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Study of the Chemical Composition of Banana Peel Waste (*Musa paradisiaca*) and Evaluation of Its Bioflocculant Properties

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Abstract

Wastewater treatment is a major environmental issue, requiring effective and sustainable solutions around the world. In this study, plantain peel is used as a natural coagulant-flocculant in the wastewater treatment process. To do this, decoctions of ripe and unripe banana peels were prepared. The main chemical constituents were then identified using characteristic reagents. The total oses, total phenolic compounds, and condensed tannins were measured using the phenol-sulfuric acid, Folin-Ciocalteu, and vanillin methods in an acidic medium, respectively. Finally, the flocculant-coagulant properties of the different aqueous extracts were evaluated using the Jar Test method. The yields of dry crude extracts were 17.91% and 25.4% for ripe and unripe banana peels, respectively. Qualitative tests revealed the presence of polysaccharides, alkaloids, tannins, and lignins in both extracts. The various assays performed showed that ripe banana peels contain significant levels of total oses, total phenolic compounds, and condensed tannins, with values of 621.297 µg EG/mg, 72.514 µg EAG/mg, and 17.315 µg EC/mg of dry extract, respectively. Fourier Transform Infrared (FTIR) analyses of the two plantain peel extracts qualitatively revealed the presence of certain functional groups characteristic of polysaccharides and phenolic compounds. The evaluation of flocculant-coagulant properties showed a better reduction in wastewater turbidity with a reduction rate of 96.93% and 88.81% at pH = 2 for concentrations of 40 µg/mL and 60 µg/mL of dry extracts from ripe and unripe banana peels, respectively. The same extracts have been shown to be effective in the reduction of organic load COD and BOD_5 and the removal of certain heavy metals such as Zn, Mn, and Hg.

Keywords

Wastewater, Banana Peels, Polysaccharides, Coagulant-Flocculant, Jar Test, Heavy Metals

1. Introduction

Global population growth and industrial expansion have led to a high demand for water. This misuse of water resources results in the discharge of industrial and domestic wastewater into the natural environment [1]. The amount of wastewater produced each year worldwide is estimated at 380 billion m^3 and is expected to increase by 51% by 2050 [2]. The discharge of wastewater remains a global environmental problem. According to the United Nations World Water Development Report 2017, more than 80% of global wastewater is released into the environment without treatment [3]. The discharge of untreated wastewater into the natural environment can contribute not only to the destruction of flora and fauna but also to the pollution of groundwater [4]. To mitigate the effects on the environment, international organizations and local authorities require industries to comply with standards for wastewater and industrial waste discharge. These standards require that water be treated before being discharged into the natural environment.

The process of water treatment involves coagulation-flocculation with chemical compounds in order to reduce pollutants present in the suspension in wastewater [5]. Chemical coagulants are widely used in urban and industrial wastewater treatment because of their effectiveness [6]. Various coagulants/flocculants such as inorganic compounds (e.g. $FeCl_3$), and organic compounds such as synthetic polymers made from compounds that are toxic to humans and the environment (e.g. polyacrylamides) are generally used [6]. The solid fraction of sludge from the process is mainly used for agricultural spreading, but this depends on the chemical composition of the sludge [7]. Recent studies have raised concerns about the existence of persistent or incurable diseases due to the presence of non-degradable organic compounds and metal residues from these chemical coagulants, which are non-degradable and remain in the water and sludge even after treatment.

Recently, naturally occurring polymers such as polysaccharides derived from plants and agricultural crop residues have attracted attention for their use as flocculants [8]. These compounds offer many advantages as they are environmentally friendly, renewable, and represent an alternative for valorization of agricultural co-products or by-products [8]. Tests have already been carried out on certain plants such as *Moringa oleifera* seeds*, okra* seeds*, Jatropha curcas, banana* skins*,* etc. [7].

Among these plants, bananas offer an advantage because they are rich in secondary metabolites and are widely consumed in several sub-Saharan African countries. However, their residues remain largely unvalued. Several studies have shown that banana peels contain macromolecules such as proteins, polysaccha-

rides, and certain phenolic compounds [9]. These groups of compounds are well known for their coagulation-flocculation properties. Polysaccharides and certain phenolic compounds are known to promote adsorption, polymer bridging, and charge neutralization during wastewater treatment [7].

The objective of this work is therefore to evaluate the "coagulant-flocculant" properties of banana peels with a view to their use as bioflocculants for wastewater treatment.

