Chemistry Extended Essay

"Investigating the chelating effect of different fruit peels such as pomegranate, lemon and orange on the calcium, magnesium, copper, zinc and lead ions in water that is determined by complexometric titration with EDTA (Ethylene diamine tetraacetic acid)"

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1. **Research Question:**

What is the chelating effect of different fruit peels such as pomegranate, lemon and orange on the calcium, magnesium, copper, zinc and lead ions in water that is determined by complexometric titration with EDTA?

2. **Introduction:**

The quality of water is significant to human health, agriculture and the industrial processes since it is directly influenced by the level of dissolved metal ions. Calcium and magnesium contribute to water hardness which determines domestic and industrial use. The trace metals like copper and zinc are vital in biological functions in very low concentrations but are toxic in high concentrations. Conversely, some of the heavy metals such as lead can be very toxic in small quantities since, when accumulated in the body, they present a significant health hazard to both the health of the human and the environment. That is why it is necessary to monitor the levels of metal-ions in water.

Industrial activities are also important in building the economy, yet their wastes are usually loaded with heavy metals that pollute water and land posing threat to the environment and food safety. Prolonged exposure to such contaminants has been linked with detrimental effects to both the human being and the animals. In turn, this raises the concern in the stability and environmental friendliness of sustainable techniques of metal ions removal in water.

Agricultural waste products are under the recent examination as a source of biosorbent. Pomegranate, lemon, orange fruit peels, are usually thrown away yet they have organic acids, polyphenols and functional groups that can bind metal ions. An investigation on their performance as bio-sorbents offers a greener method of purifying water besides value addition to agricultural wastes. In this study, the quantity of calcium, magnesium, copper, zinc, and lead ions was determined by EDTA complexometric titration, and thus, the efficacy of fruit peel biosorption was measured, and thus, analytical chemistry was connected to the environmental domain.

3. **Background Research**

   a. **Complexometric Titration**

Complexometric titration is an analytical technique used to determine metal-ion concentrations in solution using EDTA. Individual EDTA molecules have four carboxylate groups and 2 amine groups that can bind both to a metal ion, creating a very stable chelate ring.

Ethylenediaminetetraacetic acid (EDTA) is an aminocarboxylic acid.

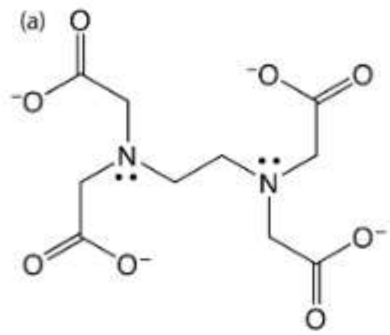

Figure 1: Structures of EDTA in its fully depronated form

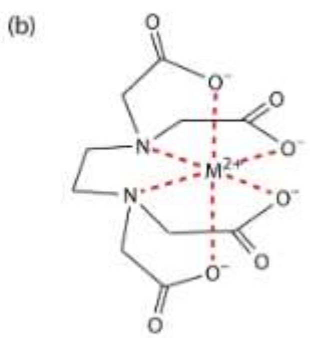

Figure 2: Six Coordinate metal EDTA complex with a divalent metal ion

Buffer solutions are used in complexometric titrations to maintain a constant pH, allowing selective determination of metal ions using appropriate indicators.

Lead and zinc can be quantitatively determined by EDTA titration at acidic pH using xylenol orange as an indicator

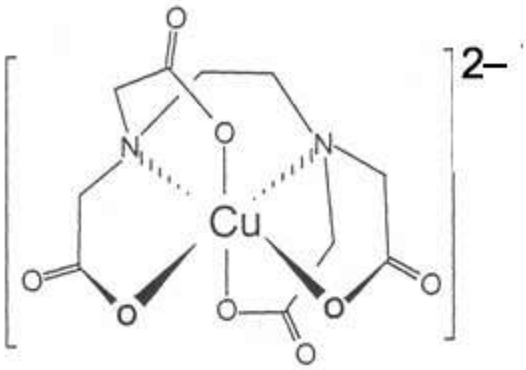

Figure 3: Structure of Cu^{2+} - EDTA dianion

Copper is determined by EDTA using murexide as an indicator. The bonding to the copper ion is nearly octahedral.

$$Cu^{2+} (aq) + (EDTA)_2 (aq) \rightarrow Cu(EDTA)_2 (aq) + 2H^+ (aq)$$

b. Lewis Acids, Ligands, and Chelating Agents

According to Lewis acid–base theory, a Lewis acid is an electron-pair acceptor, while a Lewis base is an electron-pair donor. Metal ions such as Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+}, and Pb^{2+} act as Lewis acids because they possess vacant orbitals capable of accepting electron pairs. In contrast, molecules or ions that donate lone pairs of electrons to metal ions are known as ligands and function as Lewis bases.

A chelating agent is a special type of ligand that contains multiple donor atoms and can bind to a single metal ion at several coordination sites simultaneously, forming a ring-like structure called a chelate. Chelating agents form more stable complexes than monodentate ligands due to the chelate effect, which increases complex stability both entropically and energetically.

EDTA is a hexadentate chelating agent which is a strong Lewis base, and which donates four carboxylate Oxygen atoms and two nitrogen atoms of its structure. This enables the EDTA to establish very stable 1:1 complex with a broad spectrum of divalent metal ions and therefore it is best applicable to complexometric titration and quantitative analysis.

