Removal of Nitrate Ions from Aqueous Media by Filtration and Coagulation Techniques Using Mangosteen Powder as a Bioabsorbent

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Abstract: Water contamination by nitrates is a significant environmental and health issue. With the aim of developing sustainable and economical treatment methods, this study explores the use of mango kernel powder as a natural biosorbent for the removal of nitrates in aqueous solution. Filtration technique was used to evaluate the physical and chemical retention capacity of nitrates by the powder, while coagulation process promoted particle aggregation and separation from the medium by sedimentation. These methods exploit the adsorbent properties of the powder which is rich in active functional groups capable of interacting with nitrate ions. The effectiveness of the treatment was monitored using a UV-Visible spectrophotometer, by measuring the absorbance at wavelengths characteristic of nitrate ions (272 to 300 nm). The decrease in absorbance after treatment indicates an almost total reduction in nitrate concentration. The results showed that several parameters influence the effectiveness of the process, including the pH of the solution, the dose of biosorbent, the contact time, and the initial nitrate concentration. The best performance was observed at a slightly acidic pH and for an optimal dose of powder (40mg). This approach recycles agri-food waste while offering an environmentally friendly solution for the treatment of nitrate-contaminated water.

Keywords*: Filtration, Coagulation, Mango Seed Powder, Water, Spectrophotometer, Nitrate Removal.*

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I. INTRODUCTION

Today, water resources (surface water, groundwater) are facing all kinds of pollution from industrial, agricultural (pesticides), cosmetic, textile and pharmaceutical sources [1]. Nitrate pollution, meanwhile, has a significant impact on the environment and living organisms. Studies have shown that some of these micropollutants can be retained or degraded in conventional wastewater treatment plants (WWTPs) [2].

Many studies have been developed almost everywhere in the world using filters erected for wastewater treatment. There are 8,000 such facilities in the United States and 50,000 in Germany [3][4]. This is what makes these treatment systems popular and the subject of intense research in Europe at the moment [5]. The removal of nitrate ions from water is an important concern because of its implications for drinking water quality and environmental health. High NO_3^- concentrations in water can have adverse effects on human health, including methaemoglobinaemia, often referred to as 'blue baby syndrome'. Filtration is a highly effective technique for removing BOD (biochemical oxygen demand), TSS (total suspended solids) and for significant denitrification of wastewater [6]. Given the high number, there is heavy use of these filters in Europe and the United States, while their use in developing countries remains low. This is probably due to limited resources in these countries,

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despite the significant presence of raw materials in the manufacture of these filters.

To enhance water treatment efficiency while minimizing environmental impact, novel treatment approaches employing bio-based materials are increasingly being developed [7]. In this study, mango shell powder was investigated as a sustainable adsorbent for the removal of nitrate contaminants from selected natural water sources. The results obtained demonstrate a high level of effectiveness, with removal efficiencies reaching up to 99%, which are in strong agreement with values reported in the literature.

II. MATERIALS AND METHODS

➢ *Preparation of the Solution*

The preparation of the nitrate solution requires distilled water and potassium nitrate (KNO_3). Nitrate can be present in water in low concentrations, even trace amounts. In this study, a high concentration of 0.23 M was used to better test the effectiveness of mango nut powder in removing nitrate from water. For this, 5.8075 g of KNO_3 with a purity of 99% was weighed using a precision balance and dissolved in distilled water (250 mL final volume).

➢ *Preparation of Mango Powder*

Mangoes belong to the Anacardiaceae family and their scientific name is Mangifera indica. To our knowledge, only the mango fruit is consumed, and the shell is discarded immediately afterwards. The different stages in the preparation of mango shell powder are shown in Figure 1.

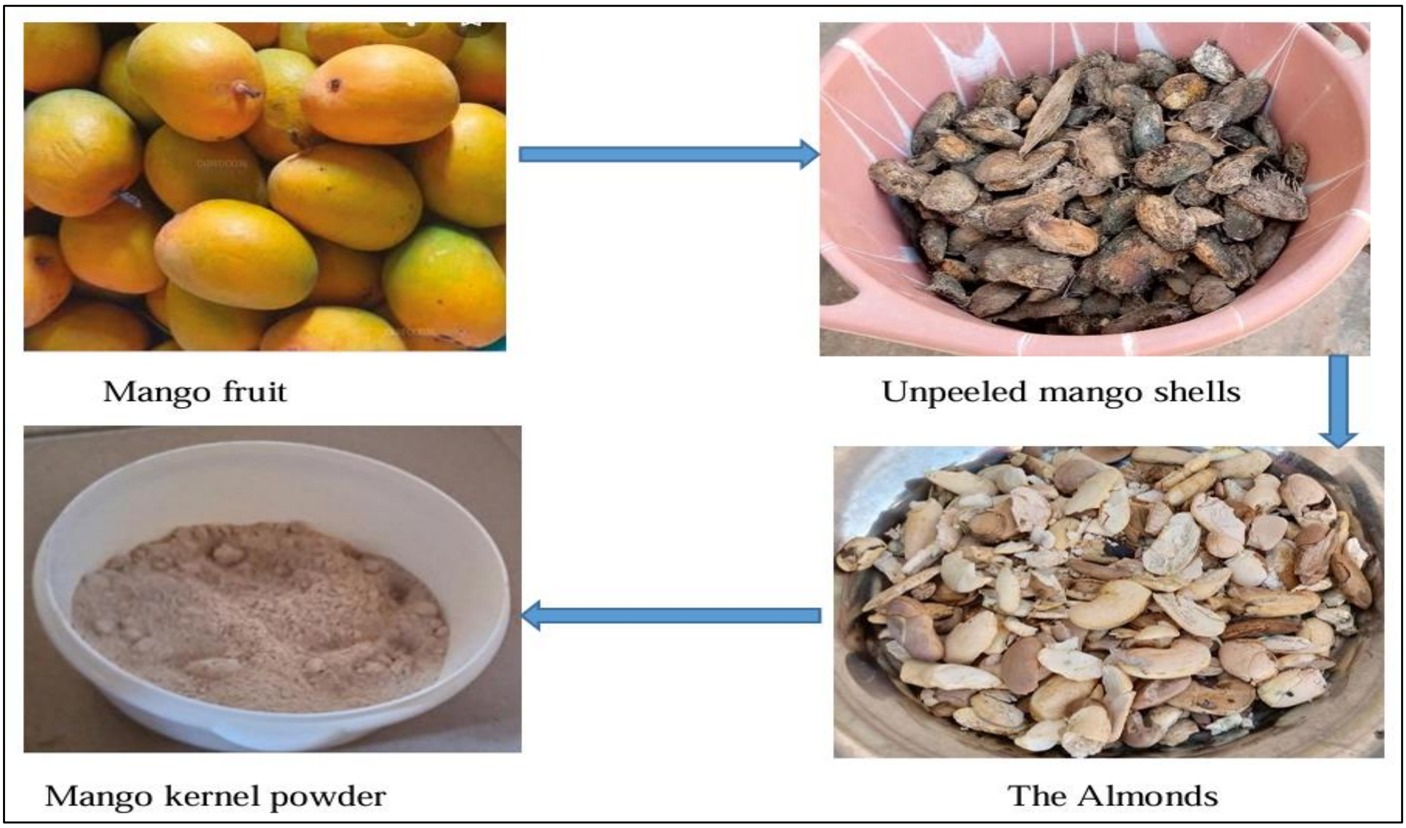

Fig 1 The Steps Involved in Preparing Mango Powder.

