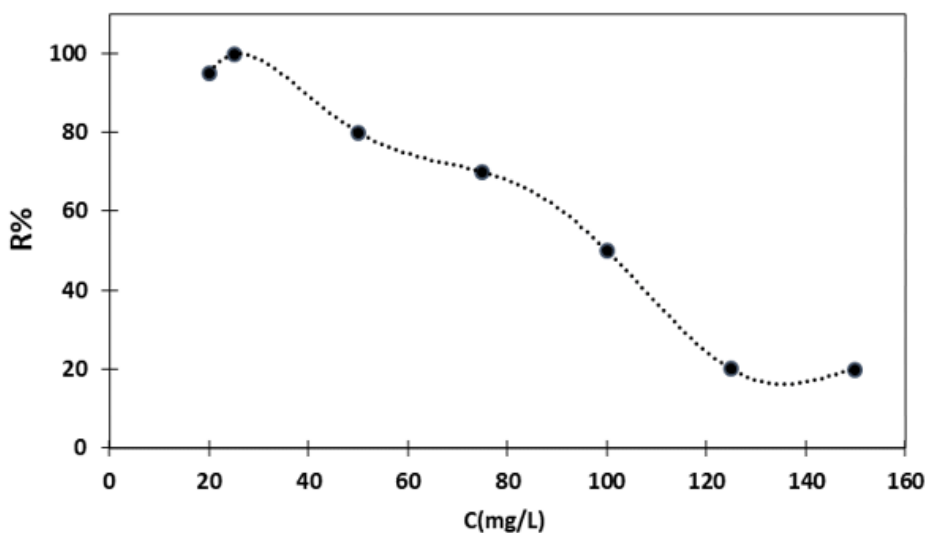


Figure 3. Evolution of the percentage of chromium elimination as a function of the initial chromium concentration

3.1.3 Initial pH

The pH of the adsorption solution is one of the most important parameters for determining the active sites present in the biosorption of heavy metal (Karoline *et al.*, 2024, Leah *et al.*, 2024). Acidification of the medium (pH 2), as in Figure 4, shows that it favors the formation of chromium (VI) (Xiang L 2021). Chromium (VI) is present in the form HCrO_4^- , CrO_7^{2-} and CrO_4^{2-} depending on the pH value

and concentration of the solution (Shi S 2018). The forms HCrO_4^- , CrO_7^{2-} are mainly available at equilibrium for pH values comprised between 0 and 6 (Nigora 2024). If the pH is greater than or equal to 7, CrO_4^{2-} would be the predominant form in solution. This can be explained by the different pKa values for chromate acid-base couples, which are (Sanchez 2018) $\text{pK}_{a1} = 0.75$ at $\text{H}_2\text{CrO}_4/\text{HCrO}_4^-$ and $\text{pK}_{a2} = 6.4$ for $\text{HCrO}_4^-/\text{CrO}_4^{2-}$. There is a slight increase in the rate of elimination of Cr (VI) from 97 to 99.5% for a variation in pH between 1 and 2 (Figure 4). These results show that at low pH, the HCrO_4^- form predominates in the solution, increasing the percentage of elimination. This can be explained by the protonation of the adsorbent surface, which facilitates electrostatic attraction between the chromium and the adsorbent (Shi S 2018). On the other hand, there is a noticeable decrease in the chromium removal rate until a constant value of 10% is reached at a pH of 8 (Figure 4). This phenomenon may reflect the presence of negative charges on the surface of the adsorbent at a basic pH, which hinders chromium elimination. In a basic environment, the CrO_4^{2-} form is in the majority in solution and by the presence of OH^- leads to electrostatic repulsion, causing competition between these negative ions (Shanti 2019). The results show the indispensability of pre-treatment by acidification to improve removal in large quantities at higher pH.

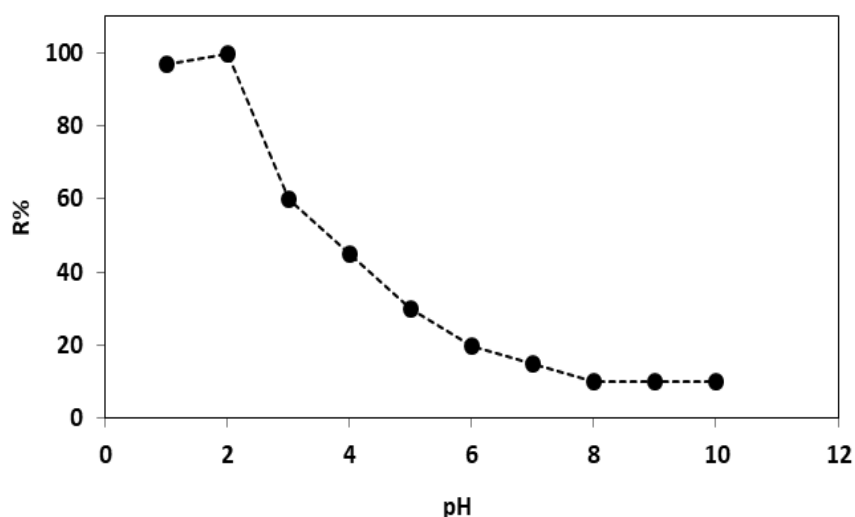


Figure 4. Effect of initial pH on the adsorption efficiency of hexavalent chromium by cassava flour

