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# EVALUATION OF THE EFFICIENCY OF COFFEE MUCILAGE AS AN ORGANIC COAGULANT FOR THE REMOVAL OF TURBIDITY, CONSIDERING THE OPTIMAL PH AND OPTIMAL DOSAGE

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**Abstract:** The urgent need to satisfy the demand of water for human use and consumption with a sustainable approach makes it necessary to look for new alternatives for the removal of turbidity in this environmental matrix.

Therefore, the present work aims to evaluate the efficiency of coffee mucilage as an organic coagulant,for turbidity removal. Considering the pH and optimal dose. Jar tests were conducted, and the concentration of coffee mucilage was determined using samples collected from different extraction methods. The optimal pH for turbidity removal was found to be 11 and 12 with the optimal dose of 10 and 20 ml of coffee mucilage as coagulant. It is proved that coffee mucilage organic coagulant is an effective and viable option for turbidity removal in synthetic water, achieving removal efficiencies of 91.38% at pH 12 and 90.99% at pH 11.

**Keywords:** Organic coagulant, coffee mucilage, water treatment, turbidity removal.

## INTRODUCTION

### JUSTIFICATION

In Mexico, the coffee industry is important for national development, as it is a source of employment and foreign exchange for the country, as well as for the conservation of biodiversity (CEDRSSA, 2019). According to the Ministry of Agriculture and Rural Development, Mexico ranks 11th in the world in terms of coffee production.

Within the coffee production process, there are two methods for obtaining the final product: the dry method and the wet method (Prada, 2014), together, throughout the entire production process, only 5% of the weight of the fresh fruit is utilized for the final beverage preparation, while the remaining 95% constitutes organic waste with various chemical compositions (Nuván & Rojas, 2018). These organic residues consist of the pulp and mucilage of the extracted fruits, and additionally, coffee fruits that cannot be considered for final production due to various factors such as quality or ripeness are also included as waste.

According to Mazille and Spuhler, regardless of the nature of the treated water and the integral treatment system applied, the coagulation-flocculation process is generally included either as pretreatment (before sand filtration) or as a stage following treatment after sedimentation (in centralized water treatment plants).

Therefore, considering that both Mexican and foreign companies continue to seek improvements in productive and industrial processes to make them sustainable and minimize environmental impact, this research aims to provide a possible alternative using coffee mucilage for the removal of water turbidity as a natural organic coagulant.

### WORK OBJECTIVES

To evaluate the efficiency of coffee mucilage as an organic coagulant for the removal of turbidity, considering the optimal pH and optimal dosage.

### BACKGROUND

One of the needs of every society is to guarantee hygiene and sanitation services for the population, as well as to provide clean, safe, affordable, and continuous water for human use and consumption (UN, n.d.). That is why microbiological, chemical, and organoleptic aspects must be considered in the quality of this vital liquid (WHO, 2011).

One of the physical and organoleptic characteristics to consider for population acceptance is turbidity since, besides being an aesthetic criterion, it can directly or indirectly indicate the presence of harmful constituents in water (Mexican National Water Commission, n.d., p. 25). Turbidity in surface waters is due to the presence of suspended, colloidal, and dissolved matter (Trussell et al., 2012), originating from erosive processes. The particles responsible for this characteristic, also known as colloids, range in size from 1 nm to 1 mm (CONAGUA, p. 27).

The importance of removing these particles, according to Trussell et al. (2012), lies in the fact that: a) they decrease water quality due to turbidity, b) they can contain infectious agents such as viruses, bacteria, and other microorganisms that are protected from disinfection reactions by the colloids (CONAGUA, p.27), and c) some components such as toxic metals may be adsorbed onto these particles.

Continuous monitoring of water turbidity is important because it is a regulated parameter in the Mexican legal framework and additionally serves as a control mechanism for the efficiency of treatment processes, as well as the quality of the treated effluent (CONAGUA, p. 68). The Mexican Official Standard NOM-127-SSA1-2021 establishes permissible quality limits for water for human use and consumption. It indicates that by the year 2023, the turbidity of water supplied to the population must not exceed 4.0 Nephelometric Turbidity Units (NTU), with this maximum permissible limit (MPL) changing to 3.0 NTU starting from the following year.

