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Comparative study of the effects of Herbal and chemical Coagulants in the clarification of raw water

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The use of aluminum sulphate in clarifying raw waters raises many concerns about its impact on human health. Thus, the present study was initiated to compare the effects of *Moringa oleifera* and aluminum sulphate besides evaluating the association between *M. oleifera* or aluminum sulphate *with Opuntia ficus*-indica or syntofloc for water treatment. The essays were carried in Jar Test using waters of 352.80 Nephelometric Turbidity Units (NTU). The monitoring of different physico-chemical and microbiological parameters at different doses and after different decanting time was used to determine optimal conditions and evaluate the effectiveness of treatment. The results showed that it took fewer doses and less decanting time for aluminum sulphate than moringa to obtain the same residual turbidity. The use of 0.9 g/L of moringa removed 99% of turbidity after 12 h of decanting. Successive use of moringa (0.9 g/L) with *O. ficus*-indica extract (0.6 ml) reduced the decanting time to 15 min. However, this treatment eliminated only about 57% of total coliforms. The moringa/cactus association, although highly effective, remains less than the treatment based on aluminum sulphate and synthofloc. This "organic" association is nevertheless an ideal alternative because of its great capacities that could be further optimized.

Key words: Coagulation-flocculation, turbidity, *Moringa oleifera*, aluminum sulphate, Cactus.

INTRODUCTION

In Burkina Faso, as in many other developing African countries, access to water is an important issue for population. Unfortunately, groundwater reserves in the country are discontinuous because of the lateritic soil which is worsen over the years by demographic explosion in towns, the Burkinabe state has implemented the construction of many water reservoirs commonly called dams, to mobilize surface water and somehow alleviate the water scarcity that strikes the populations which does not retain water. To deal with water scarcity (Zoungrana

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and Combelem, 2016). However, once mobilized, this water is not drinkable, because it had been more or less polluted by various urban discharges. Henceforth, the need to undergo a series of treatments before consumption is necessary. The main steps in the usual treatment of surface water include crucial clarification. This is based on the phenomenon of coagulation-flocculation and generally uses aluminum sulphate as a coagulant since this chemical appears to be the cheapest trivalent (Kowanga et al., 2016). However, the use of aluminum sulphate in water clarification raises significant health and environmental problems (Deshmukh and Hedaoo, 2019; Tietz et al., 2019). First, although it is relatively low-priced, it remains costly enough for developing countries like ours. Also, on environmental ground, its use inexorably generates metal residues, and its use exposes it to high risk of suffering Alzheimer, since aluminum residues in water are pointed by several scientific studies as responsible for this disease (Zhang et al., 2015). In view of this, the use of biological processes for the treatment of surface water could be a sustainable alternative because of the availability and non-toxicity of such treatment (Chong and Kiew, 2017). Thus, several studies on water clarification with natural coagulants like Moringa seeds (Adeniran et al., 2017; Camacho et al., 2017; Hoa and Hue, 2018) or other natural coagulants (Adewuyi and Adewumi, 2018; Benalia et al., 2019; Freitas et al., 2015; Hussain and Hydar, 2019; Jayalakshmi et al., 2017) have already been carried out. Other researches have shown the efficiency of addition of *Opuntia ficus-indica* extracts as coagulant aids or flocculant (Adjeroud-Abdellatif et al., 2020; Bouaouine et al., 2019; Karanja et al., 2017; Othmani et al., 2020). Bouaouine et al. (2019) revealed that quercetin and starch constitute the active agents found in *O. ficus-indica*. Currently, it is discovered that all plants being studied for flocculants production have mucilaginous constituents and it is predicted that some of the active ingredients in the mucilage (polysaccharides) are responsible for the flocculating property, but the most studied plant of the natural coagulant (*Moringa oleifera*) shows that the active agents are dimeric cationic proteins (Adjeroud-Abdellatif et al., 2020; Camacho et al., 2017). These biological molecules offer many advantages compared to conventional coagulants used for water treatment. The benefits are cost-effective, environmentally friendly, no pH alteration required, no need for the addition of alkalinity and the reduction of sludge volumes (Idris et al., 2016). Although studies conducted in Burkina Faso have proved the effectiveness of Moringa seeds in water treatment, they hardly consider its substitution with chemical coagulants in large-scale treatment. One of the factors hindering its use is the decanting time of the flocs which appears to be longer than with aluminum sulphate (Saleem and Bachmann, 2019). Hence, this prompted us to make a modest contribution by optimizing the treatment process, using successively Moringa seeds and cactus extract to reduce treatment time. This study is conducted in such context and aims at evaluating the effectiveness of natural coagulants in the treatment and determining the optimal treatment conditions. More specifically, it was all about comparing the effectiveness of Moringa seeds to that of aluminum sulphate and optimizing the two coagulants by adding a chemical flocculant, then a natural one.

