EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(10), 49–59
https://doi.org/10.12912/27197050/209961
ISSN 2719–7050, License CC-BY 4.0

Received: 2025.08.07
Accepted: 2025.09.15
Published: 2025.10.01

Bioactive synergy of moringa dust (*M. oleifera*) and aluminum sulfate in the removal of solids in wastewater from the slaughter center of Bolívar, Ecuador

Jean Myckel Bravo Muñoz[1*], Cristhian Anthony Sabando Vélez[1], Carlos Ricardo Delgado Villafuerte[1], Alexita Yaneth Peñarrieta Macias[1], Fabian Fabricio Peñarrieta Macías[1]

[1] Faculty of Environmental Engineering, Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, Calceta, 130250, Ecuador

* Corresponding author's e-mail: jean.bravomu@espam.edu.ec

ABSTRACT

The research evaluated the synergy between natural coagulants (*Moringa oleifera*) and synthetic coagulants (aluminum sulfate) in the removal of solids from wastewater from slaughter centers. The physicochemical parameters (TSS, turbidity and color) were characterized. Samples were collected at the point of discharge, filtered and homogenized. The powder of *M. oleifera* was obtained after cleaning, drying, grinding, alcoholic extraction and activation with NaCl. A completely randomized design was applied with three factors (coagulant dose and pH), generating 12 treatments evaluated with a jug test, determining removal efficiency and solids generated. The slaughtering process in the Calceta slaughterhouse generates solid and liquid waste, especially in the bleeding, skinning and evisceration. The wastewater has 450 mg/L TSS and 319 PCU of color, exceeding the regulatory limits, while turbidity (23.54 NTU) remains within the permitted range. The treatments applied achieved removals of up to 90% in color, 85% in turbidity and 98.96% in SST, highlighting treatments 9, 11 and 12. The analysis of variance showed that the dose of the biocoagulant had a significant effect on the removal of color ($p = 0.0007$) and total suspended solids ($p = 0.0005$). Aluminum sulfate dose and pH were not significant. Overall, efficiencies reached up to 90% in color and nearly 99% in solids. The production of solids ranged between 60 - 80 grams depending on the treatment applied, demonstrating that this synergy contributes to the performance in the removal of solids.

Keywords: natural coagulants, synergistic effect, wastewater treatment, solid waste generation.

INTRODUCTION

The slaughter, processing and preservation activities used in meat production in municipal slaughterhouses generate large volumes of wastewater that, when discharged, cause a negative impact on the environment, since these effluents have a high organic load, with a biochemical oxygen demand (BOD) that varies between 5000 and 10 000 mg/L, in addition to containing high levels of solids, nutrients, fats and oils of low biodegradability, which can cause serious contamination and degradation of the water and soil of the receiving environment, making it necessary to implement specialized treatment systems for the effective elimination of these contaminants (Montero et al., 2023). Coagulation-flocculation plays a key role in the primary stage of wastewater treatment, as it allows the effective removal of suspended solids and colloidal matter, which favors the development of the following stages of treatment. Among the most commonly used coagulants due to their physicochemical properties are aluminum sulfate ($Al_2(SO_4)_3 \cdot 18H_2O$), especially used due to its low cost, wide availability, and good results in the treatment of wastewater with similar characteristics, within the recommended pH range of 4.5 to 8 (Bermúdez et al., 2019)

On the other hand, natural coagulants have emerged as a promising alternative for water treatment, with *Moringa oleifera* seed powder being one of the most researched for its ability to reduce turbidity, suspended solids and microbial load in various types of effluents. The proteins present in moringa seeds act as cationic polymers that induce the neutralization of colloidal particle charges, facilitating their agglomeration and subsequent sedimentation. In addition, it has been shown that moringa has antimicrobial properties that can complement its coagulant action, which is particularly beneficial in effluents of animal origin, where there is a high risk of microbiological contamination. (Arreola and Canepa, 2013).

The cationic polyelectrolyte present in moringa, composed mainly of soluble proteins such as albumins and globulins. These proteins act by neutralizing the surface charges of colloidal particles, favoring their agglomeration and sedimentation; in particular, globulin I has been shown to remove up to 90% of color and turbidity, in addition defatted seeds contain approximately 448.16 mg of protein per gram, of which the vast majority is soluble and actively contributes to the coagulation process, (Martha and Ramón, 2022) (Leones et al., 2018)

Moringa oleifera is aligned with the principles of the circular economy due to its wide spectrum of bioactive compounds and integral use, its grain allows effective extracts to be obtained for water treatment, The proteins of its seeds have peculiar physicochemical properties, such as the reduction of turbidity (97–99%), surfactant activity, elimination of heavy metals and formation of flocs. Its functional stability in wide ranges of pH (4–9) and salinity stands out, which prevents subsequent adjustments, unlike traditional coagulants (Horn et al., 2022).

It has been evaluated that the combination of aluminum sulfate with *Moringa oleifera* seed powder improves the efficiency in the treatment of different types of wastewater, in addition the optimization and modeling of these processes are essential to maximize yield, allowing the identification of the best operating conditions through methods that consider the interaction of multiple variables simultaneously (Adesina et al., 2019)

In the case of the canton of Bolívar, this proposal is especially pertinent that integrates natural and chemical inputs under a synergistic approach that would not only improve the quality of the treated effluent, but also promote the circular economy, sustainable management of resources. This approach also responds to the sustainable development goals (SDGs), in particular SDG 6 (clean water and sanitation) and SDG 12 (responsible production and consumption), strengthening the link between science, territory and sustainability.