Within water treatment in drinking water plants, the conventional clarification system is one of the most commonly used. Through this system, the flow to be treated passes through filters or screens to retain large solids. Subsequently, the remaining solids are colloidal in nature and thus remain in suspension. These particles cannot be removed due to their size, minimal settling velocity, and generally negative surface electrical charge they possess (N.F. Gray, 2005).

The most important process employed for the removal of these solids is coagulation-flocculation, which involves the addition of chemical compounds to induce contact between the coagulant and suspended matter. The objective is to destabilize this matter, promoting the generation of aggregates and the adsorption of dissolved constituents to facilitate sedimentation and subsequent removal (CONAGUA, n.d.; Barreto Pardo et al., 2022; World Health Organization, 2011; Hendricks, 2006; Trussell et al., 2012).

This process consists of two important phases: a) the appropriate selection of the coagulant, depending on the nature of the particles, the coagulant dosage, and the necessary pH correction to achieve high removal efficiency, and b) creating contact between the chosen coagulant and the particles present in the water to form flocs (Hendricks, 2006; N.F. Gray, 2005).

Considering the above, jar testing should be conducted to obtain an optimal coagulation-flocculation process. This test allows for the measurement and control of the effects of the coagulant dosage and pH in different combinations, where turbidity and pH of the supernatant water should be measured (N.F. Gray, 2005).

The most commonly used coagulants are inorganic, composed of metal salts such as aluminum or iron, but due to environmental issues - such as the generation of high volumes of treatment sludge with toxic characteristics (Barreto Pardo et al., 2022, cited from Abebe et al., 2016) - and health concerns - like aluminum assimilation in the body, leading to neurological diseases such as Alzheimer's (N.F. Gray, 2005; Barreto Pardo et al., 2022) - that potentially can be caused by these chemical agents, natural coagulants are presented as an environmentally viable and economically feasible alternative for turbidity removal (Manzo Garrido, 2023).

Some of the benefits of natural coagulants are related to their low cost, availability, biodegradability, as well as the possibility of revaluing waste from existing production chains. To date, there are no records in Mexico of reusing coffee production waste as a coagulant agent within the coffee production chain.

## COFFEE

The coffee processing system is the transformation process of the coffee fruit or cherry into the product that, after roasting and grinding, enters the final consumer chain. Within this processing system, different coffee by-products are generated, which if not handled, treated, or disposed of properly, could have a negative impact on the environment. The main organic by-products according to (Samoaya Toledo et al., 2014, cited from ANACAFÉ, n.d.) of this process are:

1.- Coffee pulp, the by-product with the largest volume, representing 56% of the fruit's volume (Samayoa Toledo et al., 2014). It has a high organic load, so it can be used as organic fertilizer or for composting. 2.- Mucilage, a natural coagulant selected for the present research work, which will be addressed in the section below. 3.- Honey water, a liquid by-product (wastewater) of the pulping and washing process, so its characteristics depend on these two processes. 4.- Parchment (husk), this by-product does not pose a contaminating risk within the wet processing. The mucilage or mesocarp of the coffee is a layer of translucent tissues composed of water, sugars, and pectic substances that act as a hydrogel. It is located between the pulp and the seed's husk (Barreto Pardo et al., 2022; Puerta Quintero and Arias, 2011). It is exposed when the bean is pulped, and its removal is necessary to facilitate the dehydration, drying, and preservation of the quality characteristics of parchment coffee (IICA, 2010).

The characterization of this by-product has been the subject of study in various research conducted by several authors. **Table 1** shows the compositions obtained in the results of these works, for their application in different industrial purposes.

The immediate removal of coffee mucilage after pulping is challenging due to its hydrogel properties caused by pectic substances (Peñuela Martínez et al., 2011). Therefore, in the current conditions of the industry, coffee mucilage removal for coffee processing is carried out by one of the following two methods: a) Mechanical removal (demucilaginator), or b) Removal by natural fermentation (Puerta Quintero and Arias, 2011; IICA, 2010; Samayoa Toledo et al., 2014).