3.1.4 Contact time

The contact time (t_c) study was carried out by varying the chromium concentration in the solution from 25 mg/L, 50 mg/L and 100 mg/L while using the optimized dose at 6 g/L and pH 2 (Figure 5). It is observed that the efficiency of elimination of Cr(VI) ions by the sorbent increases proportionally with the contact time and reaches an equilibrium (Reena, 2022) (Figure 5). In all cases, the evolution of chromium elimination takes place in two stages, initially a rapid retention of Cr(VI) ions was observed before equilibrium was reached. The spontaneous increase in the rate of elimination at the beginning of the process is due to the availability of several active sites that favors the adsorption of Cr(VI) ions on the surface of the sorbent (Nigora 2024). The optimum time was first reached with the 25 mg/L concentration (optimized concentration) at 90 min, while for 50 and 100 mg/L, the equilibrium time was found to be 120 min and 150 min respectively. Overall, equilibrium was achieved at 90 minutes with a Cr(VI) recovery percentage of 99.96% (Figure 5).

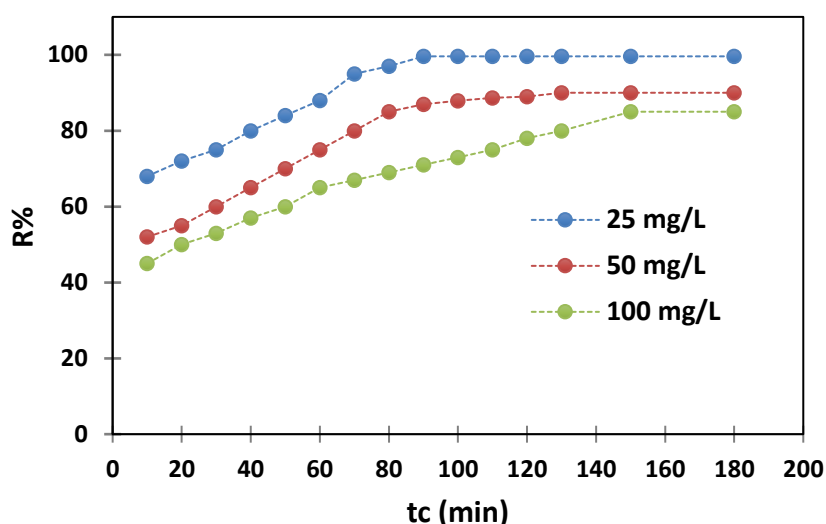


Figure 5. Effect of contact time on the adsorption efficiency of Cr(VI) by cassava for different initial concentrations

3.5 Influence of temperature as a function of contact time

The study of the temperature of the medium is crucial, in the adsorption process for the elimination of Cr(VI) ions in aqueous media, the temperature has a considerable effect on whether the process behaves exothermally or endothermally (Belcaïd 2021) (Prasanthi 2019). The increase in temperature leads to an increase in the rate of elimination of Cr(VI) ions. On the one hand, this can be explained by the fact that temperature affects the diffusion rate of chromium through the sorbent layers (Kingsley 2021). On the other hand, an increase in temperature would be synonymous with an increase in the number of active sites, thus favoring an increase in the percentage of recovery of Cr(VI) ions (Katarzyna 2022). The study was carried out by varying the temperature from 298 to 328 K and the contact time from 10 to 150 min. The pH was maintained at 2, the dose of manioc at 6 g/L (optimized dose) and the concentration at 25 mg/L (optimized concentration) (Figure 6). It can be seen that the higher temperature, the greater the percentage of Cr(VI) elimination and the shorter the contact time required to reach equilibrium.