MATERIALS AND METHODS

Location

The research was carried out at the Calceta slaughter center, while the experimentation was carried out in the environmental chemistry and soil laboratory of the Higher Polytechnic Agricultural School of Manabí "Manuel Félix López" (ESPAM-MFL) located in the province of Manabí, Bolívar canton, Calceta parish. The research is experimental, focused on evaluating the synergy of natural and synthetic coagulants in the removal of solids from wastewater generated in slaughter centers, as shown in Figure 1.

Determine the current situation of the slaughter site

The current situation of the slaughter center was carried out through a comprehensive methodology that combines the collection of bibliographic and field information. This strategy will allow a thorough analysis to identify activities and processes, The bibliographic compilation will provide a framework on relevant background, while field research will allow direct observation and interaction with personnel to obtain current information on the operational functioning of the slaughter center.

Sample collection

The water samples were collected at the discharge point randomly during the time in which the work is carried out, collecting samples every 10 minutes during the period of one hour, during the taking the water sample was filtered to eliminate lignocellulosic remains and viscera, subsequently, the samples were homogenized until reaching a total volume of 30 liters. the samples were stored in airtight containers and transported to the laboratory (Medina et al., 2020).

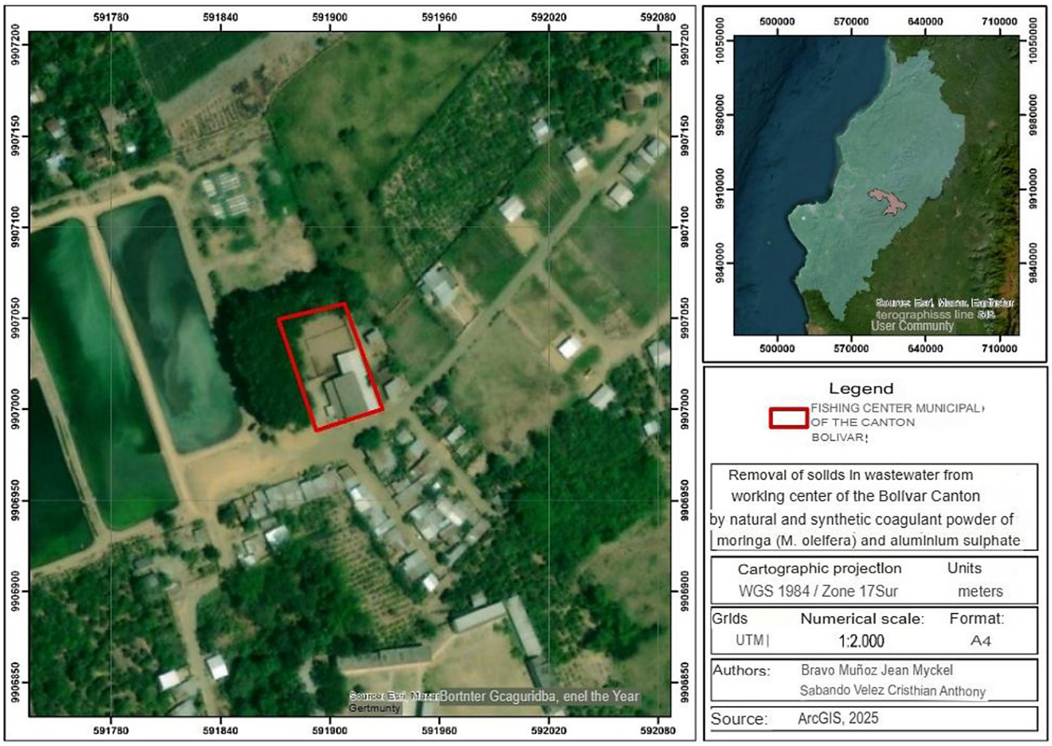

Figure 1. Location of the slaughter center of the canton of Bolívar

Physicochemical characterization of wastewater

The initial (wastewater) and final (treated) characterization will be carried out in the Environmental Chemistry and Soils laboratory of the ESPAM-MFL using the Standard methods for the examination of water and wastewater (American Public Health Association, 2020). The parameters to be evaluated are detailed in Table 1. The parameters to be evaluated are detailed in Table 1.

Obtaining and processing moringa seed powder (*M. oleifera*)

The obtaining and treatment of *M. oleifera* seed powder begins with cleaning and disinfection to remove impurities and contaminants. The seeds are then dried in a controlled manner, in order to reduce their moisture content and preserve their properties. Once dried, the hulling is carried out to obtain the cores which are ground to obtain a fine and homogeneous powder, which can be sieved to ensure uniformity, a heat treatment is carried out to eliminate microorganisms, guaranteeing the stability of the product without compromising its essential nutrients (Jain et al., 2019). After obtaining the flour, 5% (w/v) solutions of pulverized seeds were prepared using alcohol with 65% purity. The mixture was shaken for 30 minutes and left to sit for an hour. The supernatant was then removed with a pipette, and the remaining solids were initially dried at room temperature for one day and then in an oven at 70 °C for three hours. Finally, the active component of the seeds was extracted by a 5% solution of 0.25 M NaCl (Marinho et al., 2022).