Works have been developed applying coffee mucilage as a natural coagulant for turbidity removal in water, such as the one reported by Barreto Pardo et al., 2022, where they mention two types of coffee mucilage coagulants obtained by different methods. The first one is from a mixture of aqueous mucilage generated in a processing plant, and the second one is from a solution using particulate material from the mucilage after thermal treatment of the first solution. In the results, it is observed that both coagulants follow a trend although they present different removal efficiencies. The first coagulant extracted from coffee mucilage removed 65% of turbidity, with an optimal dosage of 300 mg/L. On the other hand, the second coagulant had a removal between 30% - 39%. Neither of them reports the optimal pH for coagulation.

Additionally, in the work of Cendales Arévalo et al., 2016, multiple jar tests were performed comparing the efficiency of inorganic coagulants (Ferric chloride) against coffee mucilage with two extraction methods, one with an aqueous extraction, which did not achieve turbidity removal, and another with a saline solution which showed a removal of 29% with a dosage of 120 mg/L. The low reported efficiencies were potentially generated by the small variation in pH during the jar tests, which were conducted with a pH range of 7 to 8 units. For these tests, the doses used were in the range of 20-240 mg/L.

## MATERIALS AND METHODS

A field visit was conducted to collect coffee mucilage from two coffee processing plants that use different methods for mucilage removal. These benefits belong to two municipalities in the state of Veracruz, as seen in **Figure 1**: The benefit in Teocelo, with coordinates 19.37901° N, 96.96861° W, involves removal using a demucilaginator (mechanical removal), while in Ixhuacán de los Reyes, with coordinates 19.30855° N, 97.00900° W, removal occurs through fermentation and subsequent washing. Both sampled benefits cultivate and produce coffee of the Coffea arabica species at altitudes of 1,250 meters above sea level for Ixhuacán de los Reyes and 1,335 meters above sea level for the benefit in Teocelo.

Nomenclature keys were assigned for the development of the experimental phase as follows: "Mec" for the sample of mechanical removal, which had a storage time in the benefit's cistern of three days at the time of sampling. For the second benefit, sampling was conducted at two different points in the process: "Fer" at the discharge valve of the fermentation process unit with one day of storage in said tank, and for the second, "Fer2," the water used for washing the fermented coffee beans was sampled to determine the efficiency of this liquid residue. This solution had a total of two days of fermentation.

Additionally, coffee cherries were collected to obtain a sample of mucilage in the laboratory. This sample contained fruits of different sizes, varieties, and colors. Seven kilograms of cherries were manually pulped in the laboratory, resulting in three kilograms of beans with mucilage. Subsequently, 4 liters of water were added for fermentation over 24 hours, followed by filtration.

The experimental phase in the laboratory begins with filtering the aqueous samples collected in the field and prepared in the laboratory using a No. 8 sieve (2.36 mm) to separate large solids from the coffee mucilage. This step ensures that the samples are free from contaminants that may affect the efficiency of the organic coagulant.

Based on the literature review, the concentration of mucilage in the samples collected in the field is determined using the methodology performed by Cendales et al. in 2016:

1. Three porcelain capsules are weighed on an analytical balance (OHAUS, Galaxy 160) until reaching a constant weight, following the Official Mexican Standard PROY-NOM-211-SSA1-2002, for each sample.

2. 20 ml of mucilage are added to each capsule, and then they are placed in an oven at a constant temperature of 105°C for 24 hours.

3. Once the samples have been dehydrated from the capsules, they are removed from the oven and allowed to cool in a desiccator to weigh the capsules and obtain the total solids. This process helps determine the mucilage concentration per liter of each sample.

To determine the efficiency of coffee mucilage as an organic coagulant, the jar test technique is applied, first by determining the optimal pH at which there is better solid removal. Subsequently, the optimal dose of mucilage in milliliters is determined. The jar test is carried out as follows:

1. The preparation of synthetic water involves adding 0.5 grams of kaolin per liter of potable water and stirring the mixture on a stirring hotplate (StableTemp, Cole-Parmer) at a speed of 500 rpm.

2. 900 milliliters of synthetic water are measured in the graduated cylinders and poured into one-liter beakers, which are then placed in the jar tester apparatus (Phipps & Bird, Model PB-700 Jar Tester).