2. Materials and Methods

2.1. Plant Material

Plantains of the species *Musa paradisiaca* were collected in December 2024 in Ouagadougou, the capital of Burkina Faso, and then peeled. The banana peels obtained were carefully washed with distilled water to remove impurities and contaminants, then dried in the sunlight for 72 hours. They were then ground into a fine powder using an electric grinder. This powder was later used to prepare the extracts.

2.2. Wastewater Collection

The wastewater used in this experiment comes from soakaway wells at a brewery located in the Kossodo industrial zone in the city of Ouagadougou, Burkina Faso, at the following GPS coordinates: 12˚25'15.503"N 01˚28'40.328"W. The wastewater was collected in collaboration with a brewery manager. After sampling, the water was stored in containers and kept at room temperature in the laboratory for analysis within three days.

2.3. Extraction Method

Decoction was chosen as the method for extracting polysaccharides and phenolic compounds. Thus, 70 g of ripe banana peel (RB) powder was placed in a 1 L Erlenmeyer flask containing 700 mL of distilled water. The mixture was boiled for 3 hours. After cooling, the marc was separated from the filtrate using Wattman No. 1 paper. The filtrate obtained was concentrated using a rotary evaporator, then condensed at −20˚C before being freeze-dried. The freeze-dried products obtained were stored in a dry place for further experiments. Unripe banana peel was treated with the same protocol for comparison (UB).

2.4. Chemical Screening

In this work, conventional characterization techniques were used to identify polysaccharides and some secondary metabolites in banana peel extracts. These techniques include colorimetric tests and characterization by Fourrier Transform Infrared (FTIR) spectroscopy. Each family of polysaccharides or secondary metabolites was identified by reacting the extract with a reagent specific to the chemical group being sought. Its presence in the extract is characterized by a specific coloration of the reaction mixture or by the formation of a precipitate.

2.5. Characterization of Total Oses Assay

The total oses content in the crude banana peel extract is determined using the phenol-sulfuric acid method. In the presence of hot concentrated sulfuric acid, the glycosidic bonds are hydrolyzed. These products condense with phenol to form yellow-orange complexes. These colored complexes absorb at 490 nm, which allows the total oses concentration of the analyzed sample to be determined. A mixture of 200 µL of the sample and 200 µL of 5% phenol is placed in a glass tube. After homogenization, 1 mL of sulfuric acid H_2SO_4 (96%) is quickly added to the reaction medium. The tubes are then incubated at 100˚C for 5 min, then left to cool in an ice bath for 30 min. The absorbance is measured at 490 nm for neutral sugars and at 430 nm for uronic sugars using a SPECTROstar NANO UV spectrophotometer.

2.6. Assay of Phenolic Compounds

The oxidizable groups of phenolic compounds are oxidized by Folin-Ciocalteu Reagent (FCR). The protocol consists of preparing solutions at different concentrations of each extract ranging from 0.005 mg/mL to 0.1 mg/mL. 0.5 mL of each of these solutions is then added to 0.5 mL of FCR. The mixture is incubated for 8 min at room temperature in the laboratory before adding 1 mL of a 7.5% sodium carbonate solution (m/v in g/mL). The mixture is incubated again for 1 h at room temperature before reading the absorbance at 765 nm using the SPECTROstar NANO spectrophotometer.

Gallic acid is used as the standard to establish the calibration curve from which the concentrations of total phenolic compounds in the extracts are calculated. Gallic acid solutions are prepared at concentrations ranging from 0.005 mg/mL to 0.1 mg/mL. The results are expressed in micrograms of gallic acid equivalent per milligram of extract (µg EAG/mg).

2.7. Dosage of Condensed Tannins

Condensed tannins were measured using the vanillin method in an acidic medium. Vanillin reacts with free flavan-3-ols and produces a red color whose intensity is proportional to the level of flavanols present in the medium. Vanillin was dissolved in methanol (4% m/v). To 400 µL of each sample or standard, 3 mL of the prepared vanillin solution and 1.5 mL of concentrated HCl were added. After 15 min of incubation, the absorption was measured at 500 nm using a SPECTROstar NANO spectrophotometer against a blank. Tannin concentrations are deduced from the calibration curve established with catechin (standard) and are expressed in micrograms of catechin equivalent per milligram of extract (µg EC/mg).

2.8. Evaluation of the Bio-Flocculating Properties of Extracts

The Jar Test is a laboratory method commonly used in water treatment to optimize the coagulation-flocculation process. It is used to determine the ideal condi-

tions, such as pH and optimum dose for wastewater treatment, so that effluents discharged into the environment comply with current national and international standards. The protocol consists of mixing different masses of the raw extract with a fixed volume and pH of the water to be treated. The mixture is then stirred rapidly at 140 rpm for 5 minutes. This is the coagulation stage. Afterwards, the stirring speed is reduced to 60 rpm for 25 minutes to allow flocs to form. The treated samples are decanted and then filtered. The new values of the physicochemical parameters are measured in order to find the optimal dose. The operation is repeated, this time by setting the optimal mass and varying the pH. Turbidity is measured again in order to find the optimal pH. The tests are performed in triplicate and uncertainties are SD.