Table 1. Parameters to be evaluated

Parameters	Units
Total suspended solids	mg/l
Turbidity	NTU
Colour	PCU

Experimental design

Table 2 and 3 presents a factorial design with three factors, which allow the evaluation of the interactions between them: Factor A (dose of biocoagulant *M. oleifera*), Factor B (dose of aluminum sulfate) and Factor C (pH conditions). 12 treatments were established resulting from the combination of the levels of each factor, with 3 repeats per treatment, totaling 36 experimental units. For the execution

Table 2. Experimental design

Tukey's test	DCA		Levels		
	Treatments	Repetitions	Factor A. Dosage of the biocoagulant (mg)	Factor B. Aluminum sulfate dosage (mg)	Factor C. pH
95%	12	3	A0 = 7500	B0 = 7500	C0 = 4
			A1 = 10000	B1 = 10000	C1 = 7
			A2 = 12000		

Table 3. Treatment and interactions

Treatment	Factor A (biocoagulant) (mg)	Factor B (aluminum sulfate) (mg)	C-factor (pH)
T1	A0 (7500)	B0 (7500)	C0 (pH 4)
S2	A0	B0	C1 (pH 7)
S3	A0	B1 (10000)	C0
S4	A0	B1	C1
S5	A1 (10000)	B0	C0
S6	A1	B0	C1
S7	A1	B1	C0
S8	A1	B1	C1
S9	A2 (12000)	B0	C0
S10	A2	B0	C1
S11	A2	B1	C0
S12	A2	B1	C1

of the experiment, the jar test was used, where the agitation began at a maximum speed of 280 rpm; At this time, the doses corresponding to each treatment were added simultaneously, maintaining a constant depth for addition. After 30 seconds, the stirring speed was reduced to 30 rpm to favor the flocculation process, which was maintained for 15 minutes. At the end of this stage, the agitation stopped and the paddles were removed. The jugs were left to rest on the table to allow sedimentation for 20 minutes. Subsequently, samples were taken at the same depth and simultaneously from each jar to analyze the evaluated parameters again.

Determination of removal efficiency

Equation to obtain the percentage of removal, considered the averages of the treatments, as the initial concentration and the results after the treatment as the final concentration (Cabrera et al., 2022):

$$Removal\ \% = \frac{Co - Cf}{Co} \times 100 \quad (1)$$

where: Co – initial concentration; Cf – final concentration.

Statistical analysis

Statistical analysis was performed to assess significant differences between various data sets. Data normality and homogeneity tests were carried out, which is essential to guarantee the validity of the subsequent analyses, subsequently, an analysis of variance (ANOVA) was applied to determine if there are significant differences between the groups in terms of their means. The ANOVA allows identifying if at least one group is statistically different from the others, finally, to identify the specific differences between the groups, the HSD Tukey test was applied. This post hoc test allows for multiple comparisons between groups (Bittner, 2022).

Quantification of solids generated from the coagulation process

In order to establish the solids generated as an indicator of the efficiency of the coagulation process, it is essential to quantify the solids formed during the reaction between the coagulant and the particles present in the wastewater, these solids, known as flocs, the procedure involves collecting the flocs produced after treatment at each stage and measuring their dry weight by gravimetric drying (Veliz et al., 2016).

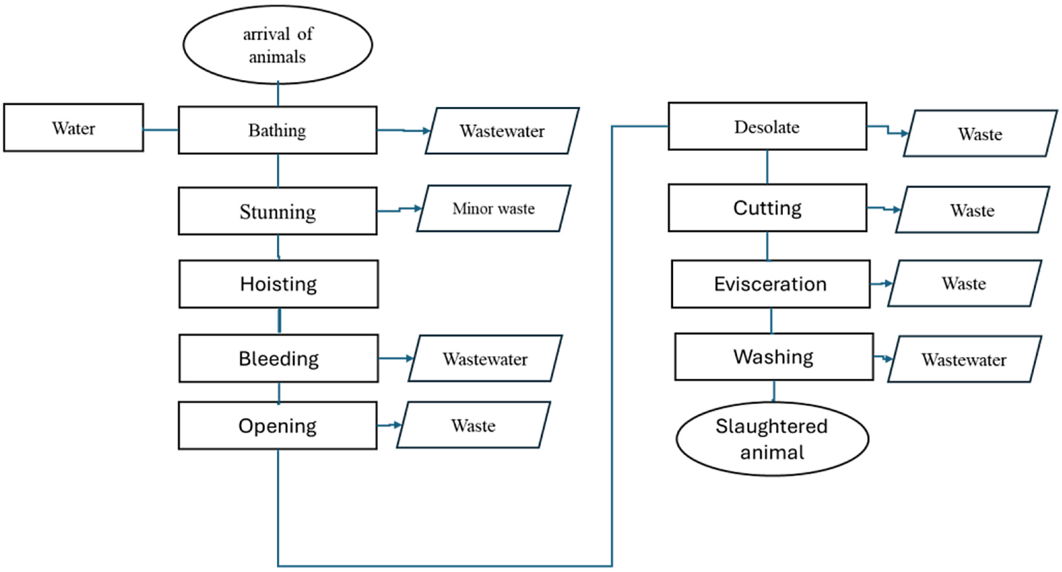

Figure 2. Flowchart of the animal slaughtering process and its main points of waste generation