MATERIALS AND METHODS

Sampling of surface waters

The raw water samples investigated on as part of this study are from *Loumbila* dam (12° 29 N, 01° 24 W). The samples were collected at *Paspanga* station of ONEA through pipes, draining the water from the dam to the station. The sampled water was screened and sand-freed, while being drained to the station. They are then able to undergo the clarification treatment in accordance with the conventional procedure of surface water treatment. The samples were collected in 20 L plastic cans and stored in a refrigerator at +4°C in the laboratory.

Biological material

The biological material used in this study consists of *M. oleifera* seeds and extracts of *O. ficus indica*. These two items stand respectively for the biological coagulant and the biological flocculant. The seeds of *M. oleifera* were obtained at the National Forest Seed Center (CNSF). They are mature and dry seeds from *Garango* and were harvested between February and March 2018. As for *O. ficus indica*, the whole plant was collected in a nursery located nearby dam n°3 at *Tanghin*. It was then transported to the laboratory (LABIOTAN) to be used for the extract preparation.

Preparation of the moringa and cactus extracts

The bio-coagulant used in this study is an aqueous solution prepared from the powder of *M. oleifera* seed. These seeds were shelled and grounded according to the method described by Folkard and Sutherland (2002). The extract was prepared at 4°C at a concentration of 100 g/L in distilled water, followed by filtration after a 2 h stirring. The stock solution containing the water-soluble substances from Moringa seeds is then stored at -18°C until use. This treatment allows a better preservation of the active ingredient. As for the extract of cactus, the organic flocculant, a stock solution of 30 g/l in distilled water, was prepared. This solution is relatively stable and keeps its flocculation ability for several days without any preservation system.

Preparation of aluminum sulfate and synthofloc solutions

The stock solution of aluminum sulphate, the chemical coagulant, was prepared by dissolving its granules in distilled water (10 g/L). Synthofloc, a chemical flocculant, was prepared at a concentration of 1 g/L in distilled water. These are stock solutions used for the coagulation-flocculation tests.

Optimum dose of coagulants determination: Jar tests

Coagulation-flocculation tests were conducted using an electric flocculator (FC6S Jar-Test Velp Scientifica) with six beakers containing 1 L of raw water. Increasing doses of aluminum sulphate (0.025-0.05 g/L) or moringa (0.2-1.1 g/L) were added to these and the whole was then subjected to vigorous stirring at 150 rpm for 5 min and then slowly for another 5 min. It was left to settle for about deux hours, the clearer of each dosage was picked as optimum for that coagulant. When the coagulant used significantly reduces the pH, lime is used as a corrector of acidity in order to enhance it.

Determination of the minimum decanting time

The minimum decanting time was determined by setting the dose of moringa or aluminum sulfate and changing the decanting time. For this, beakers were filled with 1,000 ml of raw water after which fixed doses of moringa (0.9 g/L) or aluminum sulphate (0,05 g/L) were added to these, while the last beaker was kept as a control without any coagulant. The mixtures were stirred rapidly for 5 min; followed by 5 min of gentle mixing to aid sludge formation. Subsequently, the samples were transferred and left for decantation for 15; 30; 60; 90; 120; 720 min in sedimentation cones.

Flocculation optimization: Effect of cactus extract and synthofloc

Synthofloc and cactus extracts, with similar viscous aspect, were respectively used as chemical and biological adjuvants to optimize the flocculation of flocs formed by the isolated action of aluminum sulphate and Moringa. To do this, constant volumes of moringa solution (0.9 g/L) or aluminum sulphate (0.05 g/L) were added to the beakers containing the water to be treated, followed by a rapid stirring phase (150 rpm) for 5 min. Then increasing volumes of cactus extract or synthofloc were added to these samples, followed by further stirring at 45 rpm for 10 min, followed by decantation of 15 min.