2.9. Fourier Transform Infrared (FTIR) Measurement

For FTIR analysis, the dry extract is placed on the interface of the CARY 630FTIR device module so as to cover the circle. The sample is then compressed with the vice until it clicks. Click Next to record the sample spectrum.

3. Results and Discussion

3.1. Extraction Yield

After extraction, the yield of each extract obtained is calculated using the formula below:

$$\text{Extraction yield} = \frac{\text{Mass of extract}}{\text{Mass of dried powder}} \times 100$$

All the results obtained are recorded in Table 1.

Table 1. Yields of extracts from plantain peels.

Extracts	Mass (g)	Yield (%)
UB	17.84	25.48
RB	12.54	17.91

Table 1 shows that decoction allows for the extraction of approximately 25% and 18% of the initial mass of unripe and ripe banana peels, respectively. This high extraction rate may be attributable to polysaccharides. This resultat was already shown by Ramar and *al.* (2014) who showed that decoction is the ideal method for the quantitative extraction of polysaccharides [10].

The best yield is obtained with the extract of unripe banana peels compared to the RB due to its high starch content, which is the most abundant polysaccharide compared to ripe banana peels. This high extraction yield is of paramount importance in the valorization of this agricultural waste in various fields, including wastewater treatment.

3.2. Chemical Screening

In this study, structural and reserve polysaccharides, exudates were investigated.

The results obtained are shown in Table 2 below.

Table 2. Polysaccharides identified in the extracts.

Polysaccharides	UB	RB
Starch	+	+
Fructans	+	+
Cellulose	-	+
Pectins	+	+
Exudates	+	+

Analysis of these results shows the presence of all classes of plant polysaccharides in ripe banana peel extract. These results corroborate those of other authors who found that banana peels are rich in various types of polysaccharides [11]. In the case of unripe banana peel extract, tests revealed the presence of all the polysaccharides sought except cellulose. The presence of different classes of polysaccharides could justify the use of banana peel extracts in wastewater treatment. In addition to polysaccharides, certain secondary metabolites were also identified. The results are summarized in Table 3 below.

Table 3. Chemical screening of secondary metabolites.

Chemical groups	UB	RB
Alkaloids	+	+
Flavonoids	–	+
Lignins	+	+
Tannins	+	+
Saponosides	–	–
Quinones	–	+

(+): positive test; (–): negative test.

Excepted saponosides, all tests revealed the presence of tannins, alkaloids, and lignins in both extracts. These results are consistent with the work of Bishnoi and al. 2023, Sani and Muhammad 2021 [11] [12]. They showed that banana peels are rich in secondary metabolites. However, we note the absence of flavonoids and quinones in the unripe banana extract. The presence of phenolic compounds, particularly flavonoids and tannins, in the extracts could contribute to their bioflocculating properties, in line with data reported in the literature [9].

3.3. Total Sugar Content

Total sugar (TOT) content was determined using the previously established glucose calibration curve equation (**Figure 1(a)**). TOT values, expressed in micrograms of glucose equivalent per milligram of dry extract (µg EG/mg), are

shown in Figure 1(b).

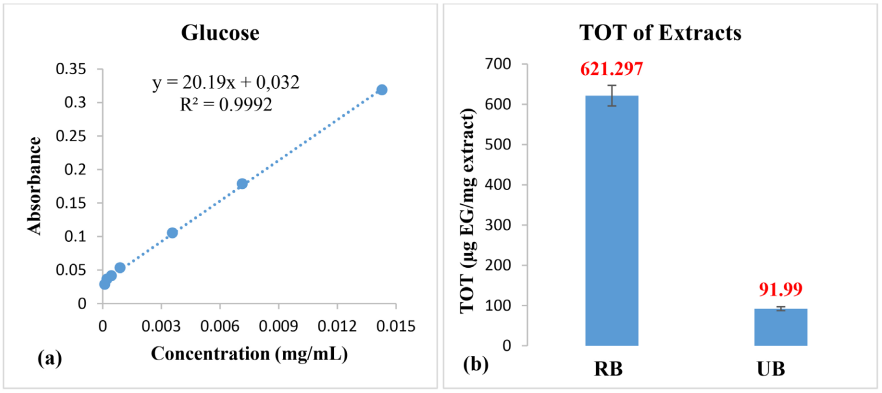


Figure 1. (a) Glucose calibration curves; (b) Total sugar content of RB and UB peel extracts. Values are given as the mean ± SD of three independent assays.