3. The jar tester apparatus is set to a speed of 100 rpm, and then the mucilage dose is added to the beakers, initiating the rapid mixing phase which lasts for one minute.

4. Subsequently, the speed is adjusted to 40 rpm for the slow mixing phase, which continues for 15 minutes.

5. After the mixing time has elapsed, operation is stopped by raising the mixing paddles, allowing the flocs to settle for 15 minutes. A sample of the supernatant is then extracted for turbidity reading using the turbidimeter (HACH, 2100N Turbidimeter).

Two jar tests are conducted, one to determine the optimal pH and the other to determine the optimal dose. For the field-collected samples, a set of two tests is conducted for each sample, while for the mucilage extraction performed in the laboratory, tests are conducted at three, six, and eight days of fermentation.

For the optimal pH test, 40 ml of coffee mucilage is prepared following the methodology recommended by Cendales et al. 2016, as it reports a higher percentage of solid removal. The test is conducted with pH values ranging from 5 to 12. Hydrochloric acid (HCl) is used to decrease the pH value, while sodium hydroxide (NaOH) is used to increase the pH value.

The second jar test aims to determine the highest solid removal efficiency by varying the volume of coagulant at the identified optimal pH. Volumes ranging from 10 ml to 70 ml of mucilage are dosed, with intervals of 10 ml between each volume.

For the determination of the removal efficiency, the following equation is used:

$$removal\% = \frac{initial\ NTU\ - final\ UTC}{initial\ NTU} * 100$$

Equation (1)

Where:
NTU: Nephelometric Turbidity Unit

## RESULTS AND DISCUSSION

### MUCILAGE CONCENTRATIONS

**Table 2** shows the different concentrations of mucilage according to the method of extraction at various days after the sample was collected. There are 4 columns, representing the mechanical method "Mec", the artisanal fermentation in the field "Fer" and "Fer2", and the artisanal extraction done in the laboratory "Lab".

The "Fer" and "Lab" samples have similar values despite a one-week difference in fermentation time. Therefore, it can be interpreted that the fermentation days do not affect the concentration of total solids; however, it is inferred that the extraction method is the influencing factor.

The "Mec" sample represents extraction through a demucilaginator, where the mucilage is removed from the bean without undergoing a fermentation process. The fermentation days are due to storage. With these results, it is confirmed that the extraction method influences the concentration of total mucilage solids, but not necessarily the turbidity removal, as shown later.

The "Fer2" sample has the lowest concentration compared to the "Fer" and "Lab" samples, which share extraction characteristics. This is due to dilution by the washing water, which is why it is decided not to continue with this sample.

### SYNTHETIC WATER AND PH VARIATION:

According to the described methodology, the initial conditions of the water to be treated were on average: initial turbidity of 625 NTU and a pH of 7.82. No other compounds were added apart from the aforementioned kaolin.

Regarding the pH of coffee mucilage, it presents as an acidic medium with fermentation days, with no considerable changes, remaining within a range of 4.03 - 3.38 for the first 8 days.

### OPTIMAL PH:

In the jar tests conducted with the selected mucilage samples, the results shown in **Figure 2** indicate that, within the 5 tests, the trend is that as the pH of the solution increases, the removal percentage behaves similarly, increasing. This means that coffee mucilage as a coagulant depends on the variables of fermentation and extraction method, with fermentation being predominant in determining the removal percentage.

The trend lines point out that the sample with the lowest efficiency as a coagulant is the "Mec" sample. This could be attributed to the low concentration of solids it presented. This may be due to the extraction method (demucilaginator) or the storage time at the time of sampling, which was 3 days in the benefit's storage without any preservation method.

The second lowest efficiency belongs to the "Fer" sample. This indicates that despite the concentration of solids not changing in the mucilage (Table 2), the change in chemical composition due to fermentation days affects the efficiency of its use as a coagulant.

In the results obtained for samples Lab 3 and Lab 6, it is observed that their behavior in a neutral pH range differs by almost 10% in removal efficiency. However, as the pH increases in the different jars for the samples, the removal trends are practically the same, approaching 80% effectiveness.