Evaluation of the efficacy of the two coagulants and the two adjuvants

Supernatants trained after each treatment were collected and analyzed to evaluate and compare the effectiveness of different coagulants and adjuvants in clarifying surface water. Turbidity, pH, conductivity, Temperature, Alkalimetric Title (AT), Complet Alkalimetric Title (TAC), Total Hardness (TH), Calcium hardness (Tca^{2+}), Na^+ and K^+ as well as Total Coliforms, Streptococci and *Escherichia coli* were determined . Turbidity was measured with a WTW Turb 550 IR laboratory turbidimeter (nephelometer) as per French Norm NF ISO 7027 (2000). The pH was measured following the electrochemical method, using a pH meter/thermometer (330i WTW) equipped with a Sen Tix 41 combined electrode according to the NF 10523 (1994) method. Conductivity as well as Temperature was measured, using a conductivity meter coupled with a WTW mark thermometer. Alkalinity (TA) and Complet Alkalinity (TAC) were determined by titrimetric series according to French Norm NF T 9963: 1996. The concentrations of calcium and magnesium and the total hardness were also determined by means of titrimetric series consistent with French Norm, NF T 90-016: 1984 and NF T 90-003: 1984, respectively for calcium and magnesium and for total hardness. Na^+ and K^+ ions were determined, using a flame photometer. As for the microbiological parameters of water, they were all determined according to the method of membrane filtration and spreading on specifics culture media as per the French Norm NF ISO 9308-1 (2000). For the search for total coliforms and *E. coli*, Chromocult coliform Agar was used for an incubation temperature of 37°C, whereas for streptococci, Enterrococus agar was used at a temperature of 44°C.

Statistical analysis

The data obtained in the application of the various treatments have been subjected to statistical analysis. The XLSTAT software (2016 Version) was used for variance analysis (ANOVA) to compare the average values of the variables considered in each case of the study. The Turkey test was used to determine significant differences between the variables considered at the 5% threshold ($P> 0.05$).

RESULTS

Influence of the coagulant dose on turbidity

Water samples with initial turbidity of 352.80 NTU were used for coagulation-flocculation tests with increasing doses of aluminum sulphate and *M. oleifera* grains extracts. Changes in the residual turbidity were recorded in Figure 1A and B. The results showed that the reduction of turbidity was dose-dependent for aluminum sulfate, that is increasing aluminum sulphate dose decreased the water turbidity. As for moringa, turbidity was evolved in two phases. At low doses, the reductions were doses dependent. Beyond 0.9 g/L of moringa used, there was another phase which resulted in an increase in turbidity. Therefore, the optimal dose of moringa needed to treat the water sample was 0.9 g/L. At this dose, a residual turbidity of 63.26 NTU was obtained. The best results were obtained with addition of aluminum sulphate. For samples with equal turbidity of 352.80 NTU, more moringa coagulant (0.9 g/L) than aluminum sulphate (0.05 g/L) was required to obtain 63.26 and 25 NTU respectively. Although these values are above the norm NF ISO 7027-2000, Moringa could also be considered as good coagulant because it has eliminated 82.06% against 92.91% obtained with aluminum sulfate, the reference coagulant.

Influence of decanting time on turbidity

The results recorded in Figure 2 showed that the reduction in turbidity also depended on decanting duration. It was important during the first 15 min and low after 30 min of decanting. Standard turbidity was reached after 90 min with 0.05 g/L of aluminum sulphate against 12 h with 0.9 g/L of moringa.

Optimization by adding synthofloc

Figures 3A and B showed a considerable reduction in turbidity after 15 min of decanting with the waters treated by the Combinations Moringa and synthofloc or aluminum sulphate and synthofloc. The addition of 0.1 ml of synthofloc resulted in a significant decrease in turbidity for increasing concentrations of aluminum sulphate or Moringa. A turbidity of 4.01 NTU was obtained with the