On the same note, peels of fruits, which are employed in the current study, have functional groups including carboxyl ($–COO^-$), hydroxyl (–OH), and phenolic groups that can also be Lewis bases. These groups make the peels bind metal ions in coordination, ion exchange or chelation. Thus, EDTA titration and biosorption with fruit peels are based on the same underlying Lewis acid-base interactions, which make them highly theoretically justified to combine analytical chemistry with the research of biosorption in the given study.

Though in titration EDTA is the chelating agent, the fruit peels are the biosorbents that supply sites of ligands and not the chelating agents.

c. Ions being investigated

The ions under study were chosen due to their occurrence of the essential minerals as well as toxic pollutants that are frequently present in natural and industrial water systems, and also exhibit varying chemical behaviours that are important in biosorption and complexation.

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are alkaline earth metal, which contribute to the hardness of water. Even though this is not normally toxic at typical concentrations, when in large quantities, it leads to scaling of pipes, low efficiency of the soap, and difficulties in the operation of domestic and industrial systems. They are worth comparing with transition and heavy metals because of their relatively less strong ability to form stable complexes.

Copper (Cu^{2+}) and zinc (Zn^{2+}) are vital trace elements, involved in enzymatic and metabolic processes; however, they are toxic to humans and aquatic organisms when they occur above recommended amounts. These ions chemically create stronger coordination complexes than Ca^{2+} and Mg^{2+}, and are therefore ideal in investigating selective biosorption.

Lead (Pb^{2+}) is a poisonous heavy metal with no known biological role. At extremely low concentrations, it is found to build up in the organism and is linked to neurological damage and long-term source beyond the environment. Pb^{2+} has a high affinity for organic ligands specifically, thus is very useful in assessing biosorbent with high functional group densities like polyphenols.

These ions usually find their way into water systems due to agricultural runoffs, industrial effluents and corrosion of pipes, thus it is important to monitor and establish sustainable ways for their removal.

d. Role of Fruit Peels in Metal Ion Absorption

The developments in green chemistry focus on the use of agricultural wastes as inexpensive adsorbents in heavy metals. Fruits that have peels like pomegranate, lemon, and orange are abundant in compounds that include lignin, cellulose, hemicellulose, pectin, and polyphenols. They have functional groups (–OH, -COOH, - NH_2 and aromatic rings) which can react with metal ions in terms of ion exchange, electrostatic attraction, complexation and chelation.

The tannin and polyphenol content of pomegranate peel is high and therefore, the peel is especially useful in the binding of heavy metals such as Pb^{2+}.

The peels of lemon and oranges contain a high amount of citric acid and pectin, which contain a large number of carboxyl groups that chelate metal.

Applying the fruit peels is a solution to two issues that are normally faced together: it is a cheap way of treating water and also offers a way of minimizing the amount of organic waste.

Besides, biosorption has some benefits over traditional methods of chemical precipitation or a filtration using activated carbon due to its environmental friendliness and its renewability.

e. Integration of EDTA Titration and Biosorption Studies

The conflunce of analytical chemistry and environmental remediation is the amount of such natural biosorbent required to measure the quality of the effectiveness of metal ions bioremediation. EDTA titration is an easy to obtain and indicate an accurate measure of the starting and ending concentration of the Ca^{+2}, Mg^{+2}, Cu^{+2}, Zn^{+2} and Pb^{+2} in untreated and treated water with the addition of fruit peels. This allows determining the efficiency of adsorption, determining percent removal, and comparing the effectiveness of various types of peels relative to each other.

The method also leads to the wider scope of water quality monitoring and sustainable solutions to pollution. These practices are in line with the Sustainable Development Goals of the United Nations (SDGs) in Goal 6 (Clean Water and Sanitation) and Goal 12 (Responsible Consumption and Production).

$$Removal\ efficiency\ (\%) = \frac{C_{initial} - C_{final}}{C_{initial}} \times 100$$

4. Hypothesis

When fruit peels, pomegranate, lemon, and orange have functional groups that can bind metal ions, then when treated with aqueous solutions of calcium, magnesium, copper, zinc and lead, the concentration of the ions will be altered by the presence of the fruit peels, where the concentration of the ions will decrease with the presence of the fruit peels, as revealed by EDTA complexometric titration.

5. Variables

Type of Variable	Variable	Method of Controlling/Measuring Variable
Independent	Type of fruit peel (pomegranate, lemon, orange)	Selecting and preparing each type of peel under identical conditions
Dependent	Final Concentration of Metal ions (Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+}, Pb^{2+}) in solution	Measure using EDTA complexometric titration by recording the volume of EDTA required to reach the endpoint.
Control	Molarity of EDTA solution	Use the same standardized 0.01 mol dm^{-3} EDTA solution for all titrations.
	Volume of water sample	Measure exactly 300.00 cm^3 using a pipette for each trial.
	Type and pH of buffer solution	Use the same buffer solution at the required pH (pH 10 for Ca^{2+}/Mg^{2+}; appropriate acidic buffers for others).
	Type and amount of indicator	Add the same indicator in the same quantity (2–3 drops) for each titration.
	Mass and preparation of fruit peels	Weigh exactly 30 g of each peel and process them identically (washed, chopped).
	Contact/adsorption time	Keep the peels in contact with the water sample for a fixed duration (5 days).
	Volume of solutions mixed	Add the same volume of peel extract to 50 cm^3 of water sample in all experiments.
	Ambient temperature during titration	Conduct titrations at constant room temperature.
	Glassware and apparatus	Use the same burette, pipette, and flasks throughout to avoid systematic errors.