Analyzing only individual results, sample Lab 3 showed the highest efficiency, reaching up to 91.8%, followed by Lab 6 (89.77%) and Lab 8 (89.45%), where in all cases the optimal pH obtained was 12.

The best result in removal efficiency for the optimal pH tests, according to the trend lines, was obtained with the laboratory sample for the test conducted at 8 days of fermentation (Lab 8). This could indicate that the days of fermentation are the most determining variable for the efficiency of coffee mucilage as a coagulant.

### OPTIMAL DOSAGE

Analyzing **Figure 3**, a similar level can be noted in all tests with a concentration of 20 ml for the different fermentation days. It can be observed that the removal percentage fluctuates by the same values in the following order according to the fermentation days: 88.27%, 89.40%, 91.00%, and 85.07% for pH values of 11, and for the removal percentages at pH values of 12, they are 91.34%, 88.97%, and 85.02%.

The difference in percentages between the 2 pH values turns out to be minimal, as can be observed with the "Lab-6" tests where the difference is from 2.5% to 5% removal, which is a small value for a pH unit. With these results, it is demonstrated that coffee mucilage presents itself as an option for organic coagulant and does not increase turbidity as reported by Cendales et al. in their work from 2016.

Similarly, changes in doses from 10 to 20 ml of coffee mucilage may result insignificant, as the difference is a maximum of 5% removal. The best removal percentages are found with values of 20 ml of coffee mucilage with a removal percentage of 91.34% at pH 12. At pH 11, the best removal percentage is obtained with the same dose of coffee mucilage.

According to the results obtained and in comparison with Barreto Pardo et al., in their work from 2022, it is demonstrated that the determination of the optimal pH proves to be predominant for better turbidity removal.

It is observed that the removal percentages remain within a range of ±5%, with changes in the fermentation days, the type of extraction, and the dosage used.

## CONCLUSIONS

The efficiency of coffee mucilage as an organic coagulant for turbidity removal was evaluated, considering the optimal pH and dosage. The results obtained show good turbidity removal efficiency for the synthetic water characteristics. For the optimal pH tests, the best efficiencies were observed in the range of 11 to 12, with 88.41% for the sample obtained from fermentation in the beneficio, and 91.80% for the coagulant obtained in the laboratory with 3 days of fermentation.

For the optimal dosage tests, the best efficiencies were obtained with 20 ml for pH values of 11 and 12. Achieving efficiencies of 90.99% and 91.38% respectively.

The efficiency of coffee mucilage as a natural coagulant for turbidity removal is primarily influenced by its fermentation time. On the other hand, the extraction method of the mucilage is not a variable that influences. This could be beneficial for its application in different coffee-growing areas, regardless of the processing method employed.

There are areas of opportunity to improve the efficiency of this coagulant, defining if there is a relationship between the planting altitude and the removal efficiency; the maturity of the harvested fruit; the species and variety of coffee; or the mixture with a chemical coagulant agent.

## ANNEXES (TABLES AND FIGURES)

| Braham and Bressani extracted from Nadal (1959) | Braham and Bressani (1978) | Puerta and Ríos (2011) |
|---|---|---|
| Water - 84.2% | Total pectic substances 35.80% | Carbohydrates 85.5% |
| Protein - 8.9% | Total sugars ½ - 45.8% | Proteins 9.3% |
| Sugar - 4.1% | Reducing sugars - 30.0% | Ashes 4.3% |
| Ácido Péctico - 0.91% | Non-reducing sugars - 20.0% | Acids (Lactic) 1.7% |
| Ashes 0.7% | (Cellulose + Ash) - 17.0% | Alcohol (Ethanol) 1.2% |
| | | Lipids 1.2% |

**Table 1.** Composition of Coffee Mucilage.

(*Own elaboration, 2023) *According to various authors*

| | Mec | Fer | Fer2 | Lab |
|---|---|---|---|---|
| Days | 9 | 7 | 7 | 2 |
| Concentration (g/L) | 8.47 | 34.48 | 6.69 | 33.65 |

Table 2. Concentration of Coffee Mucilage in Collected Samples

Mech: Mechanical. Fer: Fermented 1. Fer2: Fermented 2. Lab: Laboratory. (Own elaboration, 2023)