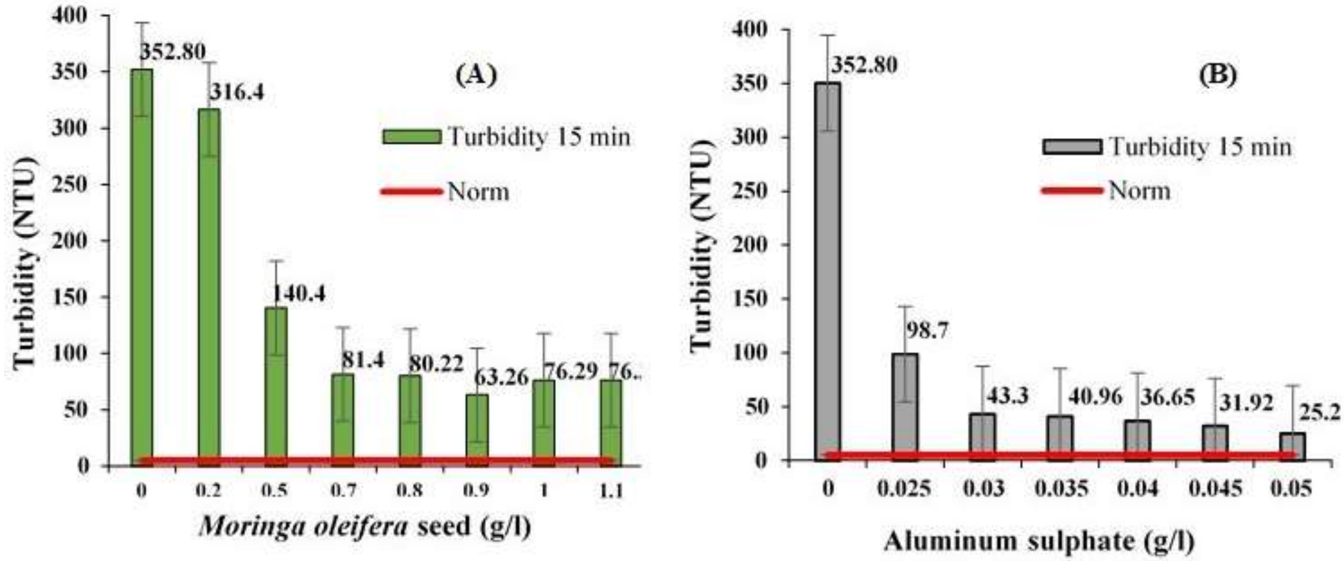

Figure 1. Evolution of water turbidity depending on *Moringa oleifera* seed concentration (A). Evolution of water turbidity depending on the concentration of aluminum sulphate (B).

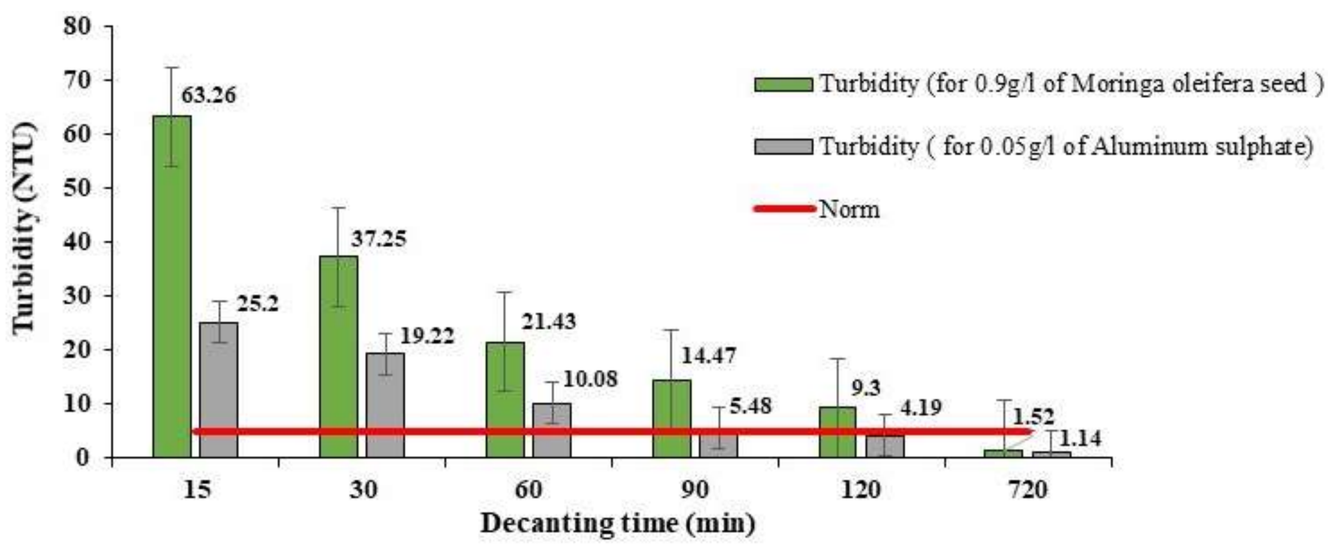

Figure 2. Turbidity comparison between moringa and aluminum sulphate-based treatments depending on duration.

initial optimal concentration of 0.9 g/L of moringa seeds. With the aluminum sulphate, a value of 4.56 NTU was obtained for a concentration of 0.04 g/L of aluminum sulphate. Synthofloc has improved the clarification of water treated with either moringa or aluminum sulphate.

Optimization by addition of cactus extract

The results of clarification tests with equal doses of Moringa extracts followed by a flocculation stage with increasing doses of cactus extracts showed that turbidity reduction was dose-dependent (Figure 4). As the dose of cactus extracts increased, the water turbidity decreased.