➢ *Method*

The experimental equipment used in this protocol consists of filters made from plastic bottles, as shown in Figure 2, which describes the experimental setup.

To carry out this work, For this experiment, we approached each step with care to ensure reliable results. We began by placing a piece of filter paper at the bottom of each filter, creating a stable base. Mango powder was then carefully added up to the marked gauge line and gently tamped down to form a compact layer. To complete the setup, another sheet of filter paper was placed on top, neatly encasing the mango powder.

To investigate the effect of the layer's thickness, we varied the amount of mango powder in different filters. Into each prepared filter, 10 mL of nitrate solution was poured, and the filtrate that passed through was collected in a beaker. Using a micropipette, each filtrate was transferred into a quartz cuvette for measurement with a UV-Visible spectrophotometer at 300 nm. Whenever absorbance was still observed, the mango layer was increased by 2 cm, and the process was repeated until the filtrate showed no further absorbance.

This approach allowed us to carefully monitor the filtration and adsorption process, ensuring that each

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measurement reflected the true effect of the mango powder layer on nitrate removal.

Fig 2 Experimental Setup.

To carry out this work, we prepared solutions at various concentrations (10, 25, 40, 55, 70, 85 and 100 mg/L) of NO_3^- by dissolving KNO_3 (99%) in distilled water. Then, different masses (20, 40 and 60 mg) of mango kernel powder were weighed. Finally, 100 mL of each solution was taken using a beaker and one of the previously weighed quantities was added. The mixture was placed on a magnetic stirrer to mix thoroughly before being left to stand for 24 hours at an ambient temperature of 25°C and a pH of 7.

The samples were analysed to determine the nitrate concentration in the filtrate using a UV-visible spectrophotometer (Thermo Scientific GENESYS 10S series, France).

The pH was measured using a WTW PH 3310 COMPLETE WITH SENTIX 41 (SET 2) portable pH meter. The aggregates formed during adsorption were characterised using a Fourier transform infrared (FTIR) spectrophotometer (Perkin Elmer, France), 8,300-350 cm^{-1}, resolution 0.4 cm^{-1}) by monitoring the evolution of the band intensity; This allows us to understand the coagulation mechanism and, potentially, the sites occupied.

III. RESULTS AND DISCUSSION

A. Removal of nitrate by filtration

➢ *Analytical Procedures*

First, distilled water was passed through the filter containing the mango powder, and then the absorbance of our solution was measured directly. We obtained the results shown in Figure 3.

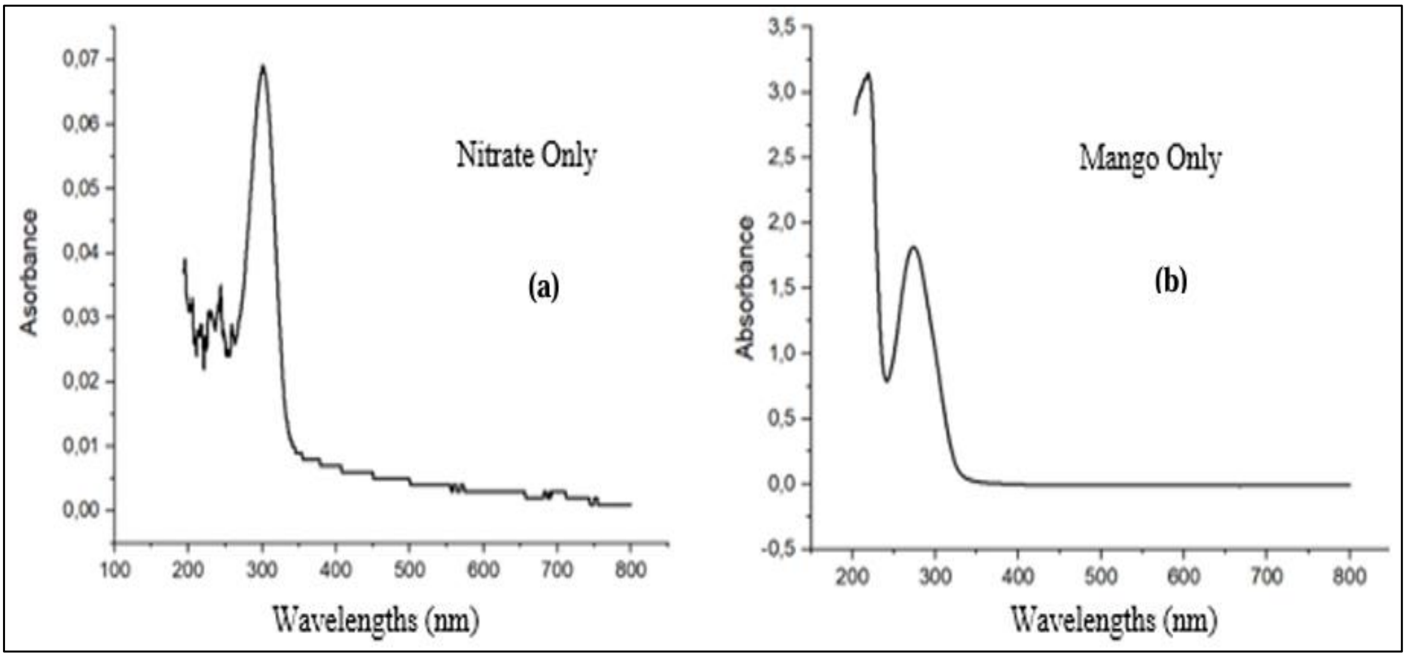

Fig 3 The Absorption Spectra of Nitrate Alone (a) and Mango Alone (b).

We note that the spectrum of mango and nitrate solutions exhibit peaks at 265 and 300 nm, respectively. These two wavelengths are close, and mango has a high absorbance due to its chromophores. The bands are assigned to n-π* transitions through the molecules [8]. To remove the chromophores responsible for this high absorption of the mango powder, the powder was kept in distilled water for 24 hours, then the solution was filtered to recover the powder, which was then sun-dried. The dried powder was washed again with distilled water, and the peak corresponding to the absorbance of the mango disappears completely from the spectrum (almost zero absorbance), confirming the disappearance of the chromophores, as shown in Figure 4.

We then could filter our nitrate solution through the filter made from mango nut powder.

