Assessing the Effect of Temperature on the Efficiency of Various Mucilaginous Powders in the Remediation of Heavy Metals in Freshwater Environments

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Abstract

With decreased accessibility to clean water, water treatment has become of utmost importance. Current aluminum-based coagulants and inorganic flocculants leave behind toxic non-biodegradable residues that disrupt the ecosystem. Moringa, guar, and acacia are mucilaginous plants which produce a thick substance called mucilage that can act as a flocculant for heavy metals because of its polysaccharide structure. This experiment seeks to answer the question: how can temperature affect the efficiency of mucilaginous powders in remediating heavy metals in water? This will be investigated by introducing mucilage powders to untreated samples via a modified jar test at varying temperatures in order to examine the effect of temperature on the efficiency of each mucilage powder in regards to decreasing Cu2+ concentration in freshwater samples. The flocculation efficiency will be measured using the absorbance of each sample at 815 nm, which is the wavelength that Cu2+ ions absorb best. It was observed guar gum had the highest absorbance decreases overall for all temperature trials indicating that it is the most effective in removing copper from the samples. The hypothesis that a decrease in temperature leads to increased percent flocculation was not fully supported by the data. A statistically significant difference was observed between the cold/room temperature trials and the heated trials, indicating that increased temperature worsened coagulation by plant powders. For example, for our most efficient plant powder guar, the absorbance value on average for the heated sample (1.87) was greater than the average at room temperature (1.58). These findings provide valuable insight into an eco-friendly wastewater treatment plan, which could be used to implement a viable, industrial testing method.

Keywords: **Mucilage, Jar Test, Spectrophotometer, Absorbance, Transmittance**

Acronyms: **FTIR (Fourier-transform infrared) Spectrophotometer**

Introduction

As water pollution has become a more pressing issue with increasing deforestation, greenhouse gas emission, and fuel spillage, it is of utmost importance to deal with potential contamination and hazards when treating water for consumption. High levels of heavy metals in water can pose a variety of health concerns including acute and chronic toxicity, liver, kidney, and intestinal damage, anemia, and cancer (Jaishankar, 2014). Currently, many aluminum and inorganic flocculants are being used in water treatment, however, utilizing natural flocculants for water treatment is essential as current aluminum based coagulants and inorganic flocculants leave behind toxic non-biodegradable residue while ridding water of contaminants affecting both humans and the environment (Krupińska, 2020).

Moringa, guar gum, and acacia gum are all mucilaginous plants, and mucilage acts as a flocculant because of its polysaccharide structure which gives it the ability to interact with metals, cations, and biological substances (Das et al., 2021). Mucilage can act as a flocculant because of its polysaccharide structure (contains negatively-charged hydroxyl groups) which gives it the ability to interact with metals, cations, and biological substances. A previous experiment done by Subramanium Sotheeswaran (2011) tested the efficacy of moringa seed powder on the removal of turbidity from water samples (Sotheeswaran,). They recorded a noticeable decrease in turbidity when moringa seed powder was added (34%) and measured turbidity between 2 hour intervals. This experiment seeks to use procedures similar to these in order to expand research on the issue by testing (a) various mucilaginous powders, (b) various temperatures for remediation and (c) mucilaginous powders' efficiency in remediating heavy metals.. The inclusion of temperature as an independent variable was warranted by chemical principles–lower temperatures lead to a decrease in particle speed, allowing the OH- molecules in the mucilaginous extract to more stably bind with the positively charged contaminant and flocculating it to the surface of the solution (higher temperatures increase collisions and binding/association, however also increase dissociation, leading to less stable and effective remediation). Water treatment facilities can utilize this information in order to create a more sustainable and eco-friendly alternative water treatment system which is essential as water becomes scarce.

Methods

Materials

Subject Species: Moringa Powder (Supplier: MOGO), Guar Gum (Supplier: Anthony's Organic), Acacia Powder (Supplier: XPRS Nutra)
Experimental Group: 0.5 M Copper (II) Nitrate Solution treated with Moringa/Guar/Acacia powder at 3 different temperatures
Control group: Untreated water samples (for each temperature)
Independent Variable: Mucilage Powder and Temperature (22.7°C, 7 °C, 33.7°C)
Dependent Variable: Absorption of treated water samples at 815 nm

Procedures

1. In a 50 mL laboratory beaker, make a paste with dried moringa seed powder and water
   a. Add 10g of moringa seed powder to 10 mL of distilled water
2. Repeat step one for each mucilage powder (guar and acacia).