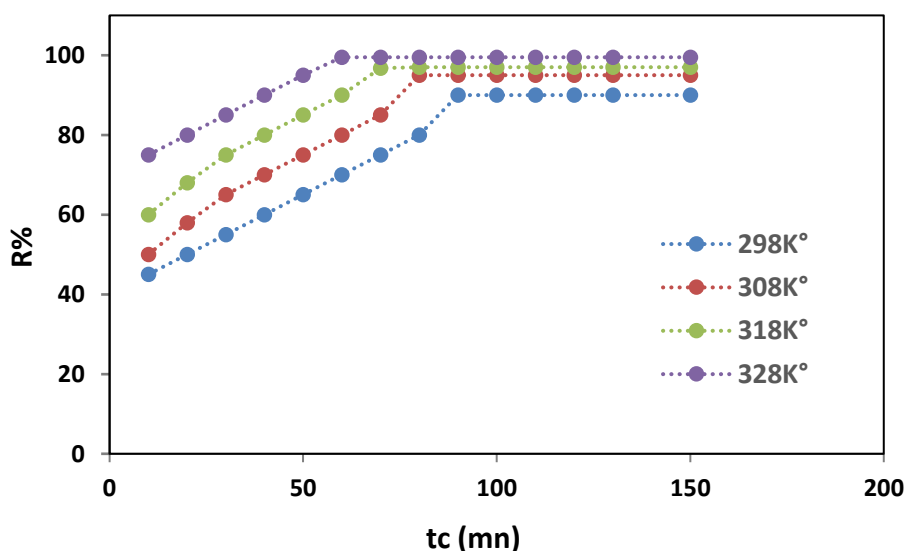


Figure 6. Effect of temperature and time contact on Cr(VI) removal efficiency

3.6 Study of adsorption kinetics

The study of the kinetic parameters provides information on the model involved in the cassava adsorption process. There are different models to describe the mechanism of adsorption of Cr(VI) ions. Pseudo first-order (Lagergren 1898), pseudo-second order (Aminul 2019) Elovich (Villabona 2020) and intra-particle diffusion (Bebba Ahmed 2017) models were studied at temperatures of 298, 308, 318 and 328 K (Figure 7). The calculated kinetic parameters are shown in Table 1. Analysis of these results shows a close coincidence between the experimental and calculated kinetic constants, and the correlation coefficient is close to unity, indicating that the pseudo-second-order model better represents the experimental kinetic constants for the adsorption of Cr(VI) ions. The intra-particle diffusion diagrams showed a multilinear correlation, as illustrated in Figure 7d. The results showed that the intra-particle diffusion of Cr(VI) adsorption on cassava occurred in two stages. In the first stage, we have the slope of the adsorption, which can be attributed to rapid external surface adsorption or external diffusion. In the second part, the slope is less steep, and we consider that the adsorption is gradual or the diffusion is intra-particle, thus limiting the speed (Ling 2021). The comparative study in Table 1 reveals that the intra-particle diffusion of Cr(VI) adsorption was in two stages. Instantaneous diffusion of Cr(VI) in the first instance where adsorption takes place on the external surface. The second part is the final equilibrium stage where intra-particle diffusion starts to slow down due to the decrease in solute concentration (Tian 2018).