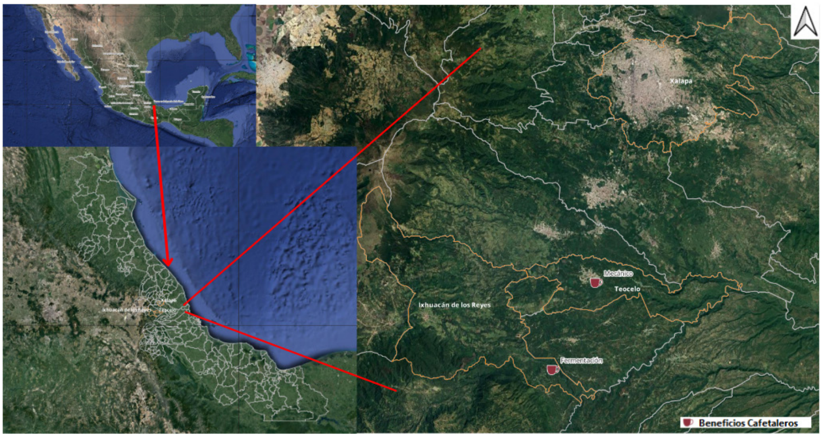


Figure 1. Location Map of Site (Own elaboration, 2023). Mexico's map is observed in the upper left corner, expanding towards the bottom area, showing the boundaries and municipalities of the state of Veracruz. The enlargement on the right indicates the municipalities of Teocelo and Ixhuacán de los Reyes, areas to which the visited benefits belong.

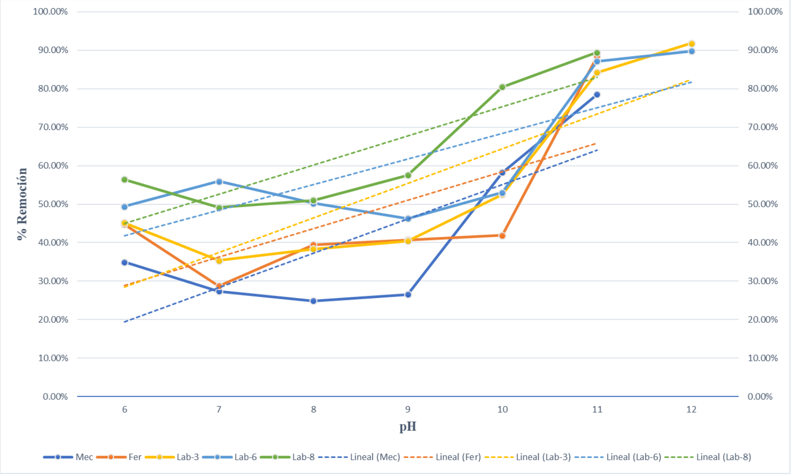


Figure 2. Efficiency of removal percentage with respect to the optimal pH (Own elaboration, 2023).

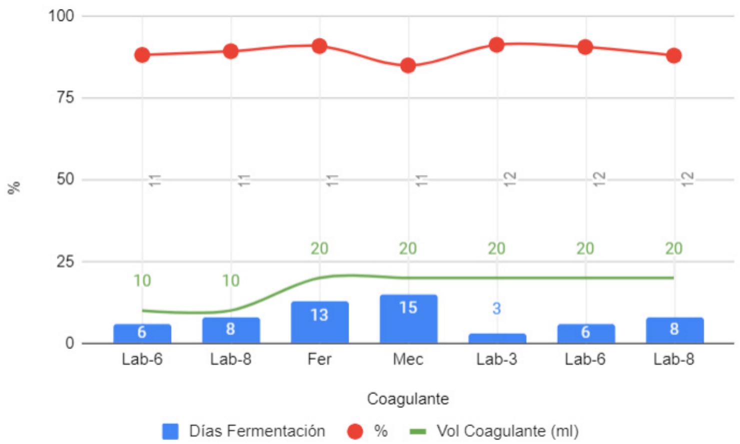


Figure 3. Removal percentage according to the coagulant used. Fermentation days are indicated in the columns, the volumes of coagulant used, as well as the optimal pH of each test (Vertically) (Own elaboration, 2023).

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