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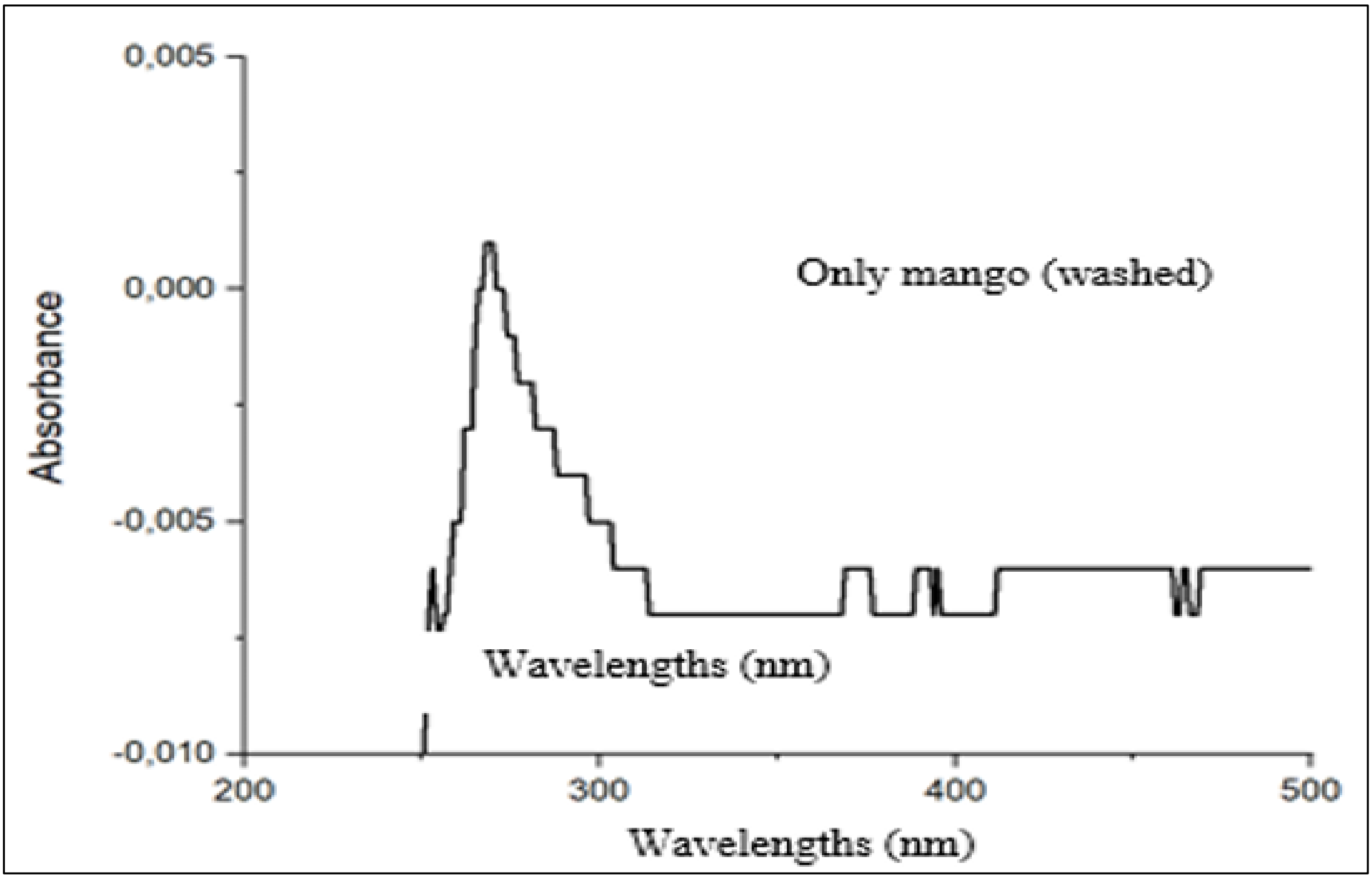
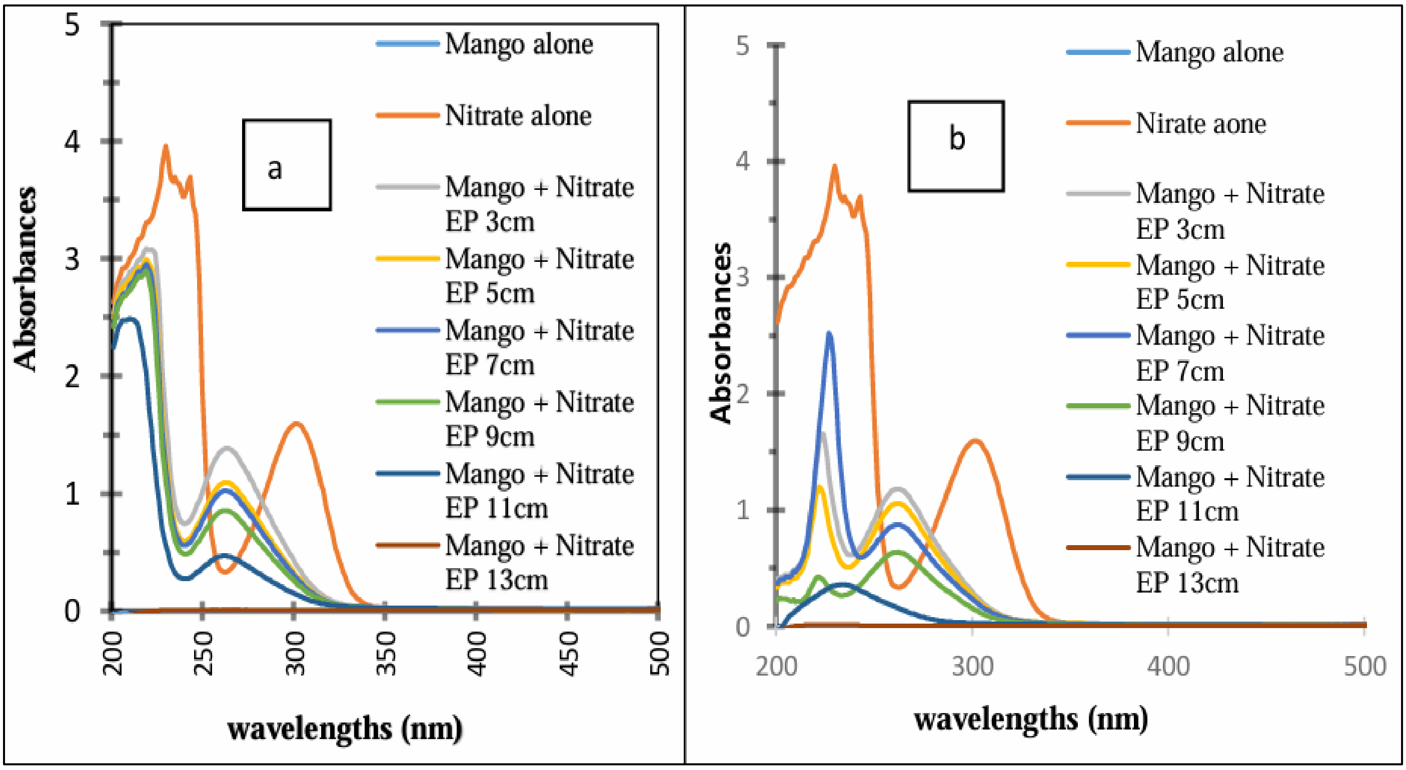


Fig 4 The Absorption Spectrum of Washed Mango.

➢ *Filter Optimization*

We began by pouring the nitrate solution into the filter which had a 3 cm layer of mango powder. We measured the absorbance and, if there is a peak, added another filter to increase the layer thickness by 2 cm, and so on until the peak disappears. To verify the effectiveness of our filter, we repeated the experiment three times (experiments a, b and c). The results are presented in Figures 5.