Upon application of 0.6 ml of cactus extracts, clear water with 4.19 NTU turbidity was obtained. This complies with the norm (≤ 5NTU). With the 0.6 ml of cactus extract, a turbidity of 2.36 NTU was obtained with 0.05 g/l of aluminum sulphate (Figure 5A and B). In view of these results, it could be said that the use of this new flocculant improves the action of the two coagulants in the like of synthofloc because it has resulted in a water turbidity

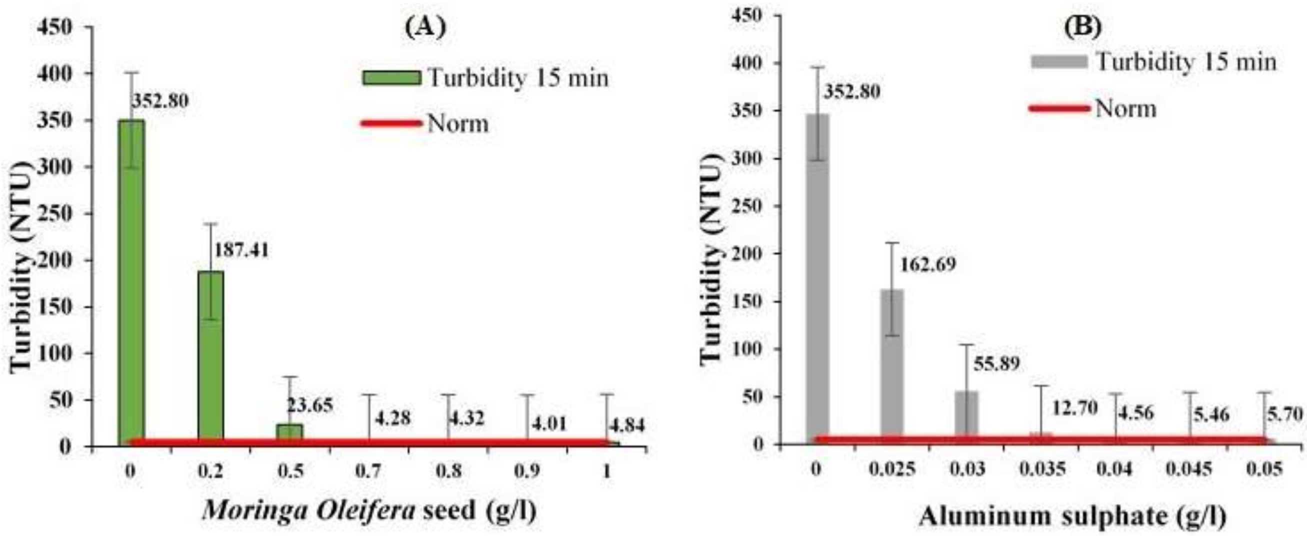

Figure 3. Figure 3 : Turbidity evolution depending on moringa concentration with synthofloc addition (A). Turbidity evolution depending on aluminum sulphate concentration with synthofloc addition (B).

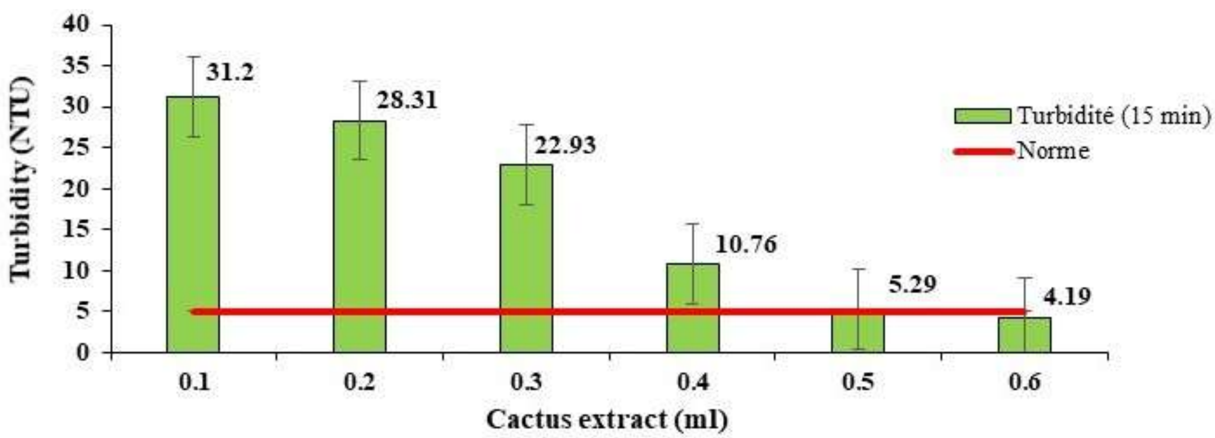

Figure 4. Turbidity evolution depending on the volume of cactus extract added in Moringa-based treatment.

complying with the norm (≤ 5 NTU).

Effects of treatments on the evolution of physicochemical parameters

With a view to assessing the effectiveness of the treatments, the evolution of some physicochemical parameters of the water samples were monitored and compared before and after treatment. The analysis of these parameters was carried out in triplicate and the averages obtained were recorded in Table 1. Analysis of the variances (at p> 0.05) showed that the applied treatments had a significant effect on almost all Physicochemical parameters of the water samples analyzed except for temperature and TA for which the variations were not significant. For the other parameters analyzed, the variations were significant regardless the coagulant and the flocculant used. For the pH value, there was no change during treatment with Moringa seeds, whereas with aluminum sulphate, the post treatment value decreased significantly, except for aluminum sulphate/synthofloc-based treatment, since lime was used as acidity corrector. Other parameters, such as calcium, sodium and total hardness, were found to be lower in waters treated with Moringa seeds than those treated with aluminum sulphate. The TAC and the potassium content were, however, higher in samples treated with Moringa seeds as compared to the ones treated with aluminum sulphate.

