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RESEARCH ARTICLE

Wastewater Treatment Using Organic By-Products from Agroindustry: A Case Study in the District of Valera, Amazonas Region, Northern Peru

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Abstract: This research evaluates the use of two types of coagulants based on organic by-products (orange and passion fruit) in wastewater (RA) treatment. The system was composed of glass tanks installed in parallel. The coagulants were elaborated and applied in aqueous solution and in powder form, and 7 physicochemical and microbiological parameters were also analyzed. Data analysis was performed using a Student's t-test to compare significant differences. The results indicate significant differences for Total Solids (TS), Chemical Oxygen Demand (COD) and Total Coliforms (TC). The highest efficiency was for pH 13.884 % with the application of orange powder coagulant. As well as for oils and fats 81.102 and 65.354 % for orange and passion fruit powder coagulants. Finally, it was concluded that the coagulants were efficient for some parameters and that these depend on the type of application; therefore, future projects should be promoted to evaluate the viability of using by-products from agroindustry for water treatment and to avoid environmental contamination by these wastes.

Keywords: Ecosystem, Fish Pond Storage, Inert, Gas, Preservation Natural Coagulants, Orange Peel, Passion Fruit Peel, Amazon

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Introduction

The world population by the year 2050 would need three times the planet Earth to provide resources for the current way of life of the population [1] and as the population increases, the demand for water has been increasing by about 1% per year and will continue to rise over the years [2, 3]. Therefore, as water demand increases, the volume of RA increases, and 80% of industrial and municipal wastewater is discharged into the environment without any prior treatment, generating serious impacts on the environment [4]. According to the United Nations (UN), only 8% of domestic and industrial wastewater is treated in developing countries, a very small percentage compared to that of developed countries, where 70% of such water is treated [5].

RA cause damage to soils and natural water sources [6], in view of this there are different treatment systems, such as physical, chemical and biological [7, 8] biological systems have been used through composite filters [9], filters in series and in parallel, even so there are limitations and disadvantages for the operation of biofilters what more researches are needed [10].

Traditional treatments use metallic coagulants [11] such as aluminum and iron to eliminate the solids present in the water [12, 13]. These have low sorption capacity and are not easy to separate from the solutions [14], which in turn generate large volumes of non-biodegradable toxic sludge that require additional treatment [15]. Likewise, coagulants are expensive [13]. In view of this, different studies show the great interest in replacing traditional coagulants with natural coagulants [16], since they generate much smaller volumes of sludge and are economically viable, which makes them a more sustainable option [17].

Therefore, it is necessary that the contaminants in the water must be removed before being used, so it is urgent to develop sorbents that have sorption capacity and are also easy to separate from the solution [18]. Thus, natural and renewable coagulant alternatives should be sought for RA treatment [19]. One of the methods is coagulation, this process aims to remove particles and organic matter [20]. Being the most used in the various pretreatments of contaminated water due to its low cost [21].

Using natural sorbents to purify water is highly cost-effective as a replacement alternative to chemicals [22], as they show properties in turbidity removal and do not alter the pH in the process [23], they also reduce the risk of sludge toxicity from chemicals such as aluminum [24] and are promising for their low cost and efficacy [7].

The use of natural coagulants in wastewater treatment has been widely studied in countries such as Brazil, Spain, Colombia, among others. However, in Peru there are few works in this line of research. Hence, it has become a great concern to develop effective natural coagulants, low cost and above all clean for the environment. Some natural absorbents have been used effectively [17], but more studies are needed to validate this alternative in the wastewater treatment process.

Natural extracts of seeds, leaves, tree bark and roots form flocs in the coagulation process in wastewater treatment. Thus, for example, they used G. ulmifolia in coagulation for the removal of BOD_5, COD and turbidity from wastewater [25, 26]. On the other hand, Singh et al. [27] used Moringa oleifera seeds as a coagulant and bio absorbent to improve water quality and microbial load.

Orange production generates quantities of by-products (orange peel and peel) that are part of household organic waste and industrial valorization is not carried out to avoid ecological problems [28]. In this sense, orange peel can be used as a natural absorbent for heavy metals [29], oil spills [30], radioactive solutions such as uranium [26], Pb II in aqueous solution [11], Cd II [31], phenol, Cu II in solution [32].