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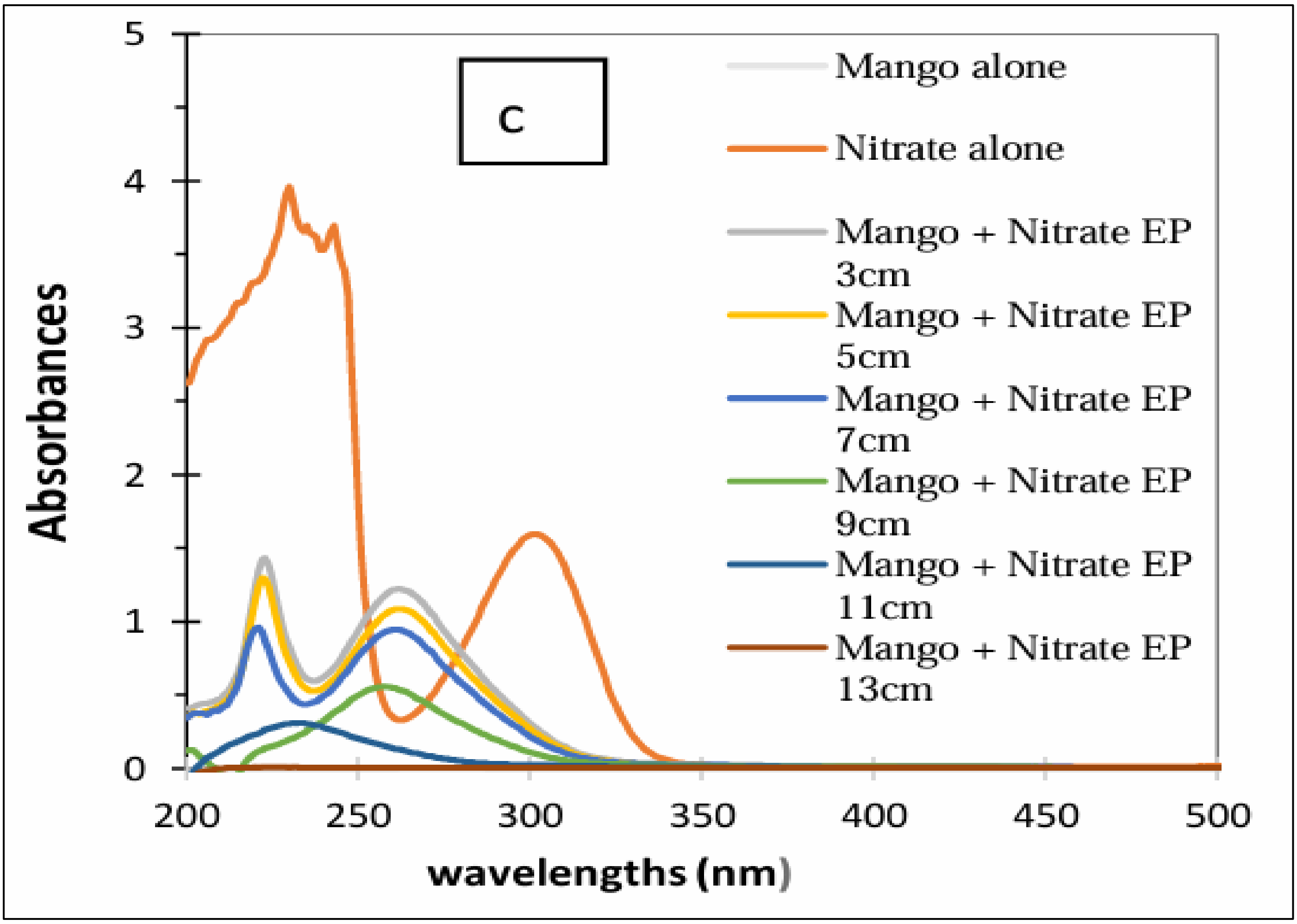

Fig 5 UV Spectra of Nitrate with Mango in Experiments a, b, and c.

Fig.5 shows a gradual decrease of the nitrate peak intensity. Thus, we can say that mango nut powder helps retain nitrate in an aqueous medium.

We observe a gradual decrease in the peak intensity, initially attributed to nitrate at 300 nm with a hypsochromic shift to 272 nm as the thickness of the mango layer increases.

This shift of the peak assigned to the n –π* transition band from 300 nm to 265 nm confirms the disappearance of nitrate, either through retention by the filter (absorption) or through combination with other molecules present in the mango powder. However, by carefully examining the spectra obtained from the three experiments, we can assume that the nitrate ion combined with the mango residue responsible for its absorption at 265 nm, thus causing an increase in optical density. In any case, we can see that this peak disappears as the thickness of the filter increases. Several authors have used mango fruit in water treatment. For example, Nur Shahzaiwa Wafa Shahimi [9, 10] used it to clarify turbid water resulting from a mixture of river water and kaolin. On the other hand, Ullah and Rathnasiri [11] showed effective removal of 96%, 89% and 97% of suspended solids (SS), COD and color, respectively, from palm oil effluent using mango. These results once again demonstrate the importance of mango and its usefulness in the treatment and purification of contaminated water.

➢ *Study of Filter Dispersion*

From a chemical point of view, dispersions are characterized by the exchanges and reactions that take place between the surfaces of the particles and the liquid medium that disperses them. As the surface area is enormous, these exchanges or reactions are very efficient. The mean and standard deviation of the absorbance are calculated for each [9] thickness during the three experiments. The standard deviation is the quadratic mean of the deviations from the mean. According to Table 1, we can say that the greater the thickness of the mango layer, the less dispersive our filter is, resulting in zero absorbance at a thickness of 13 cm. This almost zero dispersion is synonymous with almost total nitrate removal.

The mean and standard deviation are given by the following formulas.

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{i=n} X_i \qquad (1)$$

$$\sigma = \sqrt{\frac{\sum(X_i - \overline{X})^2}{n-1}} \qquad (2)$$

Table 1 Summary of means and standard deviations.

Thickness (cm)	Manip1 (Absorbances)	Manip2 (Absorbances)	Manip3 (Absorbances)	Average $\overline{X}$	Standard deviation σ
3	1.380	1.164	1.203	1.2490	0.115
5	1.009	1.008	1.009	1.0080	0.014
7	0.567	0.555	0.560	0.5600	0.014
9	0.022	0.020	0.020	0.0200	0.004
11	0.010	0.010	0.009	0.0095	0.003
13	0.009	0.09	0.008	0.0087	