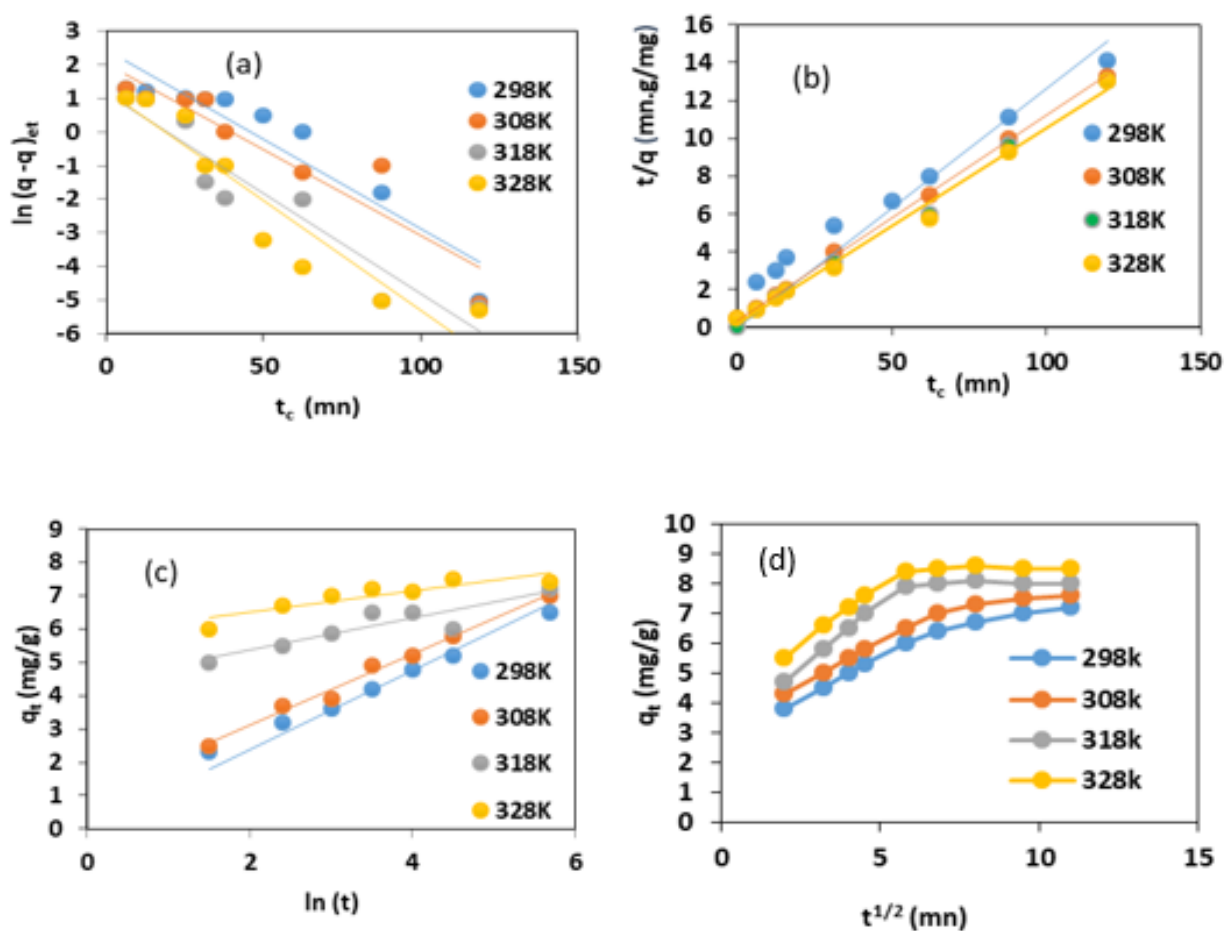


Figure 7. (a) Pseudo-first-order kinetics, (b) Pseudo-second-order kinetics(c) Elovich kinetics, (d) Intraparticle diffusion kinetics

Table 1. Kinetic parameters for Cr(VI) adsorption by cassava

Models and parameters	Temperature (K)			
	298	308	318	328
(q_e) experimental (mg/g)	6	6.8	7.5	8
Pseudo first order				
(q_e) (mg/g)	4.8	5	9	12
K_1 (mn ⁻¹)	0.0195	0.024	0.044	0.048
R^2	0.883	0.878	0.908	0.889
Pseudo second order				
(q_e) (mg/g)	6.5	7	7.8	8.2
K_2 (mn ⁻¹)	0.0105	0.0112	0.0127	0.128
R^2	0.997	0.992	0.999	0.999
Elovich				
α (m ² g ⁻¹ mn)	48	67	180	1750
β (g/g)	0.186	0.130	0.158	1.079
R^2	0.996	0.988	0.827	0.791
Intra-particle diffusion				
K_{i1} (mg g ⁻¹ mn) ^{-1/2}	0.853	0.910	1.021	1.052
C_1 (mg/g)	0.551	0.612	0.998	1.643
R^2	0.999	0.996	0.344	0.994
K_{21} (mg g ⁻¹ mn) ^{-1/2}	0.396	0.374	4.748	0.307
C_2 (mg/g)	3.710	4.256	0.771	6.219
R^2	0.974	0.912		0.713

3.7 Isothermal adsorption

The isothermal adsorption of Cr(VI) ions on cassava was studied at different temperatures (**Figure 8**). We investigated the influence of the initial chromium concentration on the adsorption process. It appeared that the quantity of adsorbed Cr(VI) ions increased with the initial chromium concentration until a saturation state was reached, as observed in previously reported works (**Wei 2022**). Adsorption isotherms describe the specific ratio between the concentration of the adsorbate and its adsorption capacity on the surface of the adsorbent at a constant temperature (**Monday 2020**). For Langmuir's model, the adsorbent surface must be absolutely homogeneous, i.e. in the form of a monolayer with a fixed number of adsorption sites, where adjacent adsorbates do not enter the process (**Langmuir 1918**). Freundlich's model, on the other hand, is based on heterogeneity of the adsorbent surface, favoring multilayer formation due to the presence of adsorption sites with variable energies (**Freundlich 1926**). For Temkin's model, the decrease in the heat of adsorption is rather linear than logarithmic and adsorption is characterized by a uniform distribution of binding energy up to a certain maximum point (**Tenkin 1940**). The results are shown in **Table 2**. **Table 2** shows the evaluation of the adsorption constants of the isotherm models with their corresponding correlation coefficients. Analysis of the results shows that chromium (VI) adsorption on cassava occurs according to the Freundlich model, which is in better agreement with the experimental data in terms of correlation coefficient ($R^2 = 0.999$), involves multilayer adsorption of Cr(VI) ions and occurs on inhomogeneous sites (**Irene 2022**). These results indicate that the system radically follows the heterogeneous Freundlich isotherm process. In addition, the value of the parameter for the slope of the Freundlich curve was less than 1, indicating that cassava has a heterogeneous surface structure. Similarly, the n value obtained ($n = 1.8$) for Cr(VI) adsorption confirms that adsorption is favorable (**Belcaïd 2021**). Using the same Freundlich model, (**Olaoye 2020**) reached a concentration of 3.33 g/L of Cr (VI) by a dose of 25 g/L of cassava peel for a contact time of 120 min at 298 K and pH 2.