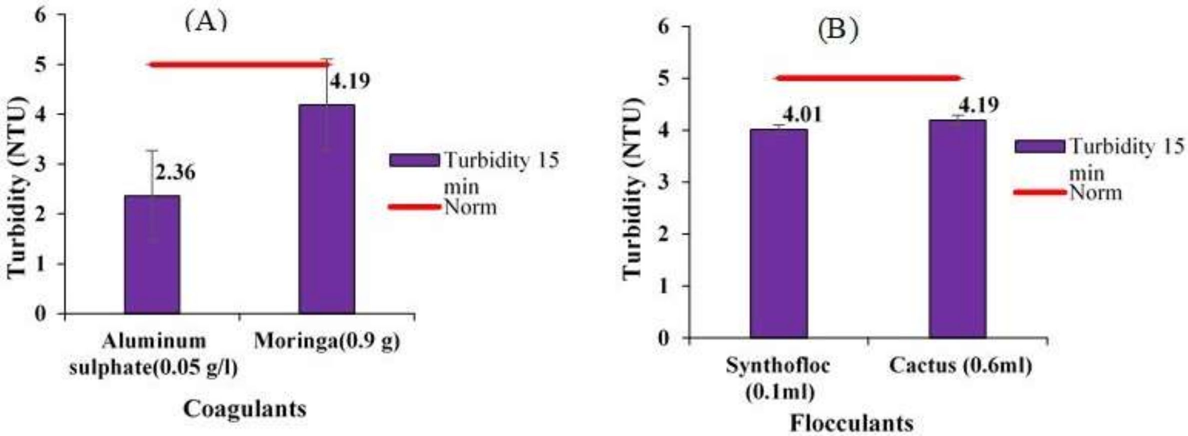

Figure 5. Comparison of moringa and aluminum sulphate-based treatments, optimized with cactus extracts (A). Comparison of Synthofloc effectiveness to that of cactus extract used as flocculants (B).

Effect of treatments on the evolution of microbiological parameters

Microbiological analyzes were also carried-out in triplicate and the averages are presented in Table 2. The microbial indicators (Escherichia *coli*, total coliforms) of the water samples varied significantly depending on the coagulant and/or flocculant used. This variation was significant for all treatments based on moringa seeds and cactus extract according to the ANOVA analysis at the 5% probability level (P> 0.05). For the other treatments based on coagulants and purely chemical flocculants (aluminum sulphate and / or synthofloc), the variation was not significant. Since streptococci were initially absent from the raw water, no variation was observed regardless of the treatment applied.

DISCUSSION

The effectiveness of moringa seeds in clarifying the water of the Loumbila dam was compared with that of aluminum sulphate, with a view to finding an alternative to the harmful consequences of the use of the latter on human health and the environment. Several studies have already been conducted on the use of Moringa seeds to clarify raw water (Adeniran et al., 2017; Camacho et al., 2017; Hoa and Hue, 2018; Zaid et al., 2019). Indeed, these ground seeds, added to water acts as primary coagulant and can clarify any water regardless of its degree of turbidity. However, no study has yet revealed the cumulative effect of moringa and synthofloc or moringa and cactus extracts in improving the clarification process. Optimization studies have indeed been conducted, but concerned the addition of *Bombax costatum*, a natural flocculant, and activated silica, a synthetic polymer in the like of synthofloc. Other combination studies have also been conducted but they combine alum with M*oringa oleifera* (Dehghani and Alizadeh, 2016) or M*oringa oleifera* with aluminum sulphate (Valverde et al., 2018).