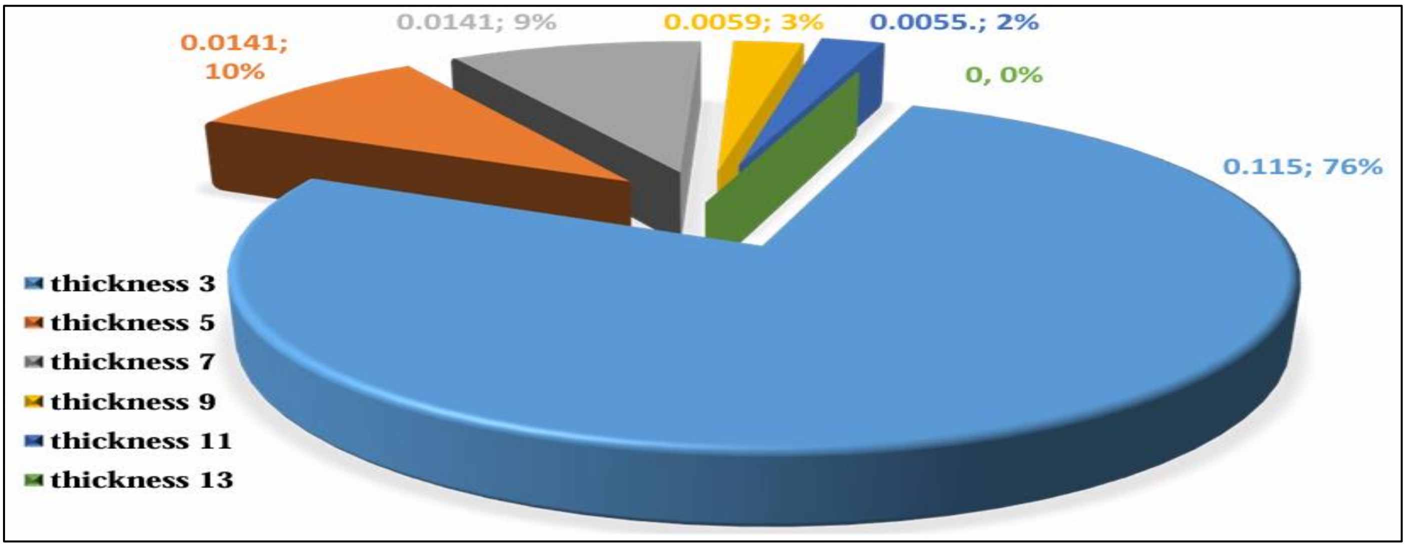

Fig 6 Sector Diagram of Standard Deviations as a Function of Thickness.

Analysis of this diagram (Figure 6) clearly shows that at a thickness of 13 cm, there is almost 0% nitrate in the filtrate, resulting in zero dispersivity. This result is consistent with other previous research results using the filtration method to remove nitrate from water [10, 11].

To better understand these results, we performed calibration by preparing different solutions with precise concentrations in order to measure their absorbance and then plot the calibration curve (Figure 7).

Table 2 Data for Calibration.

Concentration in mol/ L	0	0.001	0.010		0.100	0.150	0.200	0.250	0.300
Absorbance	0	0.001	0.058		0.670	1.060	1.400	1.690	2.080

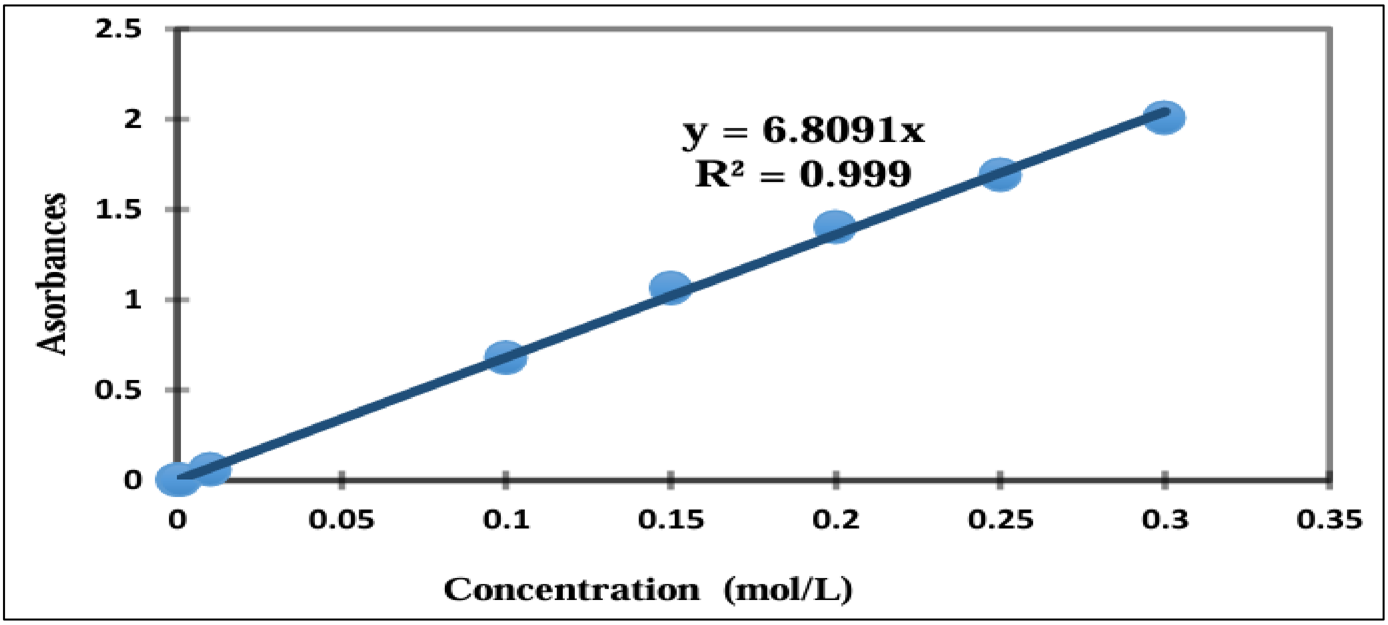

Fig 7 Nitrate Calibration Curve.

Fig.7 shows a linearity of the absorbance vs. nitrate concentration, which is in accordance with the Beer-Lambert formula. With this calibration curve, we were able to estimate the nitrate concentrations in solution after filtration. Also shows a linear decrease with concentration as a function of thickness, with a correlation coefficient very close to unity (0.999). This allows us to make an informed choice about the thickness of the filter for an estimated nitrate concentration.

Table 3 Summary of Nitrate Optical Density as a Function of Filter Thickness (Manip. 1)

Filter thickness (in cm)	Wavelength (nm)	Absorbance	C (mol/L)
0	300	1.585	0.230
3	265	1.371	0.200
5	265	1.009	0.160
7	265	1,080	0.140
9	265	0.800	0.110
11	265	0.460	0.060
13	265	0.007	0.001

Table 4 Summary of Nitrate Optical Density as a Function of Filter Thickness (Manip. 2).

Filter thickness (in cm)	Wavelength (nm)	Absorbance	C (mol/L)
0	300	1.580	0.230
3	265	1.170	0.170
5	265	1.030	0.150
7	265	0.860	0.120
9	265	0.600	0.090
11	265	0.120	0.010
13	265	0.004	0.000

Table 5 Summary of Nitrate Optical Density as a Function of Filter Thickness (Manip. 3).

Filter thickness (in cm)	Wavelength (nm)	Absorbance	C (mol/L)
0	300	1.580	0.230
3	265	1.200	0.170
5	265	0.900	0.130
7	265	0.800	0,110
9	265	0.500	0.070
11	265	0.110	0.010
13	265	0.004	0.000

- *Relative Standard Deviation (RSD %)*

We have a concentration of nitrate water on the calibration curve in these solutions where nitrate is present in large quantities, for example 0.25 M, and pass it through the spectrophotometer to measure the absorbance. We repeat the experiment three times during the day and record the results in Table 6.

Table 6 Data for Calculating Deviation

Experiment	**1**	**2**	**3**
Absorbance	**1.725**	**1.627**	**1.693**

The standard deviation is given by the following formula:

$$\text{DSR}(\%) = \frac{\sigma}{A_{moy}} \times 100 \qquad (3)$$

According to the calculations, we find:

$A_{moy} = 1.681$

$\sigma = 0.05$

DSR = 2.97%

We have a DSR that is less than 10%, which meets the standards, and the measurements are also repeatable.