RESULTS

Description of the animal slaughtering process

Figure 2 shows the animal slaughtering process at the Calceta slaughter center, beginning with the reception of the specimens, followed by a hygienic bath aimed at reducing the surface microbial load and removing visible dirt before slaughter. Then stunning is carried out, a procedure that induces the loss of consciousness in the animal to guarantee a humane sacrifice, and the hoisting continues, which facilitates subsequent operations. Bleeding is a critical stage to ensure the safety of the final product, after which skinning is carried out, consisting of the removal of the skin and the generation of solid by-products such as leather and related fabrics. The process continues with evisceration, which involves the total extraction of the visceral content, and culminates with the sanitary washing of the carcass, a stage that reduces the residual microbial load and eliminates visible residues, thus obtaining a clean carcass suitable for refrigeration, deboning or marketing processes. Throughout this operational flow, various critical points of liquid and solid waste generation are identified. Table 4 presents the results obtained; total suspended solids (TSS) show a concentration of 450 mg/L, far exceeding the maximum allowed limit of 100 mg/L established by the regulations, the turbidity, with a value of 23.54 NTU, is within the allowed range (≤ 50 NTU), however, the apparent color registers a value of 319 PCU, which could be associated with the presence of dissolved organic matter, blood, fats or other coloring compounds from the slaughtering process. Overall, the data show a discharge with physical characteristics that do not conform to Ecuadorian environmental regulations in the parameters of solids and color, which represents a risk to the receiving aquatic ecosystem and requires the implementation of treatment measures or adaptation of the effluent.

Removal efficiency

Figure 3 shows that the applied treatments have a color removal efficiency with values ranging approximately between 72% and 90%. Treatment 9 presents the highest percentage of removal, reaching a value close to 90%, Treatments 5,

Table 4. Physicochemical characterization of wastewater

Parameters		Units	Maximum allowable limit (TULSMA)
Total suspended solids	450	mg/l	100
Turbidity	23.54	NTU	50
Colour	319	PCU	-

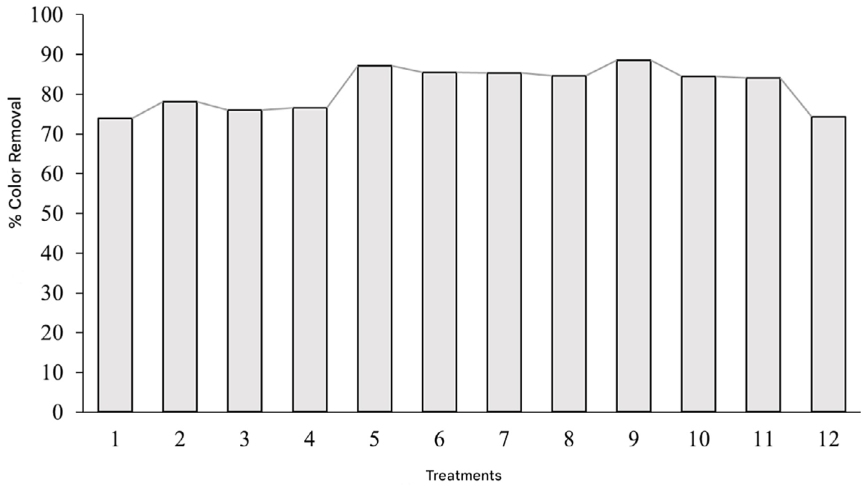

Figure 3. Color removal efficiency

6, 7, 8 and 10 also show values above 85%. Treatments 1, 3 and 4 have color removals that are between 72–75%, treatment 1–12, have a similar value to treatment 1 73%.

Figure 4 reflects a turbidity removal efficiency, with values ranging from 70% to 85%. Treatment 12 registers the highest percentage of removal, reaching a value close to 85%, on the other hand, treatments 10 and 8 also present values above 80%, showing optimal performance. Treatments 1 and 2 exhibit the lowest efficiencies (~70–72%), although they are still within an acceptable range from the point of view of primary treatment. In general, treatments from 3 to 11 show a stable trend with removals between 75% and 80%, which reflects efficiency in the treatments applied. Figure 5 evidence of TSS removal, with percentages ranging from approximately 83.52% to 98.96%. Treatment 11 has the highest removal efficiency, reaching 98.96%, which indicates a high suspended solids retention capacity. Treatments 10 (97.99%), 7 (96.15%), 8 (95.63%), 5 and 6 (95.03%), which maintain a removal rate of more than 95%, reflecting a remarkable consistency and efficacy of the method applied. Treatments 4 (94.29%), 12 (93.70%) and 9 (92.66%) also show results with removals greater than 90%. Treatments 1 (85.33%), 2 (83.52%) and 3 (86.51%) have notable percentages, although they are still adequate in the context of primary or physicochemical treatment.

Statistical analysis

The statistical analysis performed by ANOVA Table 5 shows that the dose of the biocoagulant (Factor A) has a statistically significant effect on color removal, with a p-value of 0.0007,