Passion fruit is a fruit whose pulp is used for juices and contributes to an important part of the economic movement; however, in production, large amounts of waste are generated from the discarding of passion fruit peels, which causes serious environmental problems [33]. As well as passion fruit peel which has a potential as a natural coagulant in the removal of COD in wastewater [15]. Another study shows that the absorbent is highly efficient in removing cationic dyes from water and is low cost and environmentally friendly [34].

Based on the above, the objective of this research was to evaluate the efficiency of the use of two types of coagulants based on orange and passion fruit peel as natural coagulants in the treatment of wastewater from the Cocachimba annex.

Materials and Methods

Location

The study was carried out in the Cocachimba annex (coordinates 1799339 E, 9329424 S), Valera district, Bongará province, Amazonas department, bordered to the north by San Carlos and Churuja districts, to the east by Jumbilla district, to the south by Chachapoyas province and to the west by Luya province (Figure 1).

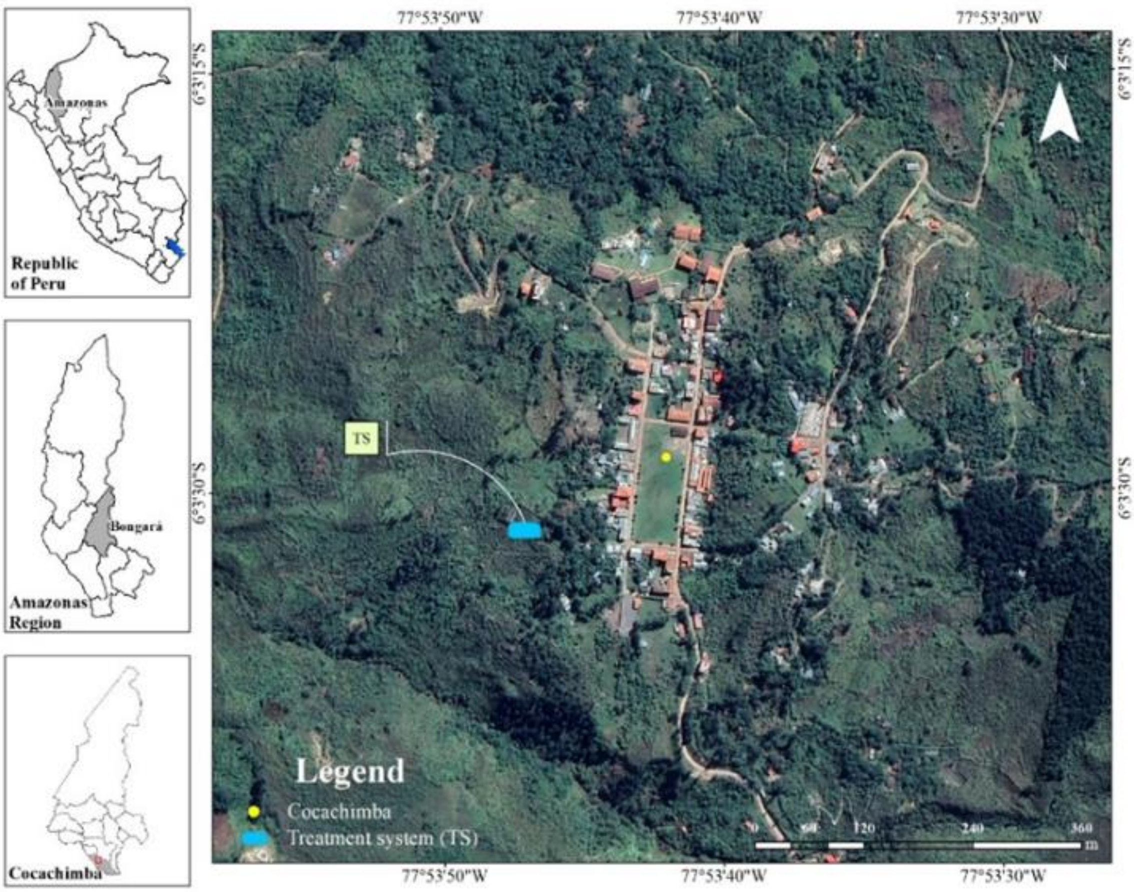

Fig. 1: Location of the experiment

The climate ranges between 14°C and 19°C, and the population is approximately 270 inhabitants [35]. The wastewater generated in the Cocachimba annex is not treated because it does not have a wastewater treatment plant; however, it does have a treatment system that consists of a grate to filter out large particles, after which it is directed to a sump where the water is stored, The bottom of the sump has crushed stone to filter the water and evacuate it through a 300-meter open channel that flows into the Cajuache stream, which 2 km downstream joins the Gocta stream, which is an effluent of the Utcubamba River, a tributary of the Marañón River.