Table 1: Different types of variables in the experiment, the variable, and the method of controlling/measuring the variable

6. Chemicals and Apparatus

- Standard EDTA solution, nominal 0.0100 mol dm^{-3} (to be standardized).
- Metal-ion solutions or water samples containing Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+}, Pb^{2+} (prepare laboratory standards or use tap samples as required)
- Eriochrome Black T (EBT) indicator (for Ca^{2+} and Mg^{2+} titration).
- Murexide indicator (for Cu^{2+} titrations).
- Xylenol Orange indicator (for Zn^{2+} and Pb^{2+} titrations).
- Buffer solutions
- Distilled/deionized water
- Fruit peels: fresh pomegranate, lemon, orange (washed)
- Filter paper

7. Glassware / apparatus

- 25.00 cm^3 volumetric pipette (or 25.00 cm^3 calibrated pipette) (±0.05)
- 50 cm^3/ 100 cm^3 conical flasks or beakers
- 50 cm^3 burette (0.01 cm^3 readability) (±0.05) and burette stand
- Analytical balance (±0.01 g)
- Blender (lab blender or domestic high-speed)
- White paper
- Funnel, stirring rod, labelled waste containers

8. Safety Precautions

Appropriate laboratory safety measures were followed throughout the experiment. At all times, safety goggles, a lab coat and protective gloves were worn to minimise exposure to skin or eyes contact with EDTA, buffer solutions and metal-ion solutions. There was additional care during the handling of lead-containing solutions because of toxicity and contact with skin was avoided.

Titrations were also performed on a stable bench on a white tile to enhance the endpoint visibility and reduce the chances of spillage. Before using, glasswares were checked to ensure any crack was detected and the burette was clamped to avoid tipping. Immediately on spillages, the area was washed with water, and the broken glassware was placed in a sharps container.

Any waste solutions that had metal ion would not be emptied into the sink but instead put in labeled waste containers that would be disposed according to the laboratory requirements. The hands were washed properly after the practical work was carried out.

9. Environmental and Ethical Concerns

This exploration favors the aspect of sustainability as it uses fruit peels (pomegranate, lemon, and orange) which are otherwise waste materials in the agricultural sector. The application of these natural byproducts as biosorbent does not only minimize the pollution of the environment, but also value addition of waste products, which is in line with the principles of the green chemistry. It is more renewable and environmentally friendly and the by-products are minimal compared to regular chemical treatment or use of activated carbon filtration.

Ethically, the experiment does not involve any hazardous or non-biodegradable adsorbents, making it oriented towards the safe, natural ones. The disposal of solutions that contain heavy metal ions (including Pb^{2+}, Cu^{2+} and Zn^{2+}) as improper disposal may lead to environmental degradation. The labelled containers were used to collect all the waste solutions and then hand them over to the waste management company that was contracted by the school which is used to dispose the hazardous chemical waste safely and in a controlled manner. The research is also conducted in ethical research practices because it is accurate, honest in reporting findings, and respectful to environmental sustainability.

10. Methodology

Part I - Preparation of Metal Ion Solutions

1. Five 1.00 dm^3 volumetric flasks were labelled Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+} and Pb^{2+}. Distilled water was used throughout.
2. For each metal salt, the required mass was calculated using

$$m = C \times V \times M_r$$

where C=0.100 mol dm^{-3} and V=1.00 dm^3.
3. The calculated mass was weighed using an analytical balance (±0.01 g).
4. Each salt was dissolved in ~200 cm^3 distilled water in a volumetric flask.
5. Distilled water was added to the calibration mark (meniscus read at eye level).
6. Flasks were topped, turned up and down a few times to make them homogeneous and labelled with ion, concentration, and date.
7. Uncertainties in apparatus: balance ±0.01 g**;** 1.00 dm^3 tolerance of a volumetric flask as indicated by the manufacturer.

Part II - Preparation of Fruit Peel Samples

8. The pomegranate, lemon and orange peels were washed, rinsed with distilled water and dried using paper towels.
9. A laboratory blender was used to mix the peels until a homogenous particle size was achieved.
10. The samples of peel prepared were kept in clean and closed containers in order to avoid absorption of moisture.

Part III – Setting Up Biosorption Experiments

11. Fifteen 500 cm^3 beakers labeled with metal ion and peel type (5 metal ions×3 peel = 15 samples).
12. Each beaker was filled with 300.0 cm^3 of the corresponding 0.100 mol dm^{-3} metal-ion solution.
13. Weighed 30.0 g of the proper blended fruit peel (pomegranate, lemon or orange) by an analytical balance (±0.01 g) and placed in each beaker.
14. Parafilm was used to seal all the beakers to reduce evaporation and contamination
15. Samples were stored in a cool and shaded place and allowed to rest in a 120-hours (5 days) to allow the process of biosorption to establish equilibrium.

Part IV – Seperation of Peels from Treated Solutions

16. 120 hour later, all the mixtures were filtered through filter paper and funnel to get the fruit peels and fruit solutions respectively.
17. The clean containers were used to gather the filtrates to be titrated later.

Part V-EDTA Complexometric Titration

General Burette Preparation

1. The burette was rinsed with small quantities of 0.01000 mol dm^{-3} EDTA in order to condition the burette and avoid dilution.
2. EDTA was added to the burette at a position above 0.00 cm^3. To empty the air bubbles, the stopcock was opened a few times and the tip of the stopcock was filled.
3. A reading was taken on the initial burette by reading the bottom of the meniscus at eye level at a white background. The readings were noted down to the nearest 0.01 cm^3 (burette uncertainty ±0.05 cm^3).
4. A standerdized 0.01000 mol dm^{-3} EDTA solution was used as the titrant for all titrations.