The results show that the RB peel extract has the highest total sugar content, with an estimated value of 621.297 ± 25.420 µg EG/mg, followed by the UB extract with a glucose equivalent of 91.992 ± 4.804 µg per milligram of dry extract. This difference could be explained by the biochemical changes that accompany fruit ripening. The sugar content increases as the banana ripens. During ripening, starch is hydrolyzed into simple sugars, the most abundant of which commonly found in ripe banana peel are fructose, sucrose, and glucose. This result is consistent with previous findings indicating that RB extract contains all classes of plant polysaccharides. However, in unripe banana skins, the amount of these free sugars is low. This is because green bananas contain high levels of insoluble starch, which is difficult to extract [13].

3.4. Phenolic Compound Content

Phenolic compound content (PCC) was determined using the previously established calibration curve equation (Figure 2(a)) for gallic acid. The PCC values, expressed in micrograms of gallic acid equivalent per milligram of dry extract (µg GAE/mg), are shown in Figure 2(b).

Analysis of the results reveals contents of 72.514 ± 2.235 and 57.853 ± 3.641 µg GAE/mg dry extract for the two extracts of RB and UB, respectively. These results corroborate the work of previous authors who have shown that banana peel is rich in phenolic compounds [11] [14] [15]. The high total phenolic compound content in both extracts compared to those obtained by Diawara et al. in 2022 could be explained by the soil and climate conditions and the variety of plantain used [16] [17]. Furthermore, during the assays, the appearance of a precipitate was observed following the addition of the Folin-Ciocalteu Reagent (RFC). These precipitates are thought to be due to reactions between polysaccharides such as starch and RFC, in accordance with data reported in the literature [16]. This confirms the results of the chemical screening, which revealed the presence of polysaccharides in both banana peel extracts.

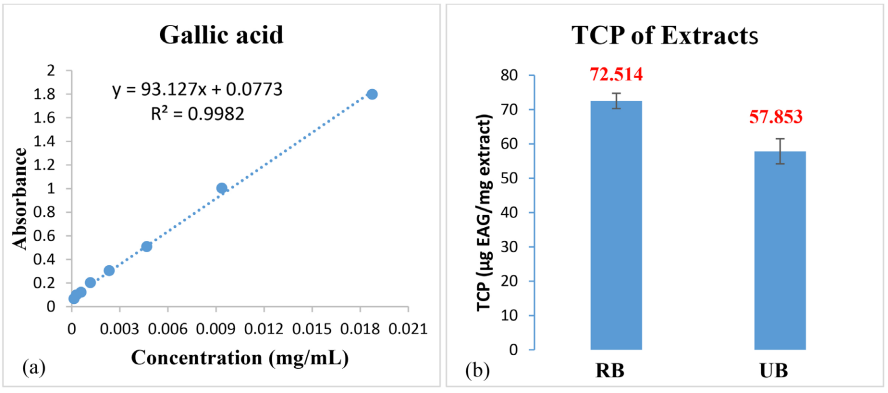


Figure 2. (a) Calibration curve for gallic acid; (b) Total phenolic compound content in extracts from RB and UB peels. Values are given as the mean ± SD of three independent assays.

3.5. Condensed Tannin Content

Condensed tannin content was determined using the calibration curve (**Figure 3(a)**) of catechin used as a standard. The different values, expressed in µg catechin equivalent per milligram of dry extract (µg CE/mg), are shown in the histogram in **Figure 3(b)**.

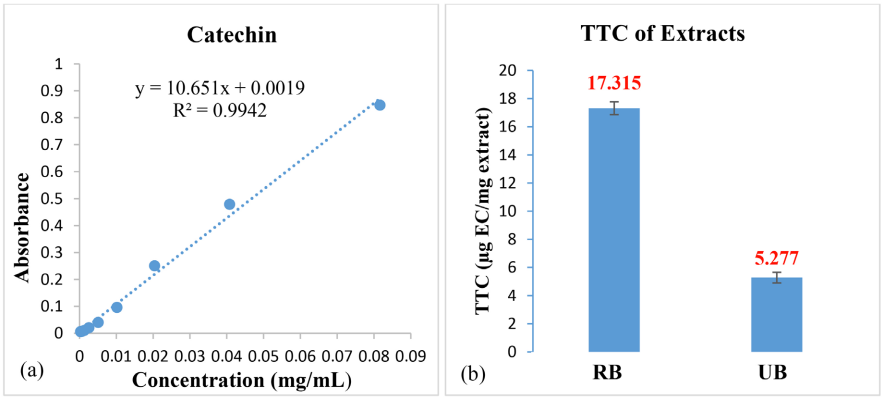


Figure 3. (a) Calibration curve for catechin; (b) Condensed tannin content of RB and UB peel extracts. Values are given as the mean ± SD of three independent assays.