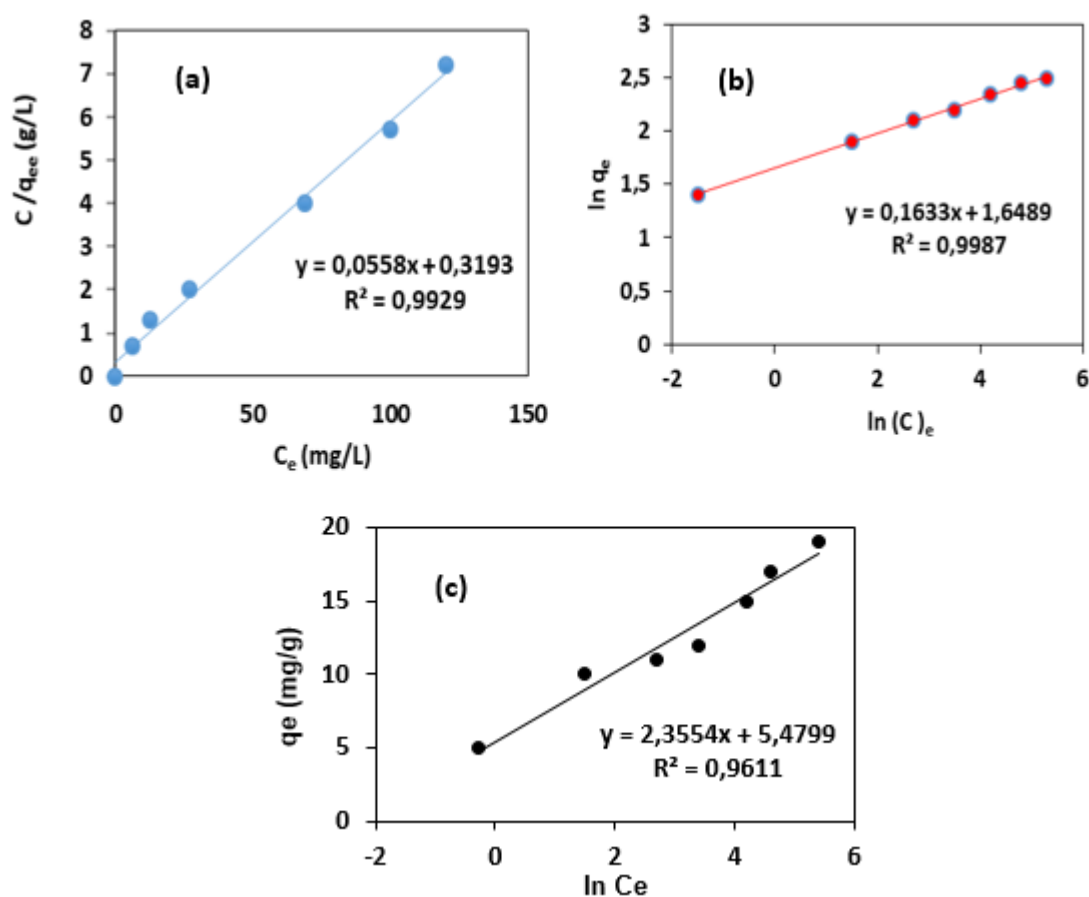


Figure 8. (a) Langmuir isotherm, (b) Freundlich isotherm and (c) Temkin isotherm

Table 2. Parameters of the Langmuir, Freundlich and Temkin isothermal models for chromium elimination by cassava

Langmuir			Freundlich			Temkin		
q_{\max} (mg/g)	K_L (L/mg)	R^2	$1/nF$	KF (L/mg)	R^2	a_t (L/mg)	b_t (kJ/mol)	R^2
18.99	0.594	0.992	0.527	1.319	0.999	2.355	0.835	0.961