Calcium (Ca^{+2}) Titration

1. A 10.00 cm^3 aliquot of the filtered sample was transferred into an Erlenmeyer flask using a volumetric pipette.
2. 40 cm^3 distilled water was added to allow effective mixing.
3. 10 cm^3 of pH 10 buffer was added to maintain optimal conditions for Ca–EDTA complex formation.
4. 2–4 drops of Eriochrome Black T (EBT) indicator were added, turning the solution wine red.
5. The solution was titrated with EDTA while swirling continuously. Near the endpoint, EDTA was added dropwise until the colour changed sharply from wine red to pure blue and persisted for at least 30 seconds.
6. The final burette reading was recorded and the EDTA volume used was calculated.

Magnesium (Mg^{2+})

1. Using a volumetric pipette, 10.00 cm^3 of the filtered magnesium sample was transferred into an Erlenmeyer flask and diluted with 40 cm^3 distilled water.
2. 10 cm^3 of pH 10 buffer solution was added to maintain optimal conditions for Mg^{2+}–EDTA complex formation.
3. 4–6 drops of Eriochrome Black T (EBT) indicator were added, producing a wine-red solution.
4. The burette, previously rinsed and filled with 0.01000 mol dm^{-3} EDTA, was used to titrate the solution while swirling continuously.
5. Near the endpoint, EDTA was added dropwise until a permanent colour change from wine red to blue persisted for approximately 30 seconds.
6. The final burette reading was recorded, and the Mg^{2+} concentration was calculated using the 1:1 EDTA–metal stoichiometry. The titration was repeated until three concordant titres were obtained.

Copper (Cu^{2+}) Titration

1. Using a volumetric pipette, 10.00 cm^3 of the filtered copper-containing sample was transferred into an Erlenmeyer flask and diluted with 40 cm^3 distilled water.
2. Acetate buffer (pH 5) 20 cm^3 was put to prepare the proper conditions of the formation of the Cu^{2+}-EDTA complex.
3. 1-2 drops of murexide indicator were put in and a purple-coloured solution was obtained.
4. The solution was titrated with the burette that had been rinsed and filled with 0.01000 mol dm^{-3} EDTA stirred constantly.
5. Towards the endpoint, EDTA was added in dropwise intervals till the colour turned to blue-violet and kept its position after about 30 seconds.
6. The last burette value was documented, and the concentration of Cu^{2+} was determined based on the 1:1 EDTA metal stoichiometry. Titration was done again until three concordant titres were achieved.

Zinc (Zn^{2+}) Titration

1. With a volumetric pipette, 10.00 cm^3 of the filtered sample containing zinc was transferred into an Erlenmeyer flask and the sample is diluted with 40 cm^3 of distilled water.
2. Acetate buffer (pH 5) 25 cm^3 was used to ensure the required pH.
3. 2-3 drops xylenol orange indicator were added, giving a reddish-orange solution.
4. A conditioned burette containing 0.01000 mol dm^{-3} EDTA was used to titrate the solution while swirling.
5. The amount of EDTA was added dropwise towards the endpoint until the colour that appeared changed to yellow and lasted about 30 seconds.
6. The last burette reading was noted and the 1:1 EDTA to metal stoichiometry was used to determine the concentration of Zn^{2+}. Until three concordant titres were obtained the titration was repeated again.

Lead (Pb^{2+}) Titration

1. A 10.00 cm^3 of the filtered lead-containing sample was transferred into an Erlenmeyer flask using a volumetric pipette and diluted with 40 cm^3 distilled water.
2. The appropriate conditions were maintained by adding 20 cm^3 acetate buffer (pH 5).
3. 2-3 drops of xylenol orange indicator were added, producing a reddish-orange solution.
4. A conditioned burette containing 0.01000 mol dm^{-3} EDTA was used to titrate the solution while swirling.
5. The amount of EDTA was added dropwise towards the endpoint until the colour that appeared changed to yellow and lasted about 30 seconds.

6. The final burette reading was recorded, and the concentration of Pb^{2+} was determined by the stoichiometry of 1:1 EDTA metals. The titration was repeated until three concordant titres were obtained.

11. Results

a. Qualitative Data

After 120-hour biosorption period, clear differences in colour of the metal solutions with the fruit peel solutions were observed, which showed the interactions between the metal ions and the biosorbent materials. Solutions treated with pomegranate peel resulted with a deep red colour, which became darker with progression of time, and this may be related to the release of anthocyanins and polyphenolic compounds. These compounds may enhance metal–ligand interactions and contribute to increased adsorption.

Conversely, the solutions that were treated with lemon and orange peels had a light yellow colour following the same period of contact. Such a weaker pigmentation could be accounted by the fact that citric acid, flavonoids, and pectin that also react with metal ions, but have not as intense a coloration as pomegranate peel do.

The treated solutions were found to be clearer than the original metal-ion solutions after filtration which indicated that some dissolved metal ions were removed. The greatest change was observed in copper-bearing samples, in which the typical blue colour of the Cu^{2+} solutions faded considerably. Solutions in which the zinc, calcium and magnesium concentrations were high were mostly colourless, but some solutions showed mild turbidity, perhaps owing to the leftover organic content of the fruit peels.

b. Quantitative Data (Raw Data)

The quantitative data collected in this investigation consist of the volumes of standardized 0.01000 mol dm^{-3} EDTA solution required to reach the endpoint in complexometric titrations of treated metal-ion solutions. For each metal–fruit peel combination, a 10.00 cm^3 aliquot of the filtered solution was titrated after 120 hours of biosorption. Multiple trials were conducted to improve reliability, and all raw data are recorded below.