The population was the wastewater from the Cocachimba annex and six samples were taken monthly, making a total of 18 samples, six samples were untreated wastewater (PM1) and twelve samples were treated with orange peel coagulant (PM2) and passion fruit (PM3).

Collection of Agro-Industrial Wastes for the Preparation of Coagulants

Orange and passion fruit peels were collected from the Pedro Ruiz market in the Jazán district and washed with tap water to remove dirt. The cleaned peels were air-dried for 24 hours and manually cut into small pieces and transferred to the Laboratory of Plant Physiology and Biotechnology (FISIOBGEG) of UNTRM, to be dried in an oven at 110 °C for 24 hours

[14, 36]. The dried peels were ground separately in a manual mill obtaining a powder that was used as a coagulant. The mode of application was in two stages.

Obtaining the Coagulant in Solution

A solution was prepared with 10 grams of powdered orange and passion fruit peel separately in one liter of distilled water, and 30 ml of solution was applied to 1 liter of wastewater. The used capacity of the treatment tanks was 100 liters of wastewater; therefore, 3 liters of each solution (orange and passion fruit) were used.

Obtaining the Coagulant Poder

Six grams of powdered orange and passion fruit peel were used separately for each liter of wastewater and 600 g of orange and passion fruit peel, respectively, for 100 liters. The application of the coagulant in each treatment, an agitation was carried out after the pouring for a reaction time of one hour, then the samples were taken to be analyzed in the laboratory.

Wastewater Treatment System Design and Implementation

The design and implementation of the wastewater treatment system consisted of two glass tanks installed in parallel (Figure 2) measuring 0.5 m long by 0.5 m wide by 0.5 m high, with a maximum capacity of 125 liters; the wastewater from the main pipeline was gravity fed into the tanks. This allowed the coagulants to be evaluated properly, given that the experiment did not control the entire flow. Samples were taken at the inlet and outlet of the treatment for physical, chemical, and microbiological analysis at the Soil and Water Research Laboratory (LABISAG) of the UNTRM.

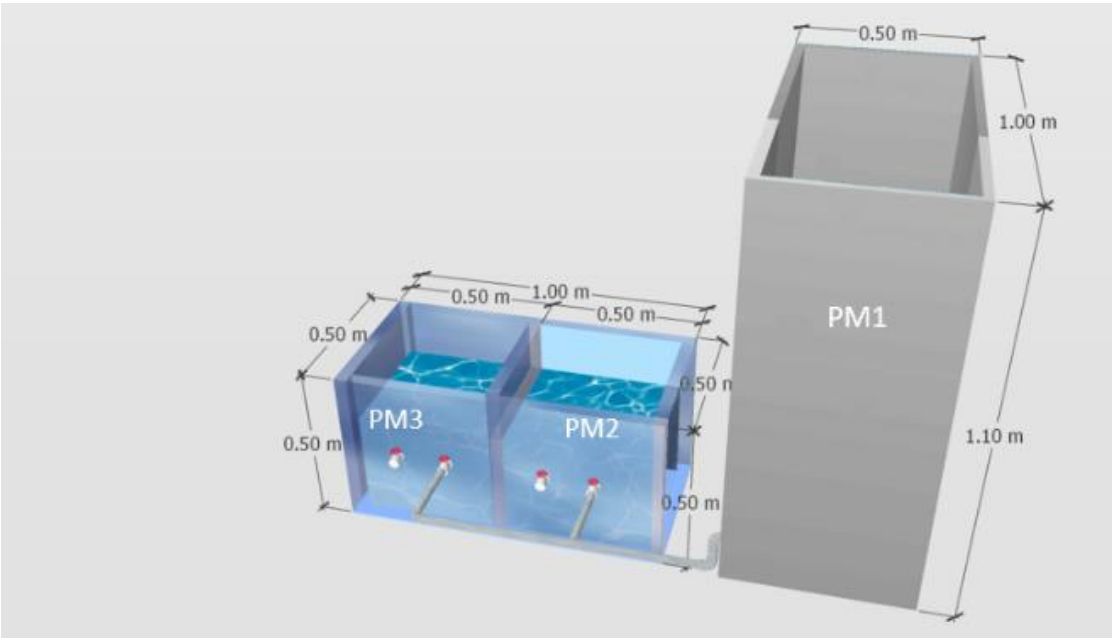

Fig. 2: Design of the wastewater treatment system; PM1 = wastewater without treatment; PM2 = treatment with orange peel coagulant; PM3 = treatment with passion fruit peel