   a. For guar, use 10g to 75 mL of distilled water. For acacia use 10g to 10 mL of distilled water.
3. Stir the mixture from step one vigorously for 2 minutes.
4. Create the water sample.
   a. Add 168.804g of copper nitrate to 1.8 L of water.
5. Using a Thermo Scientific Spectronic 200 spectrophotometer, measure and record the absorbance of the untreated water sample at 815 nm (peak absorbance for Cu 2+).
   a. Switch modes to the scan mode so that a graph will be produced on the spectrophotometer screen. Analyze the graph and record the absorbance at 815 nm.
6. Pour out 100 mL of the water sample into a 250 mL beaker.
7. For each mucilage powder, add the paste to the untreated water samples and stir gently for 2 minutes. Then let sit for 6 hours (control sunlight, pH, and temperature).
8. Separate the treated water from the flocs by pouring contents of the treated sample beaker through 2 coffee filters placed on a funnel.
9. Using a spectrophotometer, measure the absorbance and % transmittance of the treated water samples for each powder at 815 nm. (for spectrophotometer use, look at 5a)
10. Repeat these steps for 7 degree celsius, room temperature, and 33 degree celsius trials.
    a. For the 33.7 degree trial, place the treatment beaker on a hot plate and let it sit for 6 hours (all other steps for preparation and treatment are unchanged).
       i. Using a thermometer, ensure the temperature remains constant (measure temperature of the solution in 1 hour time intervals).

Results

Absorbance at 815 nm									
	22.7 °C			7 °C			33.7 °C		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
0.5 M Copper Nitrate Solution	2.37	2.04	2.14	1.99	2.06	2.08	2.13	2.26	2.06
Moringa Seeds	1.45	1.95	1.97	1.87	2.03	1.9	2.50	2.28	2.5
Guar Gum	1.52	1.71	1.51	1.72	1.55	1.59	1.78	2.01	1.82
Acacia Gum	1.67	1.99	2.06	1.94	2.05	2.08	2.34	2.37	2.5

Table 1 (above). Absorbance values of samples at 815 nm.

% Transmittance at 815 nm									
	22.7 °C			7 °C			33.7 °C		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
0.5 M Copper Nitrate Solution	0.95	0.88	0.74	0.87	0.87	0.8	0.77	0.90	0.54
Moringa Seeds	0.97	1.16	1.06	1.41	0.90	1.26	0.23	0.53	0.63
Guar Gum	2.93	1.96	3.09	1.97	2.87	3.02	1.62	0.99	1.5
Acacia Gum	1.13	1.04	0.84	1.11	0.91	0.83	0.44	0.35	0.15

Table 2 (above). % Transmittance values of samples at 815 nm.

±2 Standard Error of the Mean for Absorbance at 815 nm			
	22.7°C	7°C	33.7°C
0.5 M Copper Nitrate Solution	0.19539	0.54568	0.117188
Moringa Seeds	0.340196	0.982	0.146666
Guar Gum	0.130128	0.102632	0.141892
Acacia Gum	0.240092	0.085114	0.0982

Table 3 (above). ±2 Standard Error of the Mean for Absorbance Data Points (all trials) at 815 nm.

±2 Standard Error of the Mean for % Transmittance at 815 nm			
	22.7°C	7°C	33.7°C
0.5 M Copper Nitrate Solution	0.12347	0.0466	0.2105
Moringa Seeds	0.10974	0.302654	0.2402
Guar Gum	0.706	0.654	0.386
Acacia Gum	0.171398	0.16652	0.171398

Table 4 (above). ±2 Standard Error of the Mean for % Transmittance Data Points at 815 nm.

Graphical Representations

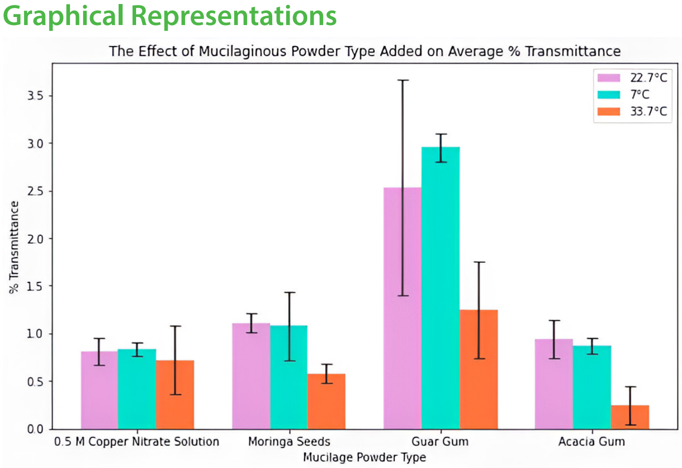

Fig. 1. (above) Average transmittance of each mucilaginous powder treated sample at 815 nm.

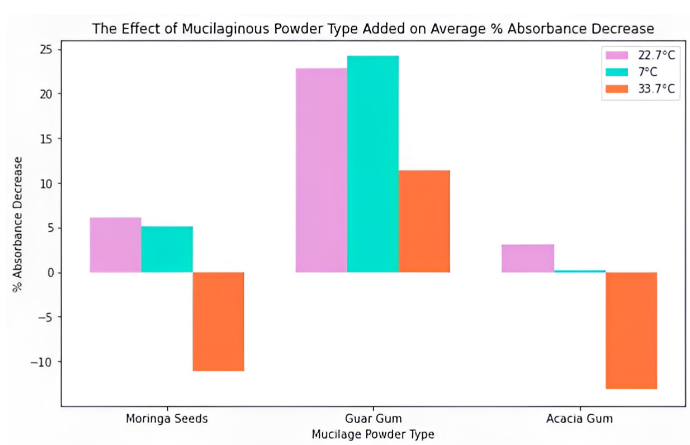

Fig. 2. (above) Average percent absorbance decrease of each mucilaginous powder treated sample at 815 nm.

b. For the 7 degree trial, place the treatment beakers in a fridge and let sit for 6 hours.