The volume of EDTA used is directly proportional to the amount of unadsorbed metal ions remaining in solution, due to the 1:1 stoichiometric relationship between EDTA and the metal ions.

Zinc (Zn^{+2})-EDTA Titration Volumes			
Peel Type	Run 1 (cm^3)	Run 2 (cm^3)	Run 3 (cm^3)
Orange	95	81	94
Lemon	90	92	92.5
Pomegranate	86	80	87

Table2: Zinc-Raw Data Table

Lead (Pb^{2+})-EDTA Titration Volumes			
Peel Type	Run 1 (cm^3)	Run 2 (cm^3)	Run 3 (cm^3)
Orange	83	79	79
Lemon	99	93	91
Pomegranate	99	95	97

Table 3: Lead-Raw Data Table

Copper (Cu^{+2})-EDTA Titration Volumes			
Peel Type	Run 1 (cm^3)	Run 2 (cm^3)	Run 3 (cm^3)
Orange	84	82	82
Lemon	76	73	75
Pomegranate	91	93	90

Table 4: Copper-Raw Data Table

Magnesium (Mg^{+2})-EDTA Titration Volumes			
Peel Type	Run 1 (cm^3)	Run 2 (cm^3)	Run 3 (cm^3)
Orange	97	96	92
Lemon	98	95	99
Pomegranate	100	98	96

Table 5: Magnesium-Raw Data Table

Calcium (Ca^{+2})-EDTA Titration Volumes			
Peel Type	Run 1 (cm^3)	Run 2 (cm^3)	Run 3 (cm^3)
Orange	75	79	73
Lemon	82	80	82
Pomegranate	50	56	56

Table 6: Calcium-Raw Data Table

c. Processed Data

The data obtained in the raw titration was then subjected to the calculation of the average volume of EDTA needed in all the metal-fruit peel combination. Mean EDTA volume is used to show the average quantity of metal ions that do not get attached to the biosorbent after the 120-hour period of biosorption. Each system was tested on a number of occasions to enhance the accuracy of the findings.

All the calculations were done using a standardized concentration of EDTA, 0.01000 mol dm^3, and 10.00 cm^3 of titrated sample. The processed data below were then utilized in the computation of the concentration and adsorption efficiency.

Metal Ion	Peel Type	Average EDTA Volumes for Each Metal-Peel System (cm^3)	$u(V_{EDTA})$(± cm^3)
Zn^{2+}	Orange	90.00	±0.14
	Lemon	91.50	±0.14
	Pomegranate	84.33	±0.14
Pb^{2+}	Orange	80.33	±0.14
	Lemon	94.33	±0.14
	Pomegranate	97.00	±0.14
Cu^{2+}	Orange	82.67	±0.14
	Lemon	74.67	±0.14
	Pomegranate	91.33	±0.14
Mg^{2+}	Orange	95.00	±0.14
	Lemon	97.33	±0.14
	Pomegranate	98.00	±0.14
Ca^{2+}	Orange	75.67	±0.14
	Lemon	81.33	±0.14
	Pomegranate	54.00	±0.14

Table 7: Average EDTA Volumes for Each Metal-Peel System

Root-sum-square:

$$u(V_{sum}) = \sqrt{(0.10)^2 + (0.10)^2} = 0.141 \approx 0.14\ cm^3$$

e. Sample Calculation

Determining the concentration of Zn^{2+} remaining in solution (Orange Peel Sample)

- Concentration of EDTA: C_{EDTA}= 0.01000 mol dm^{-3}
- Average EDTA volume for Zn^{2+}-orange: V_{EDTA}=90.00 cm^3 =0.09000 dm^3
- Aliquot (sample) volume titrated: V_{sample}=10.0 cm^3 =0.01000 dm^3

$$Zn^{2+} + EDTA^{4-} \rightarrow Zn - EDTA^{2-}$$

$$n_{EDTA} = C_{EDTA} \times V_{EDTA}$$

$$n_{EDTA} = (0.01000) \times (0.09000) = 9.00 \times 10^{-4} mol$$

Because the stoichiometric ratio is 1:1:

$$n_{Zn^{2+}} = n_{EDTA} = 9.00 \times 10^{-4} mol$$

$$[Zn^{2+}] = \frac{n_{Zn^{2+}}}{V_{sample}}$$

$$[Zn^{2+}] = 0.0900\ mol\ dm^{-3}$$

If the initial concentration of Zn^{2+} is C_0=0.100 $mol\ dm^{-3}$, then:

Initial moles of Zn^{2+}:

$$n_0 = C_0 \times V$$

$$n_0 = (0.100\ mol\ dm^{-3})(0.01000\ dm^3)$$

$$n_0 = 1.00 \times 10^{-3} mol$$

Final moles of Zn^{2+}:

$$n_f = C_f \times V$$

$$n_f = (0.0900\ mol\ dm^{-3})(0.01000\ dm^3)$$

$$n_f = 9.00 \times 10^{-4} mol$$

Percentage removal using moles:

$$\%\ Removal = \frac{n_0 - n_f}{n_0} \times 100$$

$$\%\ Removal = \frac{1.00 \times 10^{-3} - 9.00 \times 10^{-4}}{1.00 \times 10^{-3}} \times 100 = 10.0\%$$

The same percentage removal is obtained using moles because the sample volume remains constant, therefore concentration and number of moles are directly proportional.