Examination of the histograms shows that neither extract contains significant levels of condensed tannins. However, we note that the RB extract contains approximately three times more condensed tannins than UB, with a value of 17.315 ± 0.456 µg EC/mg of dry extract compared to 5.277 ± 0.382 µg EC/mg for UB. These results confirm the bitter and astringent taste of banana peel attributable to tannins. Furthermore, the presence of this family of secondary metabolites in the extracts would be a great asset in the elimination by complexation of suspended solids in wastewater [18].

3.6. Fourier Transform Infrared Spectroscopy

FTIR analyses of the two extracts of ripe (RB) and unripe (UB) plantain peel were

performed under the same conditions. The spectra obtained are shown in **Figure 4**.

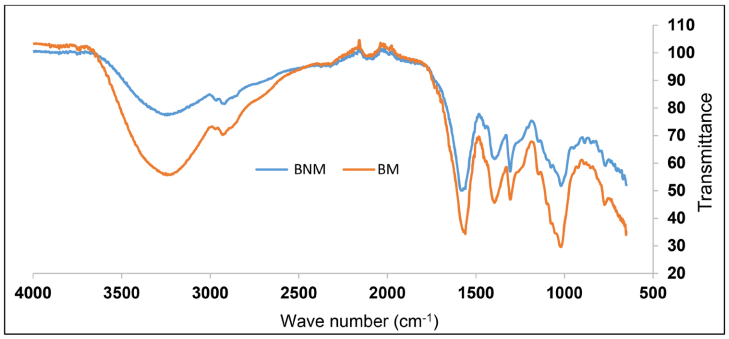


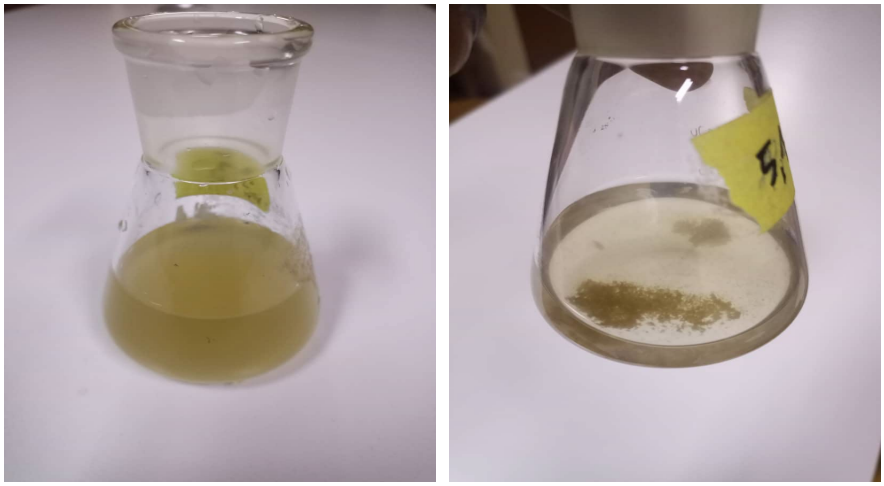
Figure 4. FTIR spectra of ripe (RB, in red) and unripe (UB, in Blue) plantain peel extracts.

The FTIR spectra of RB and UB show a broad absorption band between 3000 and 3500 cm^{-1} attributable to O-H stretching vibrations of hydroxyl (-OH) groups in carboxylic acids and phenolic compounds. The band at 1620 cm^{-1} could correspond to the stretching vibration of the C=O function of the carboxylic group (-COOH) of galacturonic acid. Weak bands of asymmetric vibrations of C-H bonds are observed between 2900 and 3000 cm^{-1} characteristic of the stretching vibrations of the CH_2 and CH_3 groups. In addition, the weak signals observed around 1200 cm^{-1} highlight the presence of acetyl groups from pectic residues as well as the vibrations of the C-O bonds of the alcohol and ether functions of the polysaccharide structures [19]. The bands observed at 1300 and 1400 cm^{-1} can be considered specific to the deformation vibration of the C-H group. Furthermore, there is a perfect superimposition of the two spectra indicating that the chemical composition of the two extracts is almost identical. However, the FTIR spectrum of ripe banana peels shows more intense bands compared to those observed in the spectrum of unripe banana peels. This suggests that ripe banana peels contain higher levels of phytoconstituents, particularly polysaccharides and phenolic compounds. These results corroborate those obtained previewly on constituents quantification shown in **Figures 1-3**.