Characterization of Wastewater

Samples for the analysis of physicochemical parameters were taken in plastic containers, disinfected and legibly labeled. The samples were completely gauged and immediately capped and placed in a cooler with dry ice for preservation, following the protocol for monitoring the quality of effluents from domestic or municipal wastewater treatment plants. For microbiological parameters, sampling was performed in sterilized and labeled glass containers [37, 38].

The characterization of the physicochemical parameters of BOD5 was by incubation and for COD the spectrophotometer was used, for total solids it was by Method 2540 B and pH was determined in situ using the HACH Multiparameter equipment;

fecal coliforms were determined by the presumptive phase and the confirmatory phase [39], in the soil and water research laboratory of the National University Toribio Rodriguez de Mendoza (UNTRM). Meanwhile, the oil and grease parameter was analyzed at the regional water laboratory of the regional government of Cajamarca. Temperature was measured in situ with a digital thermometer after calibration at the LABISAG of the UNTRM. The APHA method was used for each laboratory analysis (Table 1).

Table 1: Methods of analysis of physicochemical and microbiological parameters

Parameter	Unit of Measurement	Method
Hydrogen Potential (pH)	pH	Method 4500-H+
Temperature (T°)	°C	Method 2550 B
Total Solids (TS)	mg/L	Method 2540 B
Biological Oxygen Demand (BOD5)	mg/L O_2	Method 8043, dilution
Chemical Oxygen Demand (COD)	mg/L O_2	Method 8000, reactor digestion
Total Coliforms (TC)	NMP/100ml	Method 9221-C, Fecal Coliform MPN procedure.
Oils and Fats	mg/L	EPA Method 1664 Rev.B.2010

Source: APHA, AWWA, WEF and HACH, 2017

Evaluation of the Quality of Wastewater from the Treatment System According to National Standards

The comparison with national regulations was to verify whether they exceed the admissible values established in the Maximum Permissible Limits (MPL) for effluents from Domestic or Municipal Wastewater Treatment Plants [40], since their purpose is to control excesses in the concentration levels of effluents and thus prevent damage to health and the environment. Also, it was verified whether the treated water is suitable for reuse, in that sense it was compared with the Environmental Quality Standards (EQS) for Water [41] (Category 3: Vegetable irrigation). The criterion was established with the aim that future work can be addressed in order to obtain treated water for irrigation [42] and to safeguard the quality of water resources as a receiving body.

Data Analysis

The wastewater treatment system was designed in 3D using Autodesk Revit software version 2021, which allowed assessing the feasibility of its implementation. A double-entry table was prepared to evaluate the input and output of the application of coagulants. Likewise, it was verified that the data had a normal distribution, so the student’s t-test was applied to compare the significant differences (inputs and outputs), the statistical software used was minitab 19 [43]. Efficiency was calculated using a mathematical formula that expresses the percentage of removal of each parameter (input and output) of the system. Finally, a simple table was constructed in Excel on the basis of which a comparison was made with the Maximum Permissible Limits (MPLs) for effluents from domestic wastewater treatment plants and the environmental quality standards (ECA) for water.

Results

Characterization of Physicochemical and Microbiological Parameters

Table 2 shows the behavior of the physicochemical parameters, showing that in the application of coagulant in solution there were no significant differences ($p< 0.05$), and the reduction of contaminants was minimal, for example, the effect of the orange coagulant in aqueous solution on pH stabilized at 7.07, and the passion fruit coagulant stabilized pH values at 7.63. Meanwhile, when applying the powder coagulant, significant differences were found for the TS and COD parameters with the orange coagulant. The passion fruit-based coagulant also showed differences for TS, BOD_5, and COD. Therefore, the orange and passion fruit powder coagulants were able to reduce pH values to 5.31 and 5.35, respectively. In terms of oils and fats, the orange powder was able to reduce the values from 11.85 to 6.55 mg/L, and the passion fruit powder achieved a significant reduction from 11.85 to 2.93 mg/L.