Sample Uncertainty Calculation (Zn^{2+}-Orange Peel)

Uncertainty in final concentration arises mainly from uncertainties in EDTA volume, pipette volume, and burette reading.

EDTA volume uncertainty (burette):

$$u(V_{EDTA}) = \pm 0.05\ cm^3$$

Relative uncertainty in EDTA volume:

$$\frac{u(V_{EDTA})}{V_{EDTA}} = \frac{0.05}{90.00} = 5.56 \times 10^{-4}$$

Since concentration depends on volume:

$$\frac{u(C_f)}{C_f} = \frac{u(V_{EDTA})}{V_{EDTA}}$$

Therefore:

$$u(C_f) = C_f \times \frac{u(V_{EDTA})}{V_{EDTA}}$$

$$u(C_f) = 0.0900 \times 5.56 \times 10^{-4}$$

$$u(C_f) \approx \pm 3.1 \times 10^{-4}\ mol\ dm^{-3}$$

	Peel Type	Final Concentration	Percentage Removal	$u(C_f)$/ (mol dm^{-3})
Zn^{2+}	Orange	0.0900	10.0%	±0.00031
	Lemon	0.09150	8.5%	±0.00032
	Pomegranate	0.08533	15.7%	±0.00030
Pb^{2+}	Orange	0.08033	19.7%	±0.00028
	Lemon	0.09433	5.7%	±0.00033
	Pomegranate	0.09700	3.0%	±0.00035
Cu^{2+}	Orange	0.08267	17.3%	±0.00029
	Lemon	0.07467	25.3%	±0.00026
	Pomegranate	0.09133	8.7%	±0.00032
Mg^{2+}	Orange	0.09500	5.0%	±0.00037
	Lemon	0.09733	2.7%	±0.00039
	Pomegranate	0.09800	2.0%	±0.00034
Ca^{2+}	Orange	0.07567	24.3%	±0.00023
	Lemon	0.08133	18.7%	±0.00028
	Pomegranate	0.05400	46.0%	±0.00020

Table 8: Percentage Removal of Metal Ions

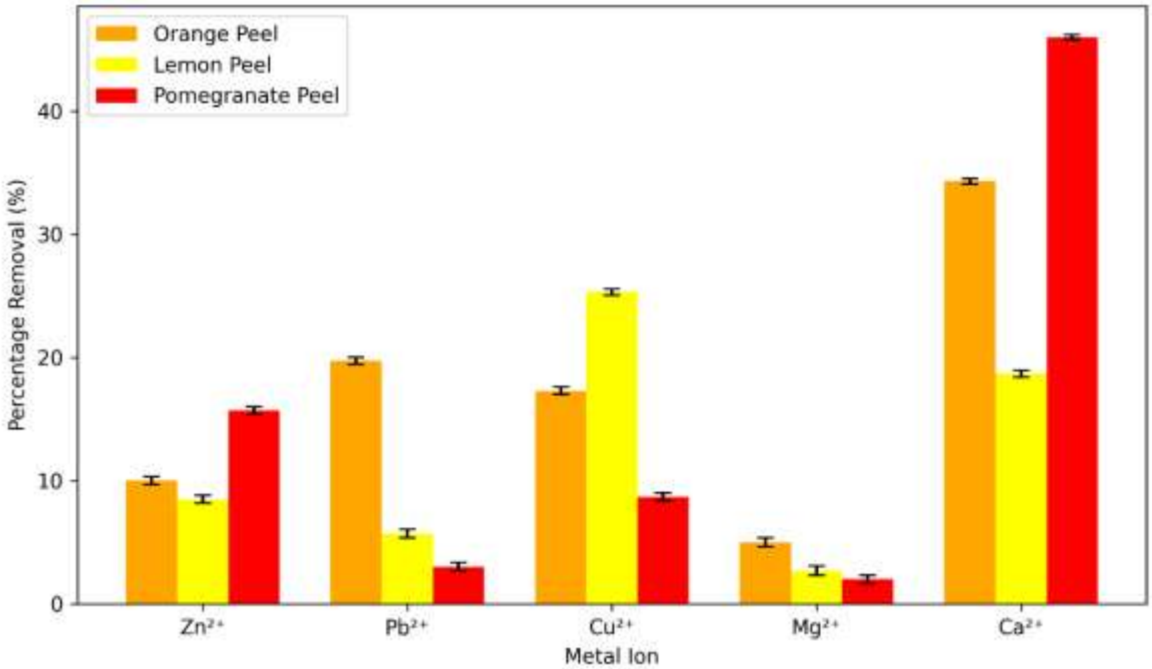

Figure 4: Comparison of percentage removal by fruit peel type (with error bars)

The grouped bar chart illustrates clear differences in metal-ion removal efficiency depending on the type of fruit peel used.

12. Conclusion

This investigation aimed at determining the ability of pomegranate, lemon, and orange peels in lowering concentrations of calcium, magnesium, copper, zinc, and lead ions content in aqueous solutions by EDTA complexometric titration. The results showed that three fruit peels could adsorb metal ions to different degrees, which validates their potential in use as cheap and biodegradable biosorbents.

The removal efficiency of the pomegranate peel was usually the highest especially in the case of the heavy metals like copper and zinc. As an example, pomegranate peel extracted up to 15.7% of Zn^{2+} and 46.0% of Ca^{2+}, which means that metal ions interact very well with the polyphenolic functional groups in the peel. The source of this behaviour is high content of polyphenols, tannin and other oxygen-containing functional groups which favour high levels of interaction between metals and ligands. Conversely, lemon and orange peels were more useful in extracting alkaline earth metals like calcium and magnesium, probably because they contained more pectin and citric acid, which can exchange ion on the carboxyl functional group.