The results of the chemical screening and FTIR analyses therefore confirm the presence of polysaccharides and certain phenolic compounds in both banana peel extracts. These results suggest that the Banana peel could be a potential source of natural floculants as it was demonstrated that phytoconstituents like polysaccharides possess flocculation properties [20]. Consequently, to support these findings, the bioflocculating potential of the two banana peel extracts was evaluated.

3.7. Evaluation of Bioflocculating Properties

In this section, the potential for reducing the initial turbidity (167 NTU) of wastewater from a brewing industry was investigated. For that, a screening was first carried out by treating 50 mL of this wastewater (pH = 6.1) with an arbitrarily chosen mass of 4.1 mg of Banana peel extract. **Figure 5** shows the preliminary results obtained.



(a) (b)

Figure 5. Photos of wastewater: (a) Before treatment; (b) After treatment with RB.

Figure 5 shows that banana peels have bioflocculating properties, as evidenced by the formation of flocs and the clarification of the water (Figure 5(b)). These results support the previous studies reported in the literature, which mention that extracts enriched with phenolic compounds and polysaccharides have proven flocculating properties [21]. In order to determine the optimum functional condition of the Banana peel extract, analysis were conducted by varying different parameters. And to do so: the dose of coagulant-flocculant and the pH of the wastewater parameters were varied.

3.8. Influence of the Quantity of Extract in the Coagulation-Flocculation Process

As previously announced, the bioflocculating properties of the two extracts were evaluated at different concentrations and at a fixed pH. The turbidity reduction rate was calculated using the following equation:

$$\text{Reduction rate (\%)} = \frac{\text{Initial turbidity} - \text{Residual turbidity}}{\text{Initial turbidity}} \times 100$$

Table 4 presents the influence of extract concentration on the efficiency of the coagulation-flocculation process at fixed pH.

Table 4. Optimization of extracts dose at fixed pH.

Mass (g)	Extracts			
	RB		UB	
	Residual turbidity (NTU)	Reduction rate (%)	Residual turbidity (NTU)	Reduction rate (%)
0	145.00	0.00	130.00	0.00
1	123.00	15.17	106.00	18.46
2	109.00	24.83	105.00	19.23

Continued

3	124.00	14.48	100.00	23.08
4	128.00	11.72	104.00	20.00
5	128.00	11.72	104.00	20.00
6	129.00	11.03	106.00	18.46

The obtained results were used to plot the turbidity reduction curves as a function of the coagulant mass, as shown in Figure 6.

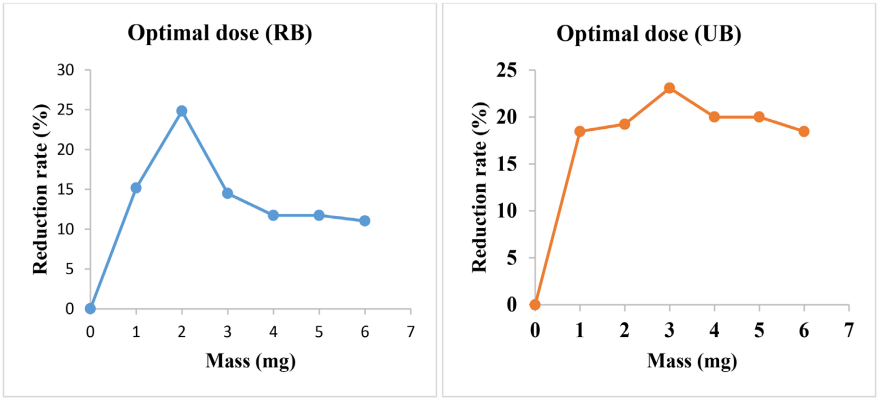


Figure 6. Optimization of the coagulant dose.

Analysis of the results shows that the reduction rate is dose-dependent, regardless of the extract used. The reduction rates peak at doses of 2 mg and 3 mg for RB and UB, respectively. Above these maximum values, the reduction rate decreases. These results could be explained by the fact that exceeding the optimal dose hinders the coagulant-particle reaction, leading to destabilization of colloidal particles and charge reversal. Indeed, an overdose causes hydrolysis of the coagulant, generating cationic species that are absorbed by the negatively charged particles, thus neutralizing their charge [22]. The destabilization mechanism facilitates flocculation, but an excess of coagulant can disrupt this process. Therefore, the optimal quantities of extracts are set at 2 mg or 40 µg/mL for the RB extract and 3 mg or 60 µg/mL for the UB extract.