- *Study of the Filter's Volume Capacity to Retain Nitrate*

At a thickness of 13 cm of mango powder in the filter, the nitrate peak in the filtrate disappears completely. Keeping the same filter, we continued to 10 mL of our solution repeatedly until the filter no longer absorbs the nitrate, i.e. until a new peak appears (Figure 8).

The appearance of this new peak at 300 nm confirms the presence of nitrate in the filtrate, hence the degradation of the filter if the volume of solution poured is 170 mL.

Table 7 Filter Optimization Data

Volume poured in mL	Absorbances in nm
10	0
20	0
30	0
40	0
50	0
60	0
70	0
80	0
90	0
100	0
110	0
120	0
130	0
140	0
150	0
160	0
170	0.004
180	0.006
190	0.476
200	1.538

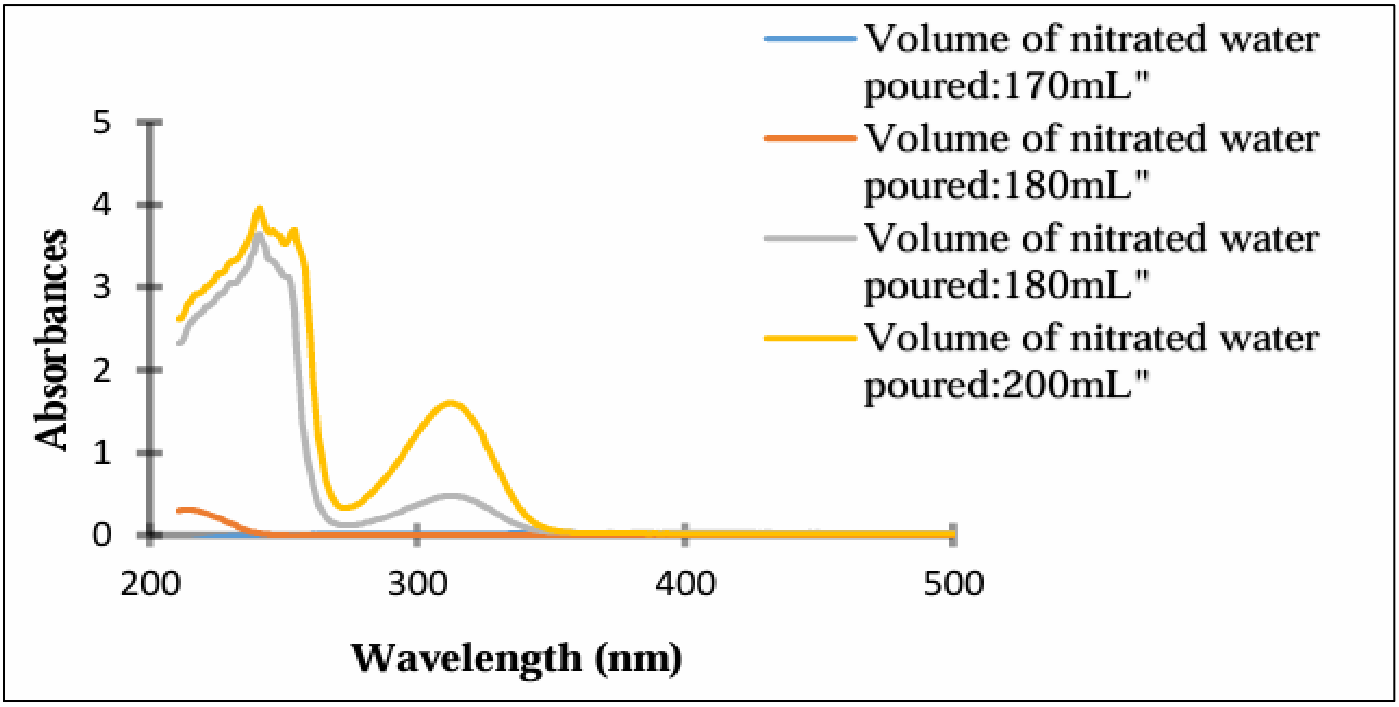

Fig 8 UV Spectra of Nitrate after Filtration with Mango Kernel Powder.

B. Nitrate Removal by Coagulation

The use of biomaterials in the coagulation process is an interesting approach to reducing nitrate levels in water [13]. Coagulation is a process whereby fine particles suspended in water are grouped together to form larger aggregates, thereby facilitating their removal. The use of biomaterials, such as plant extracts, agricultural residues or natural materials, as coagulants can offer several advantages [14 ,15]. Nitrate coagulation obeys two mechanisms [16].

- *Spectroscopic Analysis of Results*

Aggregate formation and coagulation, where nitrates are included in the aggregates formed by the biomaterial and these aggregates are heavier than water, thus facilitating their sedimentation or separation. The aggregates formed are separated from the water, thus removing nitrates from the environment.

- *Spectroscopic Analysis of Results*

Analysis of the histograms (Figure 9) shows the effectiveness of mango kernel powder, in removing nitrate ions from water. We observe that for a dose of 40 mg, we have the highest denitrification rate, and for a given dose of coagulant, the higher the initial nitrate concentration, the lower the removal rate (Figure 10). The results reveal that with a dose of 40 mg, we have a nitrate removal rate of 99.9%

for an initial concentration of 95 mg/L, which is higher than WHO standards (50 mg/L in the form of NO_3^-) [17]. The effectiveness of mango kernel powder is demonstrated by a removal rate of 99.9%. In summary, it can be concluded that the nitrate removal rate increases with the mass of the biocoagulant [18].