Table 2: Behavior of the physicochemical parameters in the treatment system based on coagulants obtained from agro-industrial by-products

Coagulant in aqueous solution					
Sampling point of treatments	Parameter	Averages		T-test	
		Input (ARCN)	Output	Value of T	p-valor
Orange Coagulant	pH	7.83±0.44	7.07±0.11	1.94	0.19
	T° (°C)	18.9±0.10	19.97±1.07	-1.07	0.39
	TS (mg/L)	97.77±52.27	135.38±112.49	-0.23	0.83
	BOD_5 (mg/L O_2)	57.89±14.93	68.73±13.19	-0.68	0.56
	COD (mg/L O_2)	102.6±85.1	188.1±32.2	-3.14	0.08
	TC (MPN/100ml)	1600±0.00	1600±0.00	0	0
	Oils and Fats (mg/L)	36.7±13.8	34.0±17.5	0.17	0.88
Passion Fruit Coagulant	pH	7.83±0.44	7.63±0.77	0.31	0.78
	T° (°C)	18.9±0.10	19.36±0.81	-1	0.42
	TS (mg/L)	97.77±163.89	117±20.3	-0.88	0.47
	BOD_5 (mg/L O_2)	57.89±14.93	63.89±15.22	-0.45	0.69
	COD (mg/L O_2)	102.6±85.1	104.4±36.4	-0.04	0.97
	TC (MPN/100ml)	1600±0.00	1600±0.00	0	0
	Oils and Fats (mg/L)	36.7±13.8	31.73±1.63	0.63	0.59
Natural powder coagulants					
Sampling point of treatments	Parameter	Averages		T-test	
		Input (ARCN)	Output	Value of T	p-valor
Orange Coagulant	pH	7.31±1.26	5.31±0.10	2.99	0.096
	T° (°C)	19.55±1.05	19.4±0.10	0.27	0.81
	TS (mg/L)	476.3±126.3	1809±91.3	10.63	0.009*
	BOD_5 (mg/L O_2)	68.80±7.85	71.05±7.30	-0.26	0.821
	COD (mg/L O_2)	17.4±14.1	1102.5±82.5	-27.46	0.001*
	TC (MPN/100ml)	1600±0.00	1600±0.00	0	0
	Oils and Fats (mg/L)	11.85±0.85	6.55±4.15	1.84	0.208
Passion Fruit Coagulant	pH	7.31±1.26	5.35±0.03	2.76	0.11
	T° (°C)	19.55±1.05	18.95±0.65	2.6	0.122
	TS (mg/L)	476.3±126.3	1728±28.5	-22.5	0.002*
	BOD_5 (mg/L O_2)	68.80±7.85	78.05±4.05	-1.28	0.033*
	COD (mg/L O_2)	17.4±14.1	804.4±71.9	-23.05	0.002*
	TC (MPN/100ml)	1600±0.00	1600±0.00	0	0
	Oils and Fats (mg/L)	11.85±0.85	2.93±2.54	8.33	0.014

ARCN = wastewater under normal conditions; *significant differences

Efficiency of Natural Coagulants Obtained from Orange and Passion Fruit Peel

The application of the orange and passion fruit coagulant in solution showed an efficiency with respect to pH of 13.8 and 12.0%. Meanwhile, the efficiency of the coagulant powder for oils and fats ranged between 81.102 and 65.354 % for orange and passion fruit respectively (Table 3). However, further studies are needed that address natural coagulants with different combinations and concentrations, intensifying agitation to prevent sedimentation, with the aim of removing the concentration of the BOD_5 and COD parameters.

Water Quality in Water Treatment System

Table 4 shows the comparison between the treatments and the parameters accepted according to national regulations (D.S N°004-2017-MINAM) for Water, category 3: Vegetable Irrigation and the MPLs for effluents from Domestic or Municipal Wastewater Treatment Plants. It is evident that the application of coagulants in solution for oils and fats was not within the MPL and ECA. However, the application of powder coagulants did comply with the regulations, but the increase in other parameters, such as COD reached values of 1102.5 mg/L of O2 with the application of orange coagulant, and the ST reached values up to 1809 mg/L.