At the end of the treatments carried out on the water samples from the *Loumbila* dam (turbidity 352.80 NTU) with increasing doses of the different coagulants, it was revealed that turbidity decreased with the increase of aluminum sulphate dose. These results are similar to those obtained by Valverde et al. (2018). On the other hand, with moringa seeds as a coagulant, the reduction in turbidity depended on the dose up to 0.9 g/l. Beyond this dose, turbidity tended to enhance. This can be explained by the re-stabilization of the colloidal particles, caused by the overdose of the coagulant. The excess makes it to play a reverse role, neutralizing all the particles. Indeed, these coagulants would contain a polypeptide, more specifically a set of active cationic polyelectrolytes (Camacho et al., 2017; Baptista et al., 2017). These positively charged poly-electrolytes thus neutralize colloids in murky waters, the majority of which are negatively charged (Valverde et al., 2018). At a very low dose of coagulant, the low level of turbidity reduction could be explained by the imbalance between the negative charges of colloidal particles and the positive charges of the coagulant. This results in strong adsorption of negative charges and prevents the appearance of flocs. It is then necessary to have balance between these charges to obtain optimum reduction of turbidity. Wandiga et al. (2017) have mentioned that once the optimal dosage is achieved, the excess polyelectrolyte proteins repel each other due to their charged nature, leading to the flocs floating or turbidity. Wandiga et al. (2017) have mentioned that once the optimal dosage is achieved, the excess polyelectrolyte proteins repel each other due to their charged nature, leading to the flocs floating or suspending in the water. Such floating flocs

Table 1. Variation of physicochemical parameters depending on the treatments applied.

Treatments	Turbidity (NTU)	pH	Conductivity (µS/cm)	Temperature (°C)	TA (meq)	TAC (meq)	TH (mg/L)	Ca^{2+} (mg/l)	K^{+} (mg/L)	Na^{+} (mg/L)
Raw water	352.33^{a}	6.86^{a}	60.24^{f}	24.13^{ab}	0^{a}	0.60^{d}	0.45^{e}	0.11^{e}	5.88^{f}	1.22^{e}
Moringa seeds	1.52^{d}	6.71^{a}	88.15^{e}	25.36^{a}	0^{a}	0.74^{c}	0.56^{de}	0.15^{de}	7.05^{d}	1.35^{e}
Aluminum Sulphate	1.14^{d}	5.82^{b}	206.62^{c}	24.03^{ab}	0^{a}	0.82^{c}	0.92^{ab}	0.50^{b}	6.49^{e}	14.49^{c}
Moringa+Synthofloc	4.01^{b}	6.84^{a}	105.61^{d}	23.96^{ab}	0^{a}	0.77^{c}	0.61^{d}	0.20^{cd}	8.72^{c}	4.81^{d}
Aluminum Sulphate +Synthofloc	4.56^{b}	6.60^{a}	109.10^{d}	24.30^{ab}	0^{a}	1.02^{b}	0.78^{c}	0.24^{c}	4.87^{g}	1.25^{e}
Moringa + Cactus	4.19^{b}	6.83^{a}	226.07^{b}	23.533^{b}	0^{a}	1.30^{a}	1.00^{a}	0.63^{a}	12.48^{a}	15.51^{b}
Aluminum Sulphate + Cactus	2.35^{c}	6.12^{b}	244.08^{a}	23.96^{ab}	0^{a}	1.14^{b}	0.83^{bc}	0.59^{a}	9.77^{b}	17.06^{a}
Pr > F	5.44E-37	1.10E-05	3.83E-23	7.58E-02	P <0.005	2.17E-10	2.25E-09	6.58E-13	4.98E-19	2.74E-22
Significant	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Norm	≤ 05 NTU	6.5 - 8.5	≤ 500	-	-	-	-	-	-	-

Table 2. Variation of microbiological parameters depending on the treatments applied.

Treatments	*Escherichia Coli* (UFC/100 ml)	Total coliforms (UFC/100 ml)	Streptococcis (UFC/100 ml)
Raw water	3.33^{b}	242^{a}	0^{a}
Moringa seeds	228^{a}	244^{a}	0^{a}
Aluminum Sulphate	0^{b}	0^{c}	0^{a}
Moringa + Synthofloc	0^{b}	123^{b}	0^{a}
Aluminum Sulphate + Synthofloc	0^{b}	0^{c}	0^{a}
Moringa + Cactus	0^{b}	138^{b}	0^{a}
Aluminum Sulphate + Cactus	0^{b}	147^{b}	0^{a}
Pr > F	1.57E-18	2.05E-11	4.63E-01
Significant	Yes	Yes	No
Norm	0	0	0

At the level of each column, the values that have the same letter in common are not significantly different according to the tukey test.

could be filtered to achieve lower turbidity. In addition, Akpenpuun et al. (2016) have shown that the reduction is not only proportional to the dose of moringa but also depends on the quality of the seeds, that is, the concentration of active proteins contained in the seeds.

A concentration of 0.9 g/L of moringa against 0.025-0.03 g/L of aluminum sulphate was necessary to obtain a reduction of approximately 80%. It appears from the statistical analysis that the difference in abatement for these two coagulants was not significant even though the dose difference between the two coagulants was significant. It is henceforth inferred that moringa seeds could be an as effective coagulant as aluminum sulphate in clarifying water. These results are explained by the fact that the active principle of moringa seeds is not the only constituent of these seeds. The raw protein extract not being separated from the rest of the non-protein fraction, then becomes less active and thus involves more powder than would be necessary if the active ingredient was isolated. Protein interactions may be the cause of this decline in moringa flocculating activity (Jayalakshmi et al., 2017). Aluminum sulphate, unlike moringa, has a higher proportion of aluminum (active ingredient) which, moreover, has a higher molecular weight.