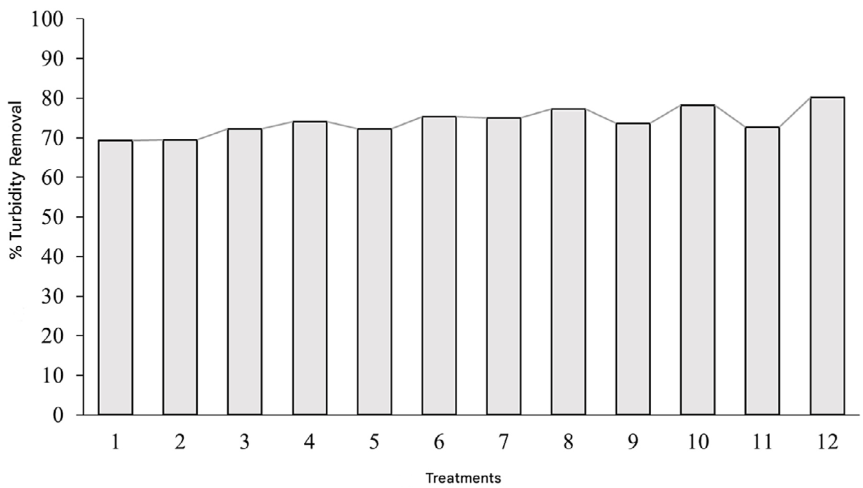

Figure 4. Turbidity removal efficiency

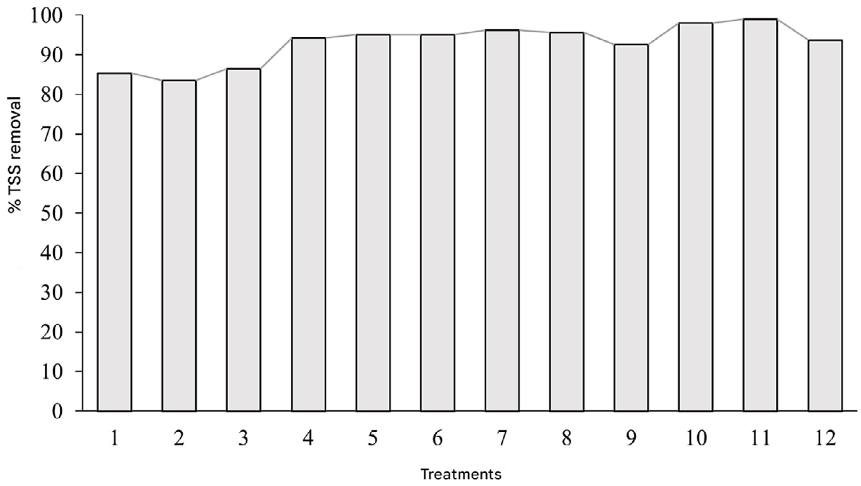

Figure 5. SST removal efficiency

lower significance level of 0.05. This indicates that varying the amount of the biocoagulant directly influences the efficiency of the treatment, improving the system's ability to remove the color from the water.

On the other hand, the dose of aluminum sulfate (Factor B) and the pH of the medium (Factor C) showed statistically significant effects ($p = 0.1321$ and $p = 0.2978$, respectively). This suggests that, under the conditions of the experiment, these factors do not generate major changes in color removal, although they may provide complementary practical benefits. Similarly, the interactions between factors (AB, AC, BC and AB*C) were also not significant, which indicates that the combinations between the evaluated variables do not present a considerable joint effect on this parameter.

Despite this, the overall results of the experiment reflect a high efficiency in color removal in most of the treatments applied. Efficiencies ranged from 72 to 90%, which evidences the feasibility of using synergy. Treatment 9 was the most effective, achieving approximately 90% removal. Likewise, treatments 5, 6, 7, 8 and 10 presented removals of more than 85%, standing out for their consistency and performance.

In contrast, treatments 1, 3 and 4 showed moderate efficiencies, with values between 72–75%, while treatment 12 presented a similar behavior to treatment 1, with a removal close to 73%.

In this statistical analysis Table 6, none of the factors evaluated—dose of biocoagulant (A), dose of aluminum sulfate (B), and pH (C)—showed a statistically significant effect on the variable analyzed, since all p-values were greater than 0.05. Nor were there any important differences in the interactions between these factors (AB, AC, BC and AB*C), which indicates that the conditions of the experiment applied did not generate statistically detectable variations. However, high

Table 5. Analysis of variance of the color parameter

F.V.	SC	Gl	CM	F	P-value
To	569.76	2	284.88	10.11	0.0007
B	68.5	1	68.5	2.43	0.1321
C	31.92	1	31.92	1.13	0.2978
A*B	97.62	2	48.81	1.73	0.1984
A*C	133.47	2	66.74	2.37	0.1152
B*C	17.33	1	17.33	0.61	0.4406
ABC	16.93	2	8.46	0.3	0.7434
Error	676.49	24	28.19		
Total	1612.02	35			

Note: SC – sum of squares; Gl – degrees of freedom; CM – mean square; F – F-value; P-value – significance level.

Table 6. Analysis of variance of the turbidity parameter

F.V.	SC	Gl	CM	F	P-value
To	157.07	2	78.54	1.88	0.1749
B	45.05	1	45.05	1.08	0.3099
C	93.93	1	93.93	2.24	0.1472
A*B	16.42	2	8.21	0.20	0.8232
A*C	40.77	2	20.38	0.49	0.6204
B*C	3.73	1	3.73	0.09	0.7678
ABC	5.71	2	2.86	0.07	0.9342
Error	1004.61	24	41.86		
Total	1367.3	35			

Note: SC – sum of squares; Gl – degrees of freedom; CM – mean square; F – F-value; P-value – significance level.

removals were observed in several treatments, suggesting that, although the effects were not statistically significant, the efficiency has potential especially if its application is considered in real scenarios where small variations can have a relevant environmental impact.

In this statistical analysis Table 7, it was observed that factor A (coagulant dose) had a statistically significant effect on the variable analyzed ($p = 0.0005$), indicating that this factor influences removal. On the other hand, factors B (dose of aluminum sulfate) and C (pH) did not show significant differences, with p values higher than 0.05. The interactions between the factors were also not significant, although it should be noted that the triple ABC interaction presented a p-value of 0.0667, close to the significance threshold, which could indicate an interesting trend that would be worth exploring in future studies. In general, these results highlight the importance of selecting the dose of the biocoagulant, since its impact was significant, while the other variables could be optimized according to practical, operational or economic criteria.