The behavior of the physicochemical parameters, with the application of powdered coagulants (orange and passion fruit) significant differences were found for the parameters of ST and COD. These coagulants achieved greater effectiveness and managed to stabilize pH values at 5.31 and 5.35 respectively, this can be encouraging given that, some studies mention that less coagulant is needed at lower pH conditions [24]. It is also associated with other studies that used as coagulants, but it will depend on the pH of the water and the dose used for its effectiveness [44]. Regarding oils and fats, powdered orange peel achieved a decrease from 11.85 to 6.55 mg/L, and passion fruit peel achieved a significant reduction from 11.85 to 2.93 mg/L. The reduction of oils and fats is important because it avoids environmental contamination of soil, air and humans [45], which in turn is generated by dishwashers that use fats and some food solids that are emitted to the RA [46].

Table 3: Efficiency of coagulants obtained from agroindustrial by-products (orange and passion fruit)

Coagulant in aqueous solution		
Parameter	**% Efficiency Orange**	**% Efficiency Passion fruit**
pH	9.78	3.23
T° (°C)	-5.64	-2.47
TS (mg/L)	-36.93	-20.06
BOD_5 (mg/L O_2)	-18.73	-10.34
COD (mg/L O_2)	-83.61	-1.77
TC (MPN/100ml)	0	0
Aceites y grasas (mg/L)	7.27	13.45
Natural powder coagulants		
Parámetro	**% Efficiency Orange**	**% Efficiency Passion fruit**
pH	13.884	12.066
T° (°C)	5.34	4.854
TS (mg/L)	-442.857	-385.714
BOD_5 (mg/L O_2)	16.83	4.305
COD (mg/L O_2)	-3664.295	-2683.355
TC (MPN/100ml)	0	0
Oils and fats (mg/L)	81.102	65.354

Table 4: Quality of wastewater treated with natural coagulants

Coagulant in solution				
Sampling point of treatments	**Parameter**	**Average output**	**D.S.004- 2017-MINAM: Environmental Quality Standards for Water (Category 3).**	**D.S.003- 2010-PCM: Maximum Permissible Limits**
Orange coagulant	pH	7.07±1.11	6.5 - 8.5	6.6 - 8.5
	T° (°C)	19.97±1.07	∆3	<35
	TS (mg/L)	135.38±112.49	-	150
	BOD5 (mg/L O_2)	68.73±13.19	15	100

	COD (mg/L O_2)	188.1±32.2	40	200
	TC (MPN/100ml)	1600±0	2000	10000
	Oils and fats (mg/L)	34.0±17.5	5	20
Passion Fruit Coagulant	pH	7.63±0.77	6.5 - 8.5	6.6 - 8.5
	T° (°C)	19.36±0.81	∆3	<35
	TS (mg/L)	117.0±20.3	-	150
	BOD5 (mg/L O_2)	63.89±15.22	15	100
	COD (mg/L O_2)	104.4±36.4	40	200
	TC (MPN/100ml)	1600±0	2000	10000
	Oils and fats (mg/L)	31.73±1.63	5	20
Natural powder coagulants				
Orange coagulant	pH	5.31±0.10	6.5 - 8.5	6.6 - 8.5
	T° (°C)	19.4±0.10	∆3	<35
	TS (mg/L)	1809±91.3	-	150
	BOD_5 (mg/L O_2)	71.05±7.3	15	100
	COD (mg/L O_2)	1102.5±82.5	40	200
	TC (MPN/100ml)	1600±0	2000	10000
	Oils and fats (mg/L)	6.55±4.15	5	20
Passion Fruit Coagulant	pH	5.35±0.03	6.5 - 8.5	6.6 - 8.5
	T° (°C)	18.95±0.65	∆3	<35
	TS (mg/L)	1728±28.5	-	150
	BOD_5 (mg/L O_2)	78.05±4.05	15	100
	COD (mg/L O_2)	804.4±71.9	40	200
	TC (MPN/100ml)	1600±0	2000	10000
	Oils and fats (mg/L)	2.93±2.54	5	20