3.8 Thermodynamic study

The enthalpies and entropies of chromium (VI) adsorption by cassava are determined from **Figure 9**. The results of the all analysis are listed in **Table 3**. The negative value of the Gibbs free energy (ΔG) explains the spontaneous nature of chromium adsorption over the temperature range studied. This spontaneity of the adsorption process becomes more important with increasing temperature resulting in a facilitation of chromium adsorption. It is therefore essential to carry out in-depth studies on the effect of temperature on the adsorption process. We calculated the inversion temperature (T_v) from the equation $\Delta G^\circ = 132 - 0.46T$ to determine the direction of evolution of the system, which is irreversible. Since at equilibrium the process is no longer evolving, $\Delta G^\circ = 0$ and $T_v = 286.95$ K. For the process to be spontaneous ($\Delta G^\circ < 0$), the temperature must be higher than the inversion temperature ($T > T_v$). The endothermic nature of the chromium adsorption process by cassava is confirmed by the positive enthalpy values ($\Delta H > 0$). In conclusion, we can say that the thermodynamic study revealed that the Cr (VI) adsorption process is thermodynamically favorable only at temperatures above 286.95 K.

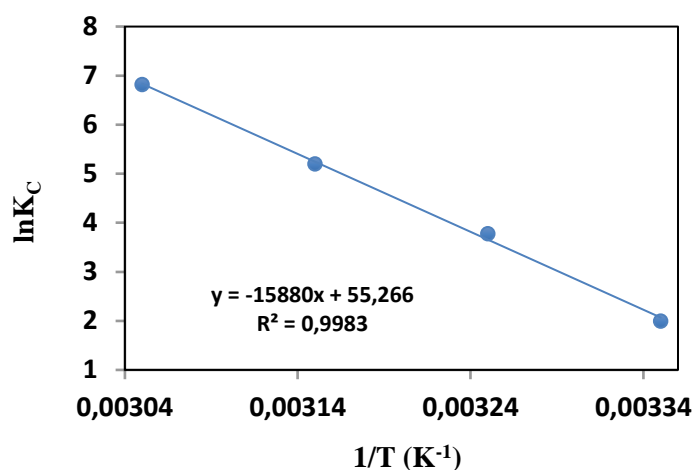


Figure 9. Determination of enthalpies and entropies of chromium (VI) adsorption by cassava

Table 3. Thermodynamic parameters of Cr(VI) adsorption by cassava

T (K)	K _C	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (kJ/mol.K)	E _a (kJ/mol)
298	7.38	-4.950			
308	90.01	-11.523			
318	181.27	-13.747	132	0.46	1.36
328	665.15	-17.725			

3.9 Study of Cr (VI) elimination by UV-visible spectroscopy

There was a decrease in the absorbance peak at 350 nm, corresponding to a decrease in chromium VI concentration. From the beginning of the process from until 30 min, we observed an increase in the peak of the absorption 260 nm, which attests to an increase in the level of chromium III ions in the medium before being reduced. This shows that cassava reduces Cr(VI) to Cr (III) before absorbing it (Jobby 2018). However, after 90 min, our solution became completely discolored, which is consistent with the effective elimination of chromium in all its forms (Figure 10).

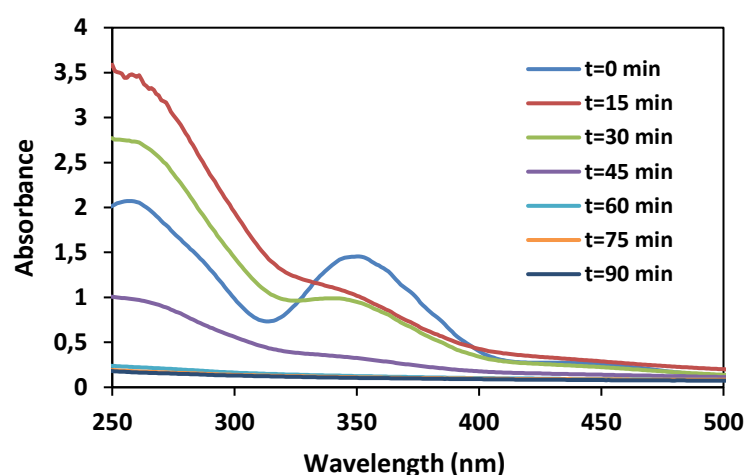


Figure 10. UV-visible Absorption spectra of chromium in contact with cassava powder

The calibration line for chromium in aqueous media shows a linear increase in absorbance as a function of concentration, with a correlation coefficient very close to unity (0.997). Thus, using the Beer-

Lambert formula and the absorption spectra given in [Figure 10](#), we were able to estimate the concentrations of Cr(VI) remaining in solution at different contact times. [Table 4](#) shows that, under optimal conditions, 145 mg/L of Cr(VI) can be eliminated up to 99.93% after 90 minutes of contact with the cassava powder.