Such difference in the removal efficiency indicates the significance of the chemical character of the metal ions and the stability of the complexes they create. Stability of metal-ligand complex is quantified by the complex formation constant (Kf) the equilibrium constant of complex formation of a metal ion with a ligand. Increased Kf values mean increased and more stable complexes. Cu^{2+} ($\log K_f \approx 18.8$) and Pb^{2+} ($\log K_f \approx 18.0$) are transition and heavy metal ions that are highly stable with the ligand (EDTA, functional groups contained in biosorbents). However, alkaline earth metals like Ca^{2+} ($\log K_f \approx 10.7$) and Mg^{2+} ($\log K_f \approx 8.7$) have weaker complexes and therefore lower adsorption efficiencies.

This trend is supported by the results of the experiment. Stronger complex formation constant metals like copper and zinc tended to have higher removal efficiencies than magnesium which demonstrated the lowest removal values in most types of peels. Calcium was more removed especially by pomegranate peel which could be owed to either a stronger interaction between the calcium and the functional groups of polyphenols. These tendencies have been observed in the earlier biosorbent researches in the use of fruit based adsorbents where polyphenol enriched substances were found to have a better adsorption capacity to transition metals and the heavy metals (Foo and Hameed, 2012).

Overall, the results show that fruit peels which are considered agricultural wastes can be highly applicable in sustainable water treatment. Also, the complexometric titration using EDTA was a valid analytical technique to track the changes in metal-ion concentrations and measure the efficiency of biosorption, which contributes to the implementation of the green chemistry concept in environmental and analytical chemistry.

13. Evaluation

The study successfully explored the use of fruit peels as natural biosorbent to determine whether it was effective to remove metal ions in aqueous solution. Nevertheless, like any experimental study, a number of constraints and error points were also noted that could have possibly affected the validity and credibility of the findings.

Even though uncertainties in regards to EDTA concentration, volumetric measurements, and mass measurements affected the obtained metal-ion concentration, these sources did not change the general tendencies. All samples were susceptible to systematic uncertainties, whereas random ones were reduced by repetition of titrations. Thus the relative findings on the effectiveness of various fruit peels remain valid.

a. Weaknesses

i. Systematic Errors

Source of Error	Effect on Data and Reliability	Improvement
Incomplete metal–EDTA complexation	EDTA complex formation is pH-dependent; slight deviations from the optimal pH may reduce complex formation, causing systematic underestimation or overestimation of metal-ion concentrations	Use appropriate buffer solutions and monitor pH carefully to maintain constant conditions during titration
Release of metal ions from fruit peels	Fruit peels may contain trace metals that leach into the solution, artificially increasing measured metal concentrations and producing lower or negative removal percentages	Pre-wash fruit peels thoroughly with distilled water before use to remove any loosely bound metal ions
Assumption of 1:1 stoichiometry for all metals	Although EDTA generally forms 1:1 complexes with divalent metal ions, slight variations in metal–ligand behaviour may introduce small systematic deviations in calculated concentrations	Verify stoichiometry through literature values and maintain controlled pH conditions to ensure stable EDTA complexes
Incomplete separation of fruit residues	Residual organic particles may interfere with the indicator colour change during titration, affecting endpoint detection and calculated concentrations	Filter the solutions carefully using fine filter paper and ensure complete removal of solid fruit residues before titration

ii. Random Errors

Source of Error	Effect on Data and Reliability	Improvement
Subjective color change detection	Small variation in endpoint determination, leading to minor difference between repeated titre volumes	Use a colorimeter or instrumental method to detect endpoints more objectively
Inconsistent mixing of solutions	Uneven distribution of metal ions, increasing uncertainty in measured concentrations	Stir solutions mechanically or for a fixed time before titration
Minor temperature fluctuations	Slight changes in reaction kinetics and EDTA complex stability, causing small variations in titre volumes	Perform titrations at constant room temperature
Measurement uncertainty in burette ($\pm 0.05\ cm^3$)	Small inaccuracies in EDTA volume readings, leading to slight deviations in calculated concentrations	Use a burette with lower uncertainty or digital burette
Use of volumetric pipette for aliquot transfer	Random variations in transferred sample volume due to meniscus reading	Use a micropipette to reduce volume-transfer uncertainty

b. Extension of Investigation

This study demonstrated that fruit peels may be used as useful biosorbents of metal ions; nevertheless, several supplementations may enhance knowledge and usability of the findings.

One extension would be to research of the influence of pH on the performance of adsorption on metal ions. Both EDTA complexation and biosorption are highly pH-dependent and therefore experiments at controllable pH would help in determining the optimal adsorption conditions and distinguish between surface-adsorption and solution based adsorption.

Another extension would be to investigate the adsorption capacity of fruit peels at various initial concentrations of metal ions. At varying concentrations, adsorption isotherms such as the Langmuir model or Freundlich model may be drawn and quantitative analysis of the maximum adsorption capacity and affinity to each biosorbent conducted.

Also, tests on reusability and regeneration of fruit peels could be conducted by desorption of metal ions using dilute acid or EDTA and reuse of the fruit peels in the subsequent adsorption cycle. This would give us a clue on the sustainability of the fruit peels in long term in treatment of water. Further studies would also compare the fruit peels to other agricultural waste products and surface analysis methods like FTIR or SEM might be adopted to affirm metal-biosorbent interactions.