Tukey tests

Figure 6 In the color graph, a clear difference between the doses applied can be observed. The 7500 mg dose shows a lower removal efficiency, with pooled values between approximately 72% and 80%, indicating reduced dispersion but lower effectiveness. Conversely, the 10000 mg and 12000 mg doses show a significant improvement in color removal, with medians above 85% and maximums approaching 95%. The dose of 10000 mg shows the highest median and lowest dispersion, suggesting greater consistency in results, while 12000 mg exhibits slightly greater variability.

In the SST Figure 7, all treatments have high efficiencies, above 90% in almost all cases. The doses of 10000 mg and 12000 mg show very similar results, with median doses close to 97%, which indicates that from 10000 mg onwards, an optimal and sustained efficiency in the removal of suspended solids is achieved. Although the 7500 mg dose has a greater dispersion, it also achieves considerable removal, with values ranging from 75% to 97%, which shows that, although effective, this dose can generate less consistent results.

Table 7. SST (total suspended solids) analysis of variance

F.V.	SC	Gl	CM	F	P-value
To	542.74	2	271.37	10.79	0.0005
B	61.47	1	61.47	2.44	0.131
C	7.64	1	7.64	0.30	0.5867
A*B	51.09	2	25.54	1.02	0.3771
A*C	19.30	2	9.65	0.38	0.6853
B*C	0.58	1	0.58	0.02	0.8808
ABC	152.71	2	76.36	3.04	0.0667
Error	603.41	24	25.14		
Total	1438.93	35			

Note: SC – sum of squares; Gl – degrees of freedom; CM – mean square; F – F-value; P-value – significance level.

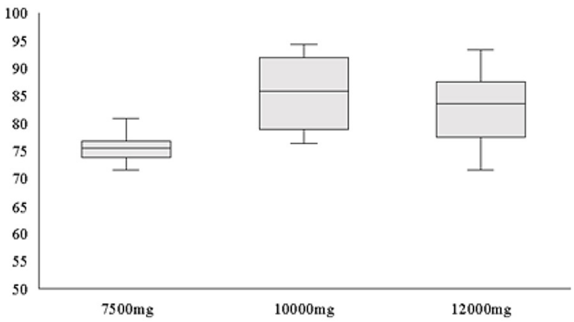

Figure 6. Tukey color test

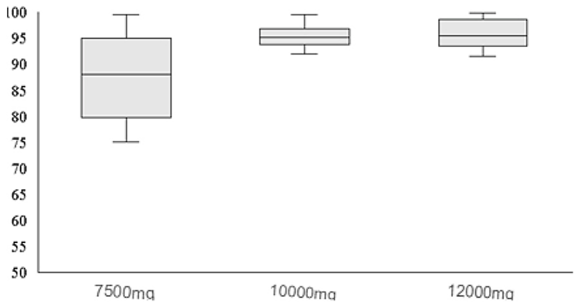

Figure 7. Tukey SST test

Quantification of solids generated from the coagulation process

Figure 8 illustrates the amount of solids generated (g) of the 12 treatments, it is observed that the initial treatments (1–3) produce amounts around 60–68 g. On the other hand, treatments (4–9) show a notable increase, stabilizing between 70 and 73 g, although with a slight downward fluctuation in Treatment 6. The peak is reached in Treatment 10, with approximately 80 g of solids, marking the maximum. Subsequently, the amount decreases slightly in the final treatments (11 and 12), standing at 78–79 g and 76 g respectively. It was shown that the amount of solids generated varies in a range of 20 g, from the initial 60 g to 80 g, suggesting that Treatment 10 represents the most effective condition for the production of solids.

DISCUSSION

The results obtained in the municipal slaughterhouse of Calceta show problems similar to those described by Velusamy and Natarajan, (2022), who highlight that a proportion of the slaughtered animal becomes unused by-products, both of plant and animal origin, this observation coincides with the types of waste identified in the study, on the other hand the amount generated is closely related to the scale of slaughter, a critical aspect in urban environments where meat demand is high. In addition, it was found that the accumulation and improper management of these wastes compromise the quality of water bodies, air quality and increase the health risks associated with the proliferation of pathogenic microorganisms. In addition, the study by Pauta et al. (2020), which evaluated the performance of the wastewater treatment plant of a slaughterhouse in the city of Mwanza, Tanzania, reported BOD_5 inlet concentrations of 1.013 mg/L, COD of 4.606 mg/L and TSS 105 mg/L, turbidity of 582 NTU in comparison to the results obtained in the municipal field of Calceta are above the results found in research (Michael et al., 2020). Meiramkulova et al. (2020) studied electrochemical methods for the treatment