3.9. Influence of Wastewater pH

The experiments were carried out by varying the pH from 1 to 9 at fixed concentrations of 40 µg/mL and 60 µg/mL for ripe (RB) and unripe (UB) banana peels, respectively. The initial pH of the effluent is measured during each analysis, and depending on whether we want to decrease or increase its value, we use sulfuric acid (H_2SO_4, 36 N) or caustic soda (NaOH, 2 N) in different volumes, respectively.

The optimization results are summarized in Table 5.

Table 5. Optimization of wastewater pH at fixed mass of extract.

pH	Extracts			
	RB		UB	
	Residual turbidity (NTU)	Reduction rate (%)	Residual turbidity (NTU)	Reduction rate (%)
1	30.16	79.20	30.63	76.44
2	4.45	96.93	14.54	88.81
3	13.13	90.94	17.54	86.51
4	3165	78.17	29.90	77.00
5	83.00	42.76	81.00	37.69
6	98.00	32.41	93.00	28.46
7	107.00	26.21	98.00	24.61
8	109.00	24.83	116.00	10.77
9	117.00	19.31	117.00	10.00

The above results were used to establish the reduction rate curves as a function of pH shown in Figure 7.

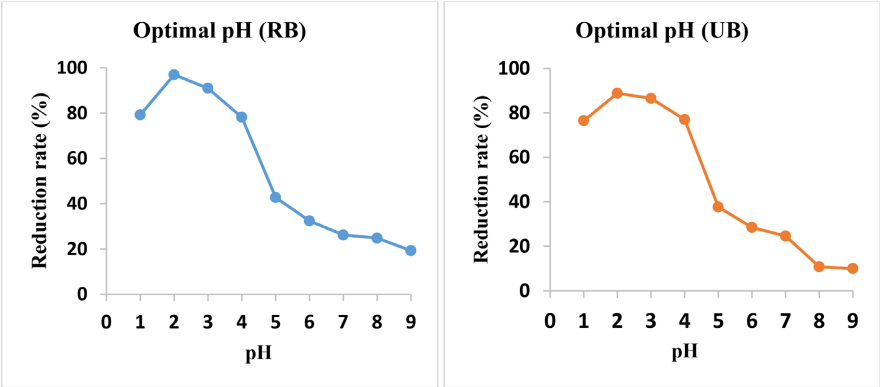


Figure 7. Optimization of wastewater pH.

This figure shows that the abatement rates increase with pH. These rates reach maximum values of 96.93% and 88.81% (pH = 2) for RB and UB, respectively. Beyond this optimal pH value, there is an exponential decrease in the abatement rate. These results are consistent with previous studies that have experimentally shown that pH is central to the effectiveness of plant extracts in removing dyes, metals, and certain organic pollutants from wastewater [23] [24]. In an acidic environment, polyphenols and polysaccharides are protonated and can trap heavy metals [25]. The surface of the biomass is positively charged overall, which also attracts negative ions and certain negatively charged organic pollutants. All of this contributes to reducing the turbidity of wastewater.

In summary, the ideal conditions for using extracts from ripe and unripe banana peels as a coagulant-flocculant agent are summarized in Table 6 below.

The results in Table 6 shows that banana peels offer a better treatment of brewery wastewater. Furthermore, we note that ripe banana peels have a better reduction in turbidity (96.93%) compared to unripe banana peels. This difference is likely due to the higher levels of total phenolic compounds, condensed tannins, and total oses observed in the RB extract. Indeed, it has been shown that an extract's ability to reduce wastewater turbidity is linked to its chemical composition, particularly in terms of phenolic compounds and polysaccharides [26] [27]. The higher the content of these compounds in an extract, the better its flocculating potential. There is also an absence of cellulose in unripe banana skins. However, cellulose has been shown to have marked flocculating properties [20].

Table 6. Ideal conditions for using ripe and unripe banana peels as coagulant-flocculant agents.

	Extracts	
	Ripe banana peel (RB)	Unripe banana peel (UB)
pH	2.0	2.0
Concentration (µg/mL)	40	60
Reduction rate (%)	96.93	88.81

The high rate of reduction in wastewater turbidity suggests that the extracts could remove major pollutants contained in these industrial effluents.

In addition to the turbidity parameter certain physicochemical parameters were therefore analyzed.