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15. Appendix

A. Zinc(Zn^{2+})

Zn^{2+}-Lemon

Average V_{EDTA}=91.50 cm^3 = 0.09150 dm^3

$$n_{EDTA} = (0.01000)(0.09150) = 9.150 \times 10^{-4} mol$$

$$[Zn^{2+}] = \frac{9.150 \times 10^{-4}}{0.01000} = 0.09150\, mol\, dm^{-3}$$

Zn^{2+}-Pomegranate

Average V_{EDTA}=84.33 cm^3 =0.08433 dm^3

$$n_{EDTA} = (0.01000)(0.09150) = 9.150 \times 10^{-4} mol$$

$$[Zn^{2+}] = \frac{8.433 \times 10^{-4}}{0.01000} = 0.08433\, mol\, dm^{-3}$$

B. Lead (Pb^{2+})

Pb^{2+}-Orange

Average V_{EDTA}=80.33 cm^3 =0.08033 dm^3

$$n_{EDTA} = (0.01000)(0.08033) = 8.033 \times 10^{-4} mol$$

$$[Pb^{2+}] = \frac{8.033 \times 10^{-4}}{0.01000} = 0.08033\, mol\, dm^{-3}$$

Pb^{2+}-Lemon

Average V_{EDTA}=94.33 cm^3 =0.09433 dm^3

$$n_{EDTA} = (0.01000)(0.09433) = 9.433 \times 10^{-4} mol$$

$$[Pb^{2+}] = \frac{9.433 \times 10^{-4}}{0.01000} = 0.09433\ mol\ dm^{-3}$$

Pb^{2+}-Pomegranate

Average V_{EDTA}=97.00 cm^3 =0.09700 dm3

$$n_{EDTA} = (0.01000)(0.09700) = 9.700 \times 10^{-4} mol$$

$$[Pb^{2+}] = \frac{9.700 \times 10^{-4}}{0.01000} = 0.09700\ mol\ dm^{-3}$$

C. Copper (Cu^{2+})

Cu^{2+}-Orange

Average V_{EDTA}=82.67 cm^3 =0.08267 dm3

$$n_{EDTA} = (0.01000)(0.08267) = 8.267 \times 10^{-4} mol$$

$$[Cu^{2+}] = \frac{8.267 \times 10^{-4}}{0.01000} = 0.08267\ mol\ dm^{-3}$$

Cu^{2+}-Lemon

Average V_{EDTA}=74.67 cm^3 =0.07467 dm3

$$n_{EDTA} = (0.01000)(0.07467) = 7.467 \times 10^{-4} mol$$

$$[Cu^{2+}] = \frac{7.467 \times 10^{-4}}{0.01000} = 0.07467\ mol\ dm^{-3}$$

Cu^{+2}-Pomegranate

Average V_{EDTA}=91.33 cm^3 =0.09133 dm3

$$n_{EDTA} = (0.01000)(0.09133) = 9.133 \times 10^{-4} mol$$

$$[Cu^{2+}] = \frac{9.133 \times 10^{-4}}{0.01000} = 0.09133\ mol\ dm^{-3}$$

D. Magnesium (Mg^{2+})

Mg^{+2}-Orange

Average V_{EDTA}=95.00 cm^3 =0.09500 dm3

$$n_{EDTA} = (0.01000)(0.09500) = 9.500 \times 10^{-4} mol$$

$$[Mg^{2+}] = \frac{9.500 \times 10^{-4}}{0.01000} = 0.09500\ mol\ dm^{-3}$$

Mg^{+2}-Lemon

Average V_{EDTA}=97.33 cm^3 =0.09733 dm3

$$n_{EDTA} = (0.01000)(0.09733) = 9.7330 \times 10^{-4} mol$$

$$[Mg^{2+}] = \frac{9.7330 \times 10^{-4}}{0.01000} = 0.09733\ mol\ dm^{-3}$$

Mg^{+2}-Pomegranate

Average V_{EDTA}=98.00 cm^3 =0.09800 dm3

$$n_{EDTA} = (0.01000)(0.09800) = 9.800 \times 10^{-4} mol$$

$$[Mg^{2+}] = \frac{9.800 \times 10^{-4}}{0.01000} = 0.09800\ mol\ dm^{-3}$$

E. Calcium (Ca^{2+})

Ca^{+2}-Orange

Average V_{EDTA}=75.67 cm^3 =0.07567 dm^3

$$n_{EDTA} = (0.01000)(0.07567) = 7.567 \times 10^{-4} mol$$

$$[Ca^{2+}] = \frac{7.567 \times 10^{-4}}{0.01000} = 0.07567\ mol\ dm^{-3}$$

Ca^{+2}-Lemon

Average V_{EDTA}=81.33 cm^3 =0.08133 dm^3

$$n_{EDTA} = (0.01000)(0.08133) = 8.133 \times 10^{-4} mol$$

$$[Ca^{2+}] = \frac{8.133 \times 10^{-4}}{0.01000} = 0.08133\ mol\ dm^{-3}$$

Ca^{+2}-Pomegranate

Average V_{EDTA}=54.00 cm^3 =0.05400 dm^3

$$n_{EDTA} = (0.01000)(0.05400) = 5.400 \times 10^{-4} mol$$

$$[Ca^{2+}] = \frac{5.400 \times 10^{-4}}{0.01000} = 0.05400\ mol\ dm^{-3}$$