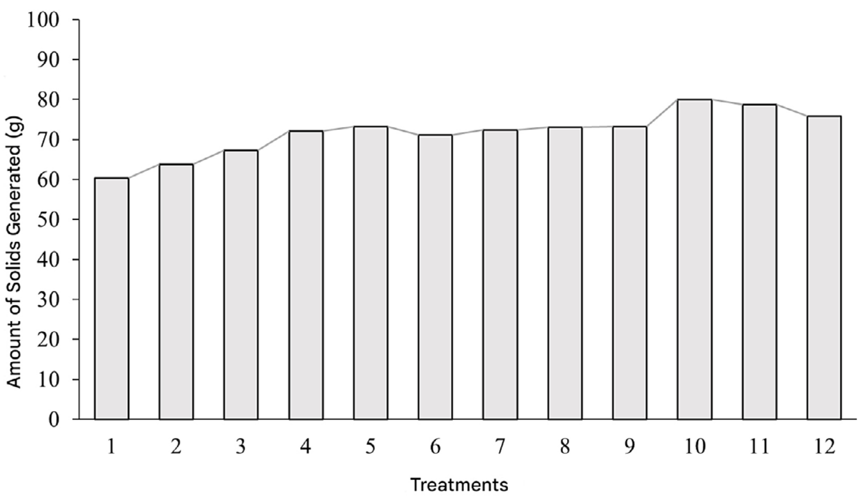

Figure 8. Solids generated by treatments

of wastewater from poultry slaughterhouses, finding high turbidity in all stages (196–238 FAU), color well above the normative limit (up to 2369 degrees) and total suspended solids of up to 374 mg/dm³, which shows a high load of organic and particulate matter. In another approach, the response surface methodology was used to optimize the coagulation process of surface waters with *Moringa oleifera* seed extract, evaluating four factors: agitation time, velocity, sedimentation time and coagulant concentration. 29 experimental tests were applied with the Box-Behnken design on 300 mL samples. Both studies demonstrate viable alternatives to improve water quality through efficient and sustainable processes.

Recent studies on the combination of aluminum sulfate (alum) with bioactive molecules extracted from *Moringa oleifera* show a high efficiency in the removal of contaminants present in municipal wastewater, the proposed process, which uses a 1:1 ratio (50:50 w/w) of alum and protein powder from Moringa, achieved a removal of more than 90% of turbidity and 75% of COD in wastewater tests, especially in those with a high solids load. These findings coincide with what was observed in the present study, where color removal efficiencies between 72% and 90% were obtained, values that are within the range reported by the literature (85%–95%) and even reaching comparable levels under certain experimental conditions. This correspondence between studies strengthens the evidence on the positive synergy between natural and conventional coagulants (Kane et al., 2017).

Another research evaluated the viability of *Moringa oleifera* (MO) seed extract compared to aluminum sulfate (alum) as coagulants for stormwater treatment. Parameters such as temperature, pH, conductivity, turbidity, and total suspended solids were evaluated before and after the application of coagulants. The results obtained on the percentage of reduction in the height of the interface showed low values (0.47%, 0.76%, 1.14% and 0.19%) when variable concentrations (50, 60, 70 and 80 mg/L) of *Moringa oleifera* seed extract were applied. In contrast, significantly higher percentages of reduction (87.07%, 90.09%, 95.27%, and 94.57%) were observed when using the same concentrations of the alum solution. However, the differences between the percentages of reduction in the height of the interface of both coagulants were statistically significant $p < 0.05$ (Bate et al., 2023).

Gohatre, (2016) evaluated the effects of different coagulants —alum, lime, polyelectrolyte, ferrous sulfate and their combinations— on the quality of industrial wastewater effluent, through tests of modified jugs in the laboratory, the potential of coagulants and their combinations to reduce the parameters of industrial effluent is good. The maximum formation of flocs occurred at pH 9 and pH 10, and the combination of lime, ferrous sulfate and polyelectrolyte gave the best result, removing color, BOD, COD, SST and volume of sludge, represented by the purple line with crosses, a tendency to low dose (0 mg/L) is observed, the volume of sludge is low, but as the lime dose increases to 120 mg/L, the volume of sludge increases steadily and significantly.

CONCLUSIONS

The animal slaughtering process in the municipal slaughterhouse of Calceta generates solid and liquid waste in different operational stages, highlighting bleeding, skinning and evisceration. The physicochemical characterization of the wastewater shows a concentration of total suspended solids (450 mg/L above the permitted limit (100 mg/L) and a high color (319 PCU) and turbidity (23.54 NTU). The treatments applied demonstrated a high efficiency in the removal of color, turbidity and TSS, with percentages that mostly exceed 85%, which shows the efficacy and greater performance of using the bioactive synergy of *moringa oleifera coagulant* and aluminum sulfate, highlighting that treatments 9 and 11, with removals at 90% and 99%, respectively.

The analysis of variance applied to the color, turbidity and total suspended solids (TSS) parameters reveals that the dose of the biocoagulant (Factor A) is the factor with a statistically significant effect on both color removal ($p = 0.0007$) and TSS ($p = 0.0005$). Tukey's test shows that the doses of 10000 mg and 12000 mg exceed 85% efficiency, with the dose of 10000 mg standing out for its high consistency. For TSS, all doses achieve removals greater than 90%, although the 7500 mg dose has greater dispersion. From 10000 mg onwards, optimal performance is observed. In contrast, aluminum sulfate (B) dose, pH (C), and their interactions showed no significance. Despite this, the treatments achieved efficiencies of up to 90% in color, 85% in turbidity and 99% in TSS.

The amount of solids generated shows variations between treatments, treatments 1 to 3 generated less solids (60–68 g), while treatments 4 to

9 stabilize between 70 and 73 g, followed by a slight decrease in treatments 11 and 12 (76–79 g), however treatment 10 stood out as the one with the highest production (80 g).