Table 4. Summary of the optical density of chromium Cr(VI) as a function of contact time at 350 nm

Contact time (min)	Absorbance	Cr (VI) concentration (mg/L)	% Removal
0	1.456	145	0
15	0.951	95	34.5
30	0.944	94	35.2
45	0.325	32	77.9
75	0.007	0.7	99.5
90	0.001	0.1	99.9

3.10 Characterization of the adsorbent

3.10.1 Analysis by FTIR spectroscopy

Analysis of the FTIR spectra of cassava before and after chromium adsorption revealed changes and the appearance of new vibrational frequency bands in the functional groups ([Figure 11](#)). The shift in adsorption peaks from 3289 cm^{-1} to 3305 cm^{-1} indicates the presence of free and water-bound hydroxide groups (O-H), from 2928 cm^{-1} to 2931 cm^{-1} corresponds to C-H vibrations, and the peaks around 1336 cm^{-1} attest to the presence of the C-O group, the stretch noted from 1076 cm^{-1} to 1073 cm^{-1} is due to the -OCH functional group. The bands between 998 cm^{-1} and 850 cm^{-1} determine the vibration of the -C-O-C- group, confirms the cellulose content in the cassava powder ([Nagarajan 2020](#)). This means that the cellulose contained in cassava enables chromium (VI) to be bound ([Ling 2021](#)). In addition, we recorded a broadening of certain band peaks: at 1418 cm^{-1} we have a weak band attributed to the -N=N- group, at 1203 cm^{-1} corresponds to a C-OH alcohol elongation, at 922 cm^{-1} , and at 767 cm^{-1} indicates the Ctri-H aromatic group. All these vibrations confirm the adsorption of chromium by cassava powder.

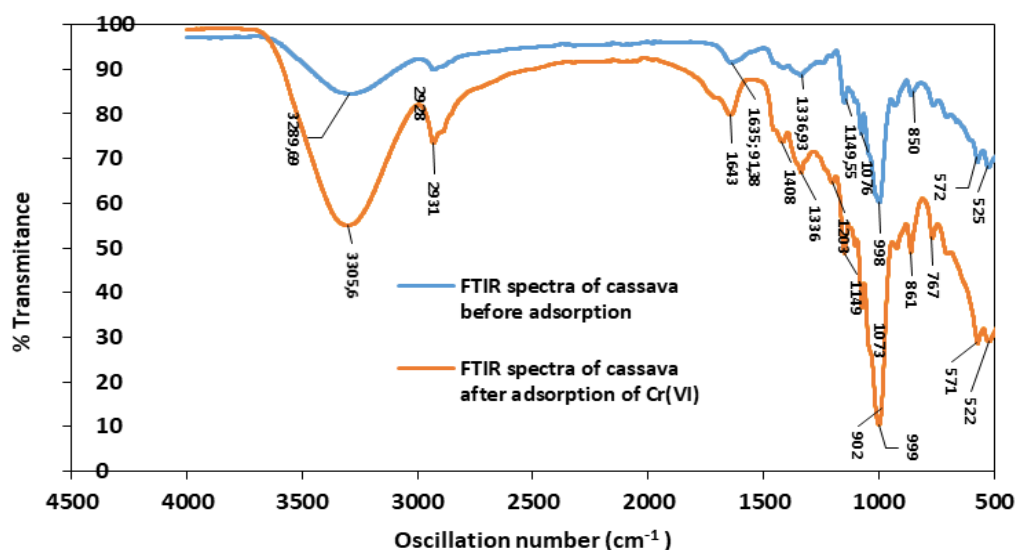


Figure 11. FTIR spectra of cassava powder before and after adsorption of Cr(VI) ions

3.10.2 SEM and EDS analysis

The surface morphology of the cassava powder before and after chromium (VI) adsorption (**Figure 11**) shows a clear difference between the two structures. The configuration of the cassava powder before adsorption (**Figure 11a**) reveals micropores on the surface, giving it a rough appearance (**Ling 2021**). After contact with Cr(VI), the surface texture of the cassava powder is smooth, attesting to significant particle fixation (**Figure 12b**) due to Van Der Waals forces. It can be said that the adsorption of chromium by cassava is governed by the phenomenon of physisorption. These results are in phase with the analysis of the EDS spectra, before (**Figure 12c**) and after (**Figure 12d**), showing the retention of Cr(VI) by cassava, which explains the change in morphology of the sorbent surface. The use of cassava as a bio-absorbent is of vital importance because of its ability to retain the sulphur in the sulphuric acid used to adjust the pH. All these results clearly illustrate that cassava is a safe bet for eliminating chromium from aqueous media, as is activated carbon from cassava sludge (**Ling 2021**). In addition to this, the study of infrared spectra before and after adsorption reinforces our results with a profound change in the FTIR spectra by a change and the appearance of new bands. Comparing the SEM-EDS with other previous results (**Villabona 2023, Li. Anyu 2020**) shows the morphological change in the sorbent surface, confirming the effective removal of Cr(VI) by adsorption.