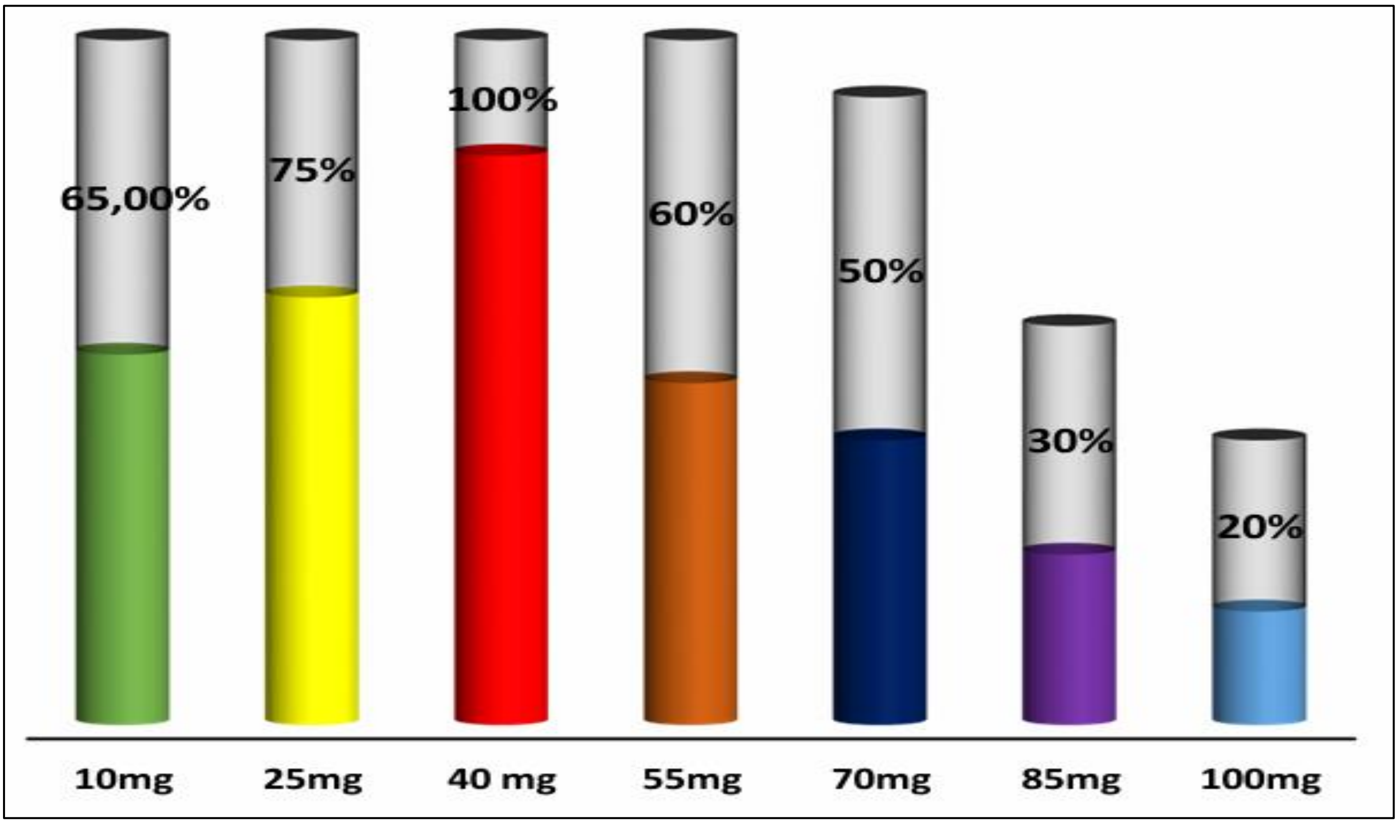

Fig 9 Change in Nitrate Removal Rate as a Function of Initial Nitrate Concentration and Coagulant Dose.

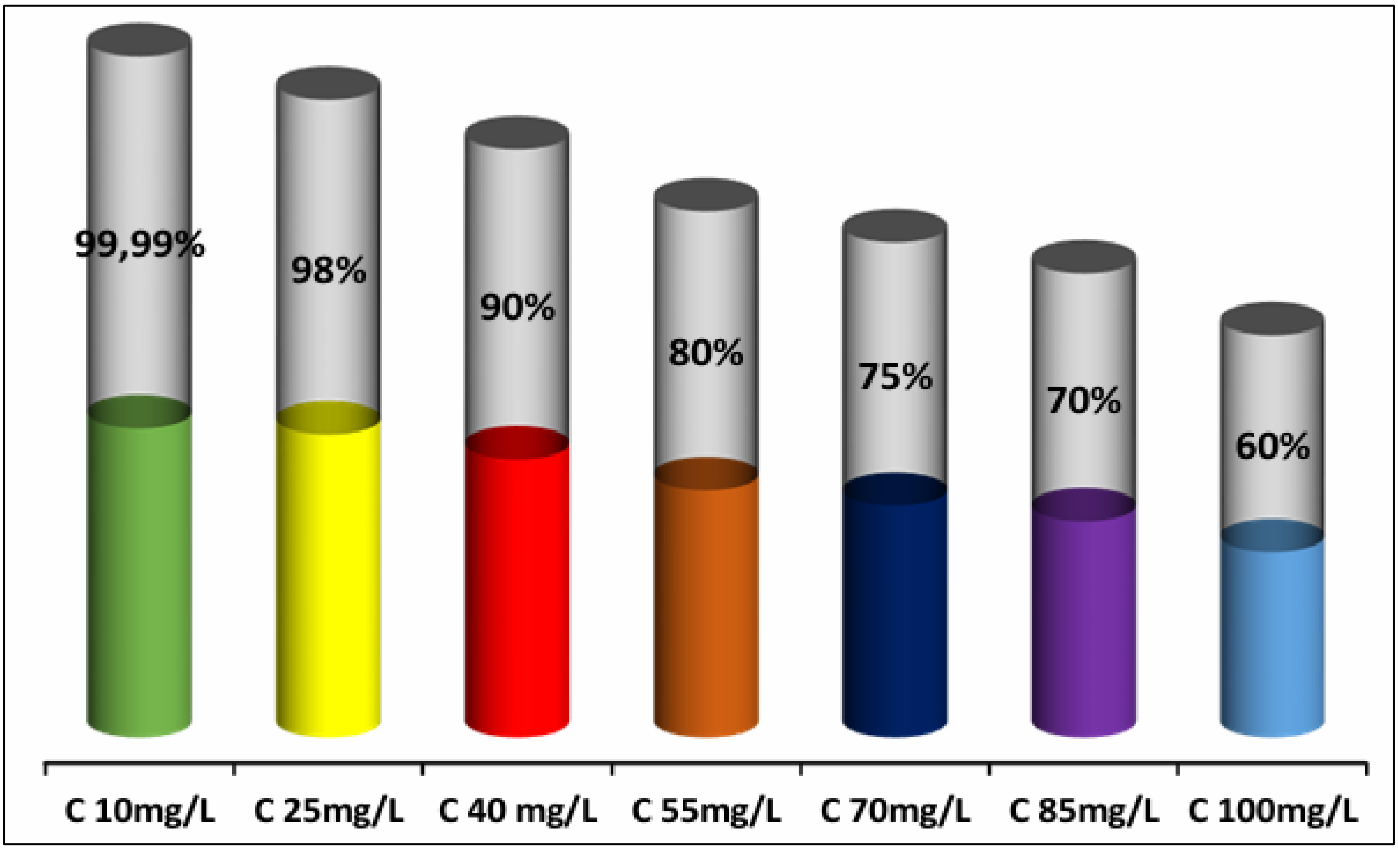

Fig 10 Evolution of the Nitrate Removal Rate as a Function of the Initial Nitrate Concentration for a Coagulant Dose set at 40 mg.

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➢ *pH Effect of Coagulation*

We note that, in addition to the mass of the biocoagulant, pH is an essential parameter for evaluating the effectiveness of the coagulation process using mango kernel powder in removing nitrate from aqueous media. The nitrate removal rate is highest (between 90 and 99.9%) at a pH between 3 and 5 (Figure 11), and decreases sharply to a minimum of 10% at a pH of 10. These results are consistent with those of previous studies[19][20].