Discussion

The highest ST was visualized with the orange coagulant with 1809 mg/l and the lowest was in the passion fruit coagulant with 1728 mg/l. As expected, these values are attributed to the application of the coagulant powder and the sediment of the coagulant particles themselves. According to the references consulted, the efficiency of orange and passion fruit coagulants could be influenced by the process of obtaining the coagulant powder or by the chemical characteristics present in the water to be treated [47]. Comparing with the application of coagulants in aqueous solution, lower values of 135.38 and 117 mg/L were evidenced; however, their effectiveness on other parameters in the experimental dose applied (10 g dissolved in 30 ml of solution) did not influence the reduction. Natural coagulants in some cases can have a good removal performance and are a function of the amount of coagulant used [48], and this is evident as this study reaffirms the importance of the exact dosage per liter of water.

Organic matter such as BOD5 showed an increase after treatment with the coagulant in aqueous solution and in powder form compared to wastewater under normal conditions. Similarly, increases were evidenced for COD, which could be associated with the accumulation of sediment that influences microbial growth and increased turbidity in the water, as well as temperature variation [49, 50].

During the application of the coagulant in solution, the parameters evaluated did not exceed the MRLs for effluents from domestic wastewater treatment plants, except for oils and fats, which exceeded the RCTs for irrigation by 5 mg/L [41] (MINAM, 2017) and the MRLs established at 20 mg/L [51], evidencing a contamination problem for the environment and evidently future studies should work on the reduction of these components, for their application to obtain water for vegetable irrigation and animal drinking water. Meanwhile, the efficiency of the orange and passion fruit peel coagulant powder for the reduction of oils and fats is remarkable, in both cases the values were within the ECA and MPL. The TC values were >1600 NMP/100mL, being within the Maximum Permissible Limits and the Environmental Quality Standards for Water, although no reduction effect of the coagulants was evidenced. However, Yasmeen et al. [52] mention that treatments with coagulants for microbiological parameters have not been very efficient, and there is no evidence of studies related to the use of orange and passion fruit peel, compared to other natural products such as moringa [53].

The powder coagulants were more efficient for pH with 13.8 and 12.0 %, and for oils and fats the efficiency ranged between 81.1 and 65.3% for orange and passion fruit, respectively, being an economical and sustainable method. This may be related to the efficiency of orange peel powder and is even considered to be close to that of the chemical coagulant alum [54].

For all of the above, more related studies should be promoted to close the gaps of high numbers of water discharged without prior treatment, showing the need to conduct research on environmentally safe options and to be able to reuse water. The reuse of wastewater would facilitate the optimization of water resources, since using wastewater for irrigation will allow volumes of clean water to be used for human consumption [55]. Thus, future projects should address the use of coagulants from agro-industrial waste, and identify the correct application of these coagulants, as well as the contemplation of more prolonged sampling according to the environmental conditions of each place.

Conclusion

The orange and passion fruit coagulants were efficient for some physicochemical parameters such as pH and oils and fats, the efficiency was 81.1 and 13.8%, while for other parameters they showed deficiencies in the treatment. In this sense, it is evident that the application of coagulants depends on the form of application and the amount of coagulant per liter of water. The study showed that the application of the powder coagulant was more efficient and was able to stabilize the pH, oil and grease parameters, achieving compliance with the MPL.

Coagulants of natural origin can provide an alternative to chemical coagulants in the treatment of RA, but the economic profitability and their application in rural communities that do not have an RA treatment plant should be further analyzed.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author's Contributions

Eli Morales-Rojas: Conceptualization, investigation, writing original draft, writing review and edited.
Sayda Karina García Caro and Jesús Rascón: Conceptualization, investigation, writing review and edited.
Edwin Adolfo Diaz: Formal analysis, statistical analysis, writing review and edited.
José Marchena: Methodology, Project administration, Resources, Software, Validation, Data visualization.
Ítalo Maldonado Ramírez: Data curation, investigation, writing review and edited.
Pompeyo Ferro, Euclides Ticona, Edita Fernández and Roberto Santa Cruz Acosta: Investigation, data collection.
Lily Juarez-Contreras: Investigation, data analysis.
Cesar Balcazar-Zumaeta: Data analysis, project administration.
Carlos Máximo Gonzales Añorga: Validation, writing review and edited.

Fredy Velayarce Vallejos: Investigation, project administration.
All authors have read and approved the final version of the manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all authors have read and approved the manuscript and that there are no ethical issues.

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