Differing amounts of water were added to mucilaginous plant powders solely due to differences in compound water absorption capabilities in order to form a paste with each

Discussion

The T-Test is a statistic used to determine if there is a statistically significant difference between two sets of data. This is done so by comparing the means of the two sets of data and determining if the difference is significant. The formula for the t-test is as follows $t = \frac{M1-M2}{SE}$ where M_1 and M_2 are the means of the two data sets and SE is the standard error of the two samples. The T-Test was conducted using code written on python using the scipy library. The test was conducted using the three trials for each gum at a certain temperature and comparingthat data to another set of three trials by either having the type of gum or the temperature remain constant.

T-Test (Guar vs Copper Nitrate Control - Absorbance):

- Alternate Hypothesis: The addition of plant powders did affect the remediation of heavy metals.

-At 22.7 °C, the P-Value between copper nitrate and guar was 0.0068, At 7 °C, the P-Value between copper nitrate and guar was 0.0019, At 33.7°C, and the P-Value between copper nitrate and guar was 0.0383. Since the P-values for guar at all temperatures were lower 0.05 (95% confidence), we reject our null hypothesis and accept our alternate.

T-Test (22.7°C vs 33.7°C - Absorbance):

-Null Hypothesis: Temperature did not affect the efficiency of the plant powders in remediating heavy metals.

-Alternate Hypothesis: Temperature did affect the efficiency of the plant powders in remediating heavy metals.

-For moringa, the P-Value between 22.7°C and 33.7°C was 0.0105. For guar, the P-Value between 22.7 and 33.7°C was 0.0327. For acacia, the P-Value between 22.7°C and 33.7°C was 0.0047. Since the P-values for all plant powder types between the temperatures, 22.7°C and 33.7°C, were lower 0.05 (95% confidence), we reject our null hypothesis and accept our alternate.

T-test values for all intersecting data points for all tables were obtained, however only those relevant for analysis and trend creation were included here.

As depicted by Figure 2, guar gum had the highest absorbance decrease overall for all temperature trials indicating that it is the most effective in removing copper ions from the samples. However, the hypothesis that a decrease in temperature leads to increased percent flocculation due to decreased copper ion solubility was not fully supported. There was a statistically significant difference between the cold/room temperature trials and the heated trials, indicating that increased temperature worsened heavy metal remediation by plant powders. Overall there was a statistically significant difference between the average absorbance levels of both 22.7°C and 7°C trials and 33.7°C trials (Figure 2) indicating that lower temperatures are ideal for flocculation. The data did not support the initial prediction that Moringa would have the highest absorption decrease overall which was supported by the scientific research that was used as a reference for this experiment nor that the 7°C trial would have the highest absorbance decrease percentage. The results demonstrate that Moringa seed powder and Acacia gum was less effective in heavy metal remediation than guar gum powder. The findings build upon the study done by Subramanium which tested Moringa powder, wheat powder, peanut powder, etc. which found moringa to be the most efficient, however this study did not test guar/acacia powder (also mucilaginous plant powders) and measured turbidity in relation to organic suspended particles. The findings, however, support the results obtained through Fox's study that utilized cactus mucilage for remediation, which detail how lower temperatures support charge neutralization for the heavy metals present, bettering flocculation. Sources of Error present: Slight variation in temperatures of the 33.7°C trial (+/-3°C), cuvette inadequacies, one irregularity in the data was that for Trial 1 at 22.7°C, the solution settled for 12 hours instead of the standard 6 hours, so we omitted this data from the graphical interpretations. The difference in timing however indicated that with increased settling times (6-12 hours), the absorbance decrease observed was greater.

Conclusions

These findings provide valuable insight into a sustainable method for water filtration utilizing guar gum (highest percent absorbance level decrease) at room temperature to cold temperatures (statistical significance between 22.7°C and 33.7°C). To further expand on the experiment, we look forward to conduct testing adapted for the assessing the effectiveness of heavy metal remediation by the mucilaginous powders at various pH values, testing the capability of the mucilaginous powder at even the most acidic and harmful water, expanding the use of the eco-friendly solution. Furthermore, we look forward to expanding testing on several other contaminants, metals such as iron/lead and microplastics providing an insight into the viability of these powders in an industrial setting. This could potentially limit an individual's exposure to harmful molecules (due to inorganic coagulants) that could have adverse effects on health as well as provide a more environmentally friendly yet viable option for water treatment.

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