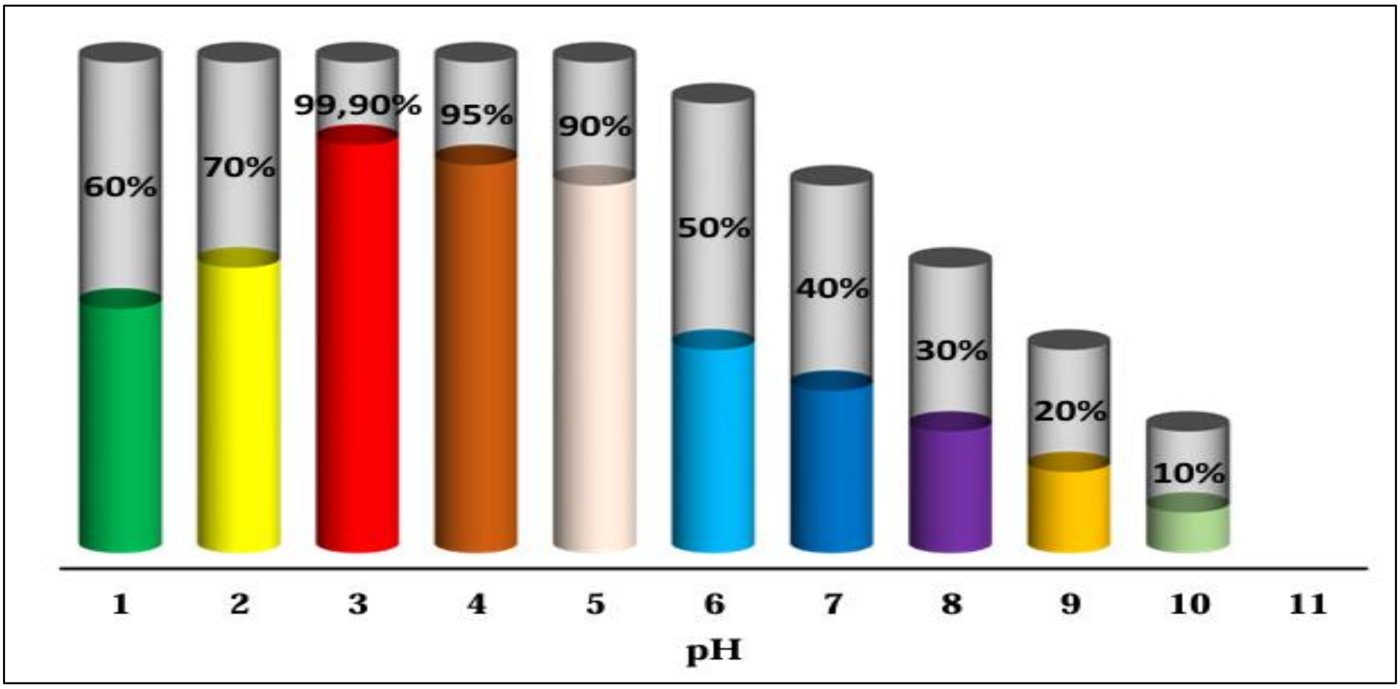

Fig 11 The Effect of pH on the Rate of Nitrate Ion Removal.

➢ *FTIR Spectroscopy Characterization of the Coagulants*

Analysis of FTIR spectra of mango kernel powder and its coagulate after coagulation in a nitrified aqueous medium revealed changes and the appearance of new vibrational frequency bands in the functional groups. The broadening of the band at a frequency of 3275 cm^{-1} indicates the presence of free and bonded hydroxide (O-H) groups.

We note a narrowing of the peak at a frequency of 2914 cm^{-1} corresponding to the tetrahedral carbon functional group bonded to hydrogen (H-Ctét) with a weak band. The peaks at frequencies 1597 cm^{-1} and 1638 cm^{-1} indicate the presence of functional groups of an aromatic carbon bonded to a nitrogen atom (C=N). The medium bands at absorption frequencies of 1335 cm^{-1} and 1019 cm^{-1} show the presence of nitrate (NO_3^-). This allows us to confirm that mango kernel powder is indeed capable of removing nitrate in an aqueous medium by coagulation (with a removal rate of 99.99%) (Figure 12). Compared to other biocoagulants such as aluminium (87%) and ferric chloride (77%) ‖[21], mango kernel powder has a major advantage for water denitrification given the multiplicity of its fixation sites.

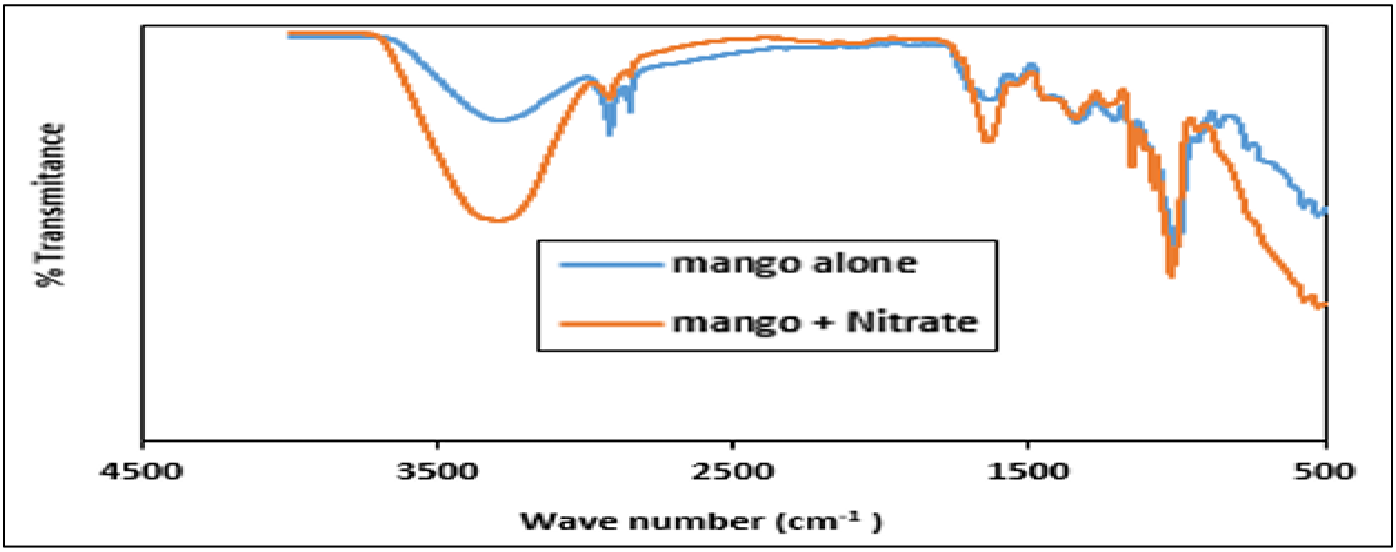

Fig 12 FTIR Spectrum of Mango Kernel Powder before and after Coagulation.

IV. CONCLUSION

The removal of nitrates from aqueous media using mango kernel powder combined with filtration and coagulation techniques offers a promising approach to treating this type of pollution. Filtration traps nitrates and other contaminants present in the water, ensuring effective removal through physical retention. This method has the advantage of being simple, inexpensive and environmentally friendly, as it does not involve the use of chemicals. Coagulation, on the other hand, offers a complementary approach by promoting the aggregation of nitrate particles dispersed in water, forming flocs that can be easily removed by sedimentation or subsequent filtration.

By combining these two approaches (coagulation + filtration), it is possible to achieve synergistic results for more effective removal of nitrates from water using mango kernel powder. This integrated method offers additional benefits such as improved treatment performance, reduced operating costs and a smaller environmental footprint compared to conventional techniques. However, it is important to note that the appropriate selection of biomaterials, the design of treatment systems, and continuous monitoring of water quality are essential to ensure the effectiveness and sustainability of this decontamination process. Further research and pilot studies are needed to refine these techniques and adapt them to the specific conditions of each nitrate-contaminated water treatment site.

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