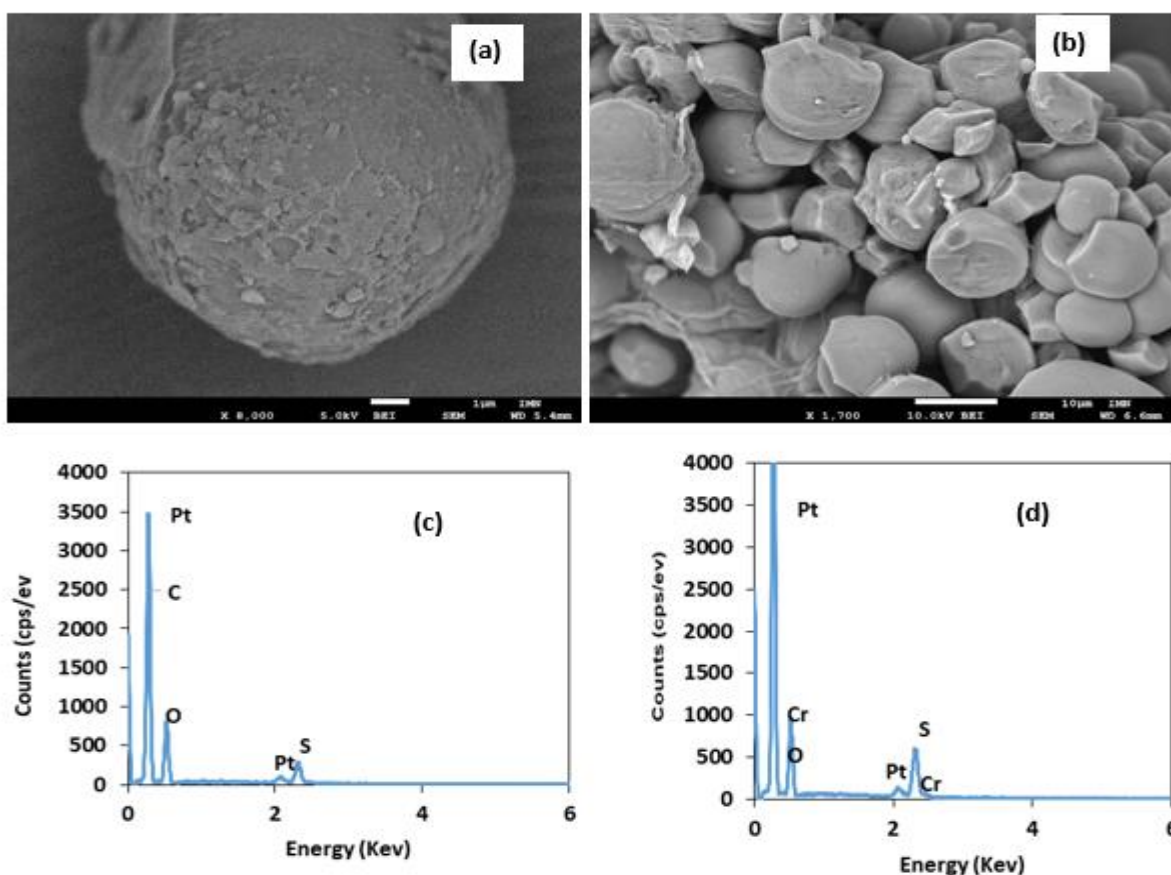


Figure 12. (a) and (b): SEM micrographs, (c) and (d): Energy-dispersive X-ray spectroscopy (EDS) spectra of MKP before and after adsorption of Cr(VI) (0.8 mg/L)

Conclusion

Chromium pollution of water is a major environmental concern because of its harmful effects on human health and aquatic ecosystems. In particular, the presence of hexavalent chromium (Cr(VI)), a highly toxic form, is often associated with various industrial activities such as metallurgy, waste treatment

and other chemical processes. The use of cassava powder as a biomaterial offers a promising approach to eliminate chromium from contaminated water, with a rate of 99.96%. Cassava acts by trapping chromium through physical adsorption or by facilitating biological processes such as the microbial reduction of Cr(VI) to Cr(III), in a less toxic form, thereby limiting the harmful impact on human health and the environment. Cassava thus offers advantages such as availability, low energy cost and eco-compatibility. However, the judicious use of cassava powder opens up an encouraging avenue for reducing chromium pollution of water and preventing any further release into the environment.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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