3.10. Analysis of Physicochemical Parameters

The effectiveness of banana peel extracts in removing certain pollutants likely to be found in industrial effluents was tested. This involved measuring their concentration before and after treatment. The results obtained are shown in Table 7.

Table 7. Analysis of the physicochemical parameters of wastewater from the brewing industry before and after treatment.

Physicochemical parameters	Concentrations before treatment (mg/L)	Concentrations after treatment (mg/L)		Reduction rate (%)	
		RB	UB	RB	UB
MES	539	88	86	83.67	84.04
Conductivity (µS/cm)	1290	3510	2590	----	----
COD	417	344	392	17.5	6.0
BOD_5	45.8	22.5	40.5	50.87	11.57
NH_4^+	21.65	16.3	14.25	24.71	34.18
Cu^{2+}	<0.01	<0.01	<0.01	----	----
Al^{3+}	<0.001	<0.001	<0.001	----	----

Continued

Zn^{2+}	0.14	0.08	0.04	42.86	71.43
Mn^{2+}	0.2	0.075	0.09	62.5	55.00
Hg^{2+}	0.004	<0.001	<0.001	>75.0	>75.00
Pb^{2+}	0.002	0.003	0.008	----	----
Fe^{2+}	0.33	0.67	0.32	----	----
Na^{+}	643.3	8976	8902	----	----
K^{+}	17.4	21.4	25.2	----	----
SO_4^{2-}	8	<1	<1	>87.50	>87.50
PO_4^{3-}	22.03	26.12	24.11	----	----
F^{-}	1.26	2.56	3.42	----	----
Cl^{-}	57.5	1440	1550	----	----
NO_2^{-}	<0.002	<0.002	<0.002	----	----
NO_3^{-}	11.4	28.7	32	----	----

The data in the table show that banana peels are highly effective at removing suspended solids, with similar reduction rates (>83%). This can be explained by the presence of fibers and polysaccharides in banana peels, which act as biosorbents. These results are consistent with the data in **Table 6**. In addition, a sharp increase in conductivity is observed after treatment. This may be caused by a significant release of anions (Cl^{-}, NO_3^{-}, PO_4^{3-}) and cations (Fe^{2+}, Na^{+}, K^{+}) content in plantain peels, which increases the salinity of the treated water. Indeed, it has been shown that plantain peels contain mineral salts [12] [28]. The peels show good selective adsorption capacity for sulfates (SO_4^{2-}) and certain heavy metals ions (Zn^{2+}, Mn^{2+}, Hg^{2+}), but release others such as Pb^{2+} and Fe^{2+}. In addition, the peels absorb some of the ammonium, but the reduction remains limited. Other physicochemical parameters such as Cu^{2+}, Al^{3+}, NO_2^{-} could not be measured due to their very low concentrations, which were below the detection limit of the device. The significant reduction in turbidity, total suspended solids, and biochemical oxygen demand in wastewater from the brewing industry has demonstrated the potential of banana peel powder as an alternative to synthetic, chemical, or even expensive natural coagulants, in addition to the added value of using available banana peel waste. These results corroborate those of other authors who have worked on banana peels [29]-[31]. Furthermore, the increase in certain physicochemical parameters such as conductivity and metal ions after treatment is thought to be due to leaching of the extract and/or solubilization induced by pH. Dialysis of the extract or post-treatment polishing would be a feasible mitigation option.

4. Conclusions

The objective of this work was to evaluate the "coagulant-flocculant" properties

of decocted extracts from plantain peels regardless of their phytoconstituents with a view to their use as an alternative for wastewater treatment. The chemical screening of the peel extract revealed the presence of polysaccharides and certain secondary metabolites such as phenolic compounds in banana peels. UV-visible spectrometry measurements revealed that banana peels contain significant amounts of total oses and total phenolic compounds.

Both extracts proved to be highly effective in treating effluents from the brewing industry, with regard to certain parameters such as turbidity, MES, BOD_5 and certain cations and anions species of wastewater. The results show that turbidity reduction rates of 96.93% and 88.81% at pH = 2 for ripe and unripe banana peels, respectively. In addition, plantain peels appear to be a promising biosorbent for the removal of certain heavy metals from brewing wastewater. More interestingly, the possibility of modifying the Banana peel extracts opens the way for further investigations into the use of plantain peel as a sustainable, environmentally friendly, and less expensive alternative for wastewater decontamination. However, a pH of 2 is well below normal conditions (often pH 5 - 7 for optimal coagulation). This therefore requires the use of materials resistant to acid corrosion and neutralization after treatment. This situation therefore constitutes a limitation of the present work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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