REFERENCES

1. Adesina, O. A., Abdulkareem, F., Yusuff, A., Lala, M., and Okewale, A. (2019). Response surface methodology for the optimization of surface water coagulation process parameters using *Moringa oleifera* seeds. *South African Journal of Chemical Engineering*, 46–51. https://doi.org/10.1016/j.sajce.2019.02.002
2. Arreola, M. S., Canepa, R. L. (2013). *Moringa oleifera* is an alternative to replace metal coagulants in water treatment. *Engineering*, 93–101.
3. Bate, G. B., Adeleye, A. O., Amoo, A. O., Ijanu, E. M., Asaju, C. D., and Mohammedicina, H. S. (2023). Comparative evaluation of moringa oleifera seed extract and aluminum sulfate solution efficiency as coagulants for stormwater treatment. *Journal of the Bangladesh Academy of Sciences*, 119–125. https://doi.org/10.3329/jbas.v47i1.61838
4. Bermúdez, X. C., Ramírez, M. F., and Moya, A. C. (2019). Study of the coagulation-flocculation process of wastewater of the textile company "Desembarco del Granma". *Chemical Technology*, 64–73.
5. Bittner, A. (2022). Analysis of Variance (ANOVA) assumption review of tions: Normality, variance Quality and Independence. *Annual International Occupational Ergonomics and Safety*. https://doi.org/10.47461/isoes.2022
6. Cabrera, J. J., Alcivar, L. C., Grijalva-Endara, A., Tinedo, R. W., and Tomalá, J. A. (2022). *Removal efficiency and impact of the wastewater treatment system of the urban and rural sector of the Province of Santa Elena*. 177–187. https://doi.org/10.17268/manglar.2022.022
7. Gohatre, C. (2016). Effects on the quality of industrial wastewater effluent through coagulation and flocculation. *International Journal of Engineering Research and Technology*. http://dx.doi.org/10.17577/IJERTV5IS100146
8. Horn, L., Shakela, N., Mutorwa, M. K., Naomab, E., and Kwaambwa, H. (2022). *Moringa oleifera* as a sustainable and climate-smart solution to the challenges of nutrition, disease prevention, and water treatment: a review. *Journal of agricultural and food research*.
9. Jain, A., Subramanian, R., Manohar, B., and Radha, C. (2019). Characterization and functional properties of *Moringa oleifera* seed protein isolate. *Journal of Food Science Technology*. https://doi.org/10.1007/s13197-019-03690-0
10. Kane, C., Bâ, A., Ayessou, N., Mbacké, M. K., and Diop, C. G. (2017). Combination of alum and powder of bioactive molecules extracted from Moringa oleifera for the treatment of municipal wastewater. *International Journal of Biological and Chemical Sciences*, https://doi.org/10.4314/ijbcs.v10i4.39
11. Leones, M. M., Donado, K. R., and Martínez, I. M. (2018). Evaluation of the coagulant power of aluminum sulfate and *Moringa oleifera* seeds in the process of clarifying the water of the Malambo swamp, Atlántico. *UIS Ingenierías*, 95–103.
12. Marinho, Y., Oliveira, A. P., Oliveira, C. Y., Napoleão, T., Guedes, P., Sant'Anna, M. C.,... Gálvez, A. (2022). The use of residual seeds of *Moringa oleifera* promotes the efficient flocculation of Tetradesmus dimorphus biomass. 1–9. https://doi.org/10.1007/s13399-022-02789-3
13. Martha, S. A., and Ramón, L. C. (2022). Removal of contaminants in wastewater by means of the cationic polyelectrolyte extracted from *Moringa oleifera* seeds. *Hydraulic and Environmental Engineering*, 93–101.
14. Medina, C., Uriarte, W., Cárdenas, E., and Orrego, S. (2020). *Treatment wastewater of slaughterhouses through technology advanced oxidation: fenton process*. UC Engineering Journal, 27(2). Retrieved from https://www.redalyc.org/journal/707/70764230005/html/
15. Meiramkulova, K., Meiramkulova, K., Orynbekov, D., Orynbekov, D., Tashenov, E., Tashenov, E.,... Inglezakis, V. (2020). Evaluation of electrochemical methods for the treatment of wastewater from poultry slaughterhouses. *Sustainability*. https://doi.org/10.3390/su12125110
16. Michael, S., Pascuales, C., Kivevele, T., Rwiza, M., and Njau, K. (2020). Investigating the performance of a slaughterhouse's wastewater treatment plant: the case of the slaughterhouse in the city of Mwanza, Tanzania. *Water Practice and Technology*, 1096–1110. https://doi.org/10.2166/wpt.2020.085
17. Montero, A. A., Arrieta, Y. B., and Serrano, E. P. (2023). Treatment of slaughterhouse wastewater using a series system: anaerobic upflow reactor and artificial wetland. *Water*, 2–14.
18. Mozhiarasi, V., and Natarajan, T. S. (2025). Slaughterhouse and poultry waste: management practices, raw materials for the production of renewable energy and recovery of value-added products. *Biomass Conv. Bioref.*, 1705–1728. https://doi.org/10.1007/s13399-022-02352-0
19. Veliz, E., Llanes, J. G., Fernández, L. A., and Bataller, M. (2016). Coagulation-flocculation, filtration and ozonation of wastewater for reuse in agricultural irrigation. *Technology and water* sciences.
20. Velusamy, M., and Natarajan, T. S. (2022). Slaughterhouse and poultry wastes: management practices, feedstocks for renewable energy production, and recovery of value added products. *Biomass Conv. Bioref*, 1705–1728. https://doi.org/10.1007/s13399-022-02352-0