Monitoring turbidity evolution against the decanting time has shown that turbidity reduction depended on the decanting time. The minimum durations that allowed achieving turbidity at acceptable limits for drinking water were 90 min with 0.05 g/L of aluminum sulphate; against 12 h with 0.9 g/L of moringa seed extracts. Ngbolua et al. (2016) found a higher optimal decanting time (24 h) for the treatment of a turbid water of 9.06 NTU with 0.3 g/L of moringa. The process optimization by adding synthofloc to moringa and aluminum sulphate coagulants significantly reduced the decanting time to 15 min. When synthofloc which is a chemical polymer is combined with the optimal dose of coagulant, it agglomerates micro-flocs into larger flocs called macro-flocs after coagulation. These larger flocs are heavier and decant much faster and reduce the decanting time.

Comparing the water treatment with moringa and aluminum sulphate coagulants optimized with synthofloc, it shows a significant improvement in decanting time as compared to the same treatment without synthofloc. Thus, in the 15 min instead of 12 h of decanting, the turbidity obtained was complied with acceptable limits for drinking water. The use of a flocculant makes it possible to improve the performance of the flocculation and decanting process. These results are comparable to the ones of the study conducted by Dehghani and Alizadeh (2016), on the optimization of coagulation-flocculation using silica in addition to aluminum sulphate. Other studies by Mumbi et al. (2018) have also shown the positive impact of using a polymer in addition to aluminum sulphate on flocculation.

However, the variation in the concentration of aluminum sulphate in this study, which went from 0.05 to 0.04 g/L, could be explained by lime addition. The purpose of this was to raise the water pH, initially reduced by aluminum sulphate, which is known to modify pH, unlike moringa seeds. Since synthofloc is only effective for a pH between 6 and 7, this addition in the treatment with aluminum sulphate was necessary, hence the modification of the optimal pH of action of the flocculant, and therefore also that of the optimal coagulant dose. Synthofloc substitution tests with cactus extracts as flocculants revealed satisfactory results. For a volume of 0.6 ml of cactus extracts the same effects expected with synthofloc was achieved. The difference with this new biofloculant is that it does not require any acidity corrector as is the case with synthofloc because it seems to work at any pH. Nharingo et al. (2015) highlighted the efficiency of cactus extracts as flocculant in the clarification of industrial effluents. Prodanović et al. (2020) also achieved satisfactory results, almost similar to the present ones with extracts of another plant, *Bombax Costatum.* These authors stated that the use of plants mucilage as flocculant significantly improves both turbidity and decanting duration in raw water clarification process.

The effect of the treatments (based on moringa seeds and aluminum sulphate only, then optimized by synthofloc and cactus extracts) on some other parameters were allowed to deepen the comparison. As far as pH is concerned, there was no significant change across the various treatments with *Moringa* seeds as a coagulant (optimized or not), whereas with aluminum sulphate, the value of this parameter decreased significantly except for the case of treatment with synthofloc because of lime addition. It is inferred that the effectiveness of Moringa as a coagulant does not change the water pH, thus avoiding the use of acidity rectifiers (lime); while the use of aluminum sulphate as a coagulant still requires an acid rectification during the process if the water pH is to meet the norm. These results corroborate the ones of Shan et al. (2017) since their studies concluded that moringa-based treatment has little influence on the water pH and the variation of the latter is not statistically significant. Ngbolua et al. (2016) also reported the same observations with respect to pH variation for pond water from the *Batéké Plateau* (DRC) treated with moringa seed. Valverde et al. (2018) also found results similar to the ones of the present study as they concluded that there is no significant change in pH as a result of Moringa-based treatment, while aluminum sulphate-based treatment was maked it to vary from 7 to 6.

Microbiological analyzes revealed the absence of streptococci in the water after the different treatments. This is explained by their absence even in the initial raw water sample. On the contrary, total coliforms including *Escherichia coli*, initially present in the raw water sample have seen an increase in the Moringa-based treatment which settled for 12 h. This can be explained by the presence of organic substances in moringa. Theses organic substances served as food source for bacteria and fostered their proliferation during the long treatment time. Similar results were also obtained by Ngbolua et al. (2016). Valverde et al. (2018) have also shown in the same direction that *M. oleifera* seeds contain nearly 94%

of organic substances and cause an increase of 100 to 400% of the rate of organic substances in the processed water. Other moringa-based treatment with 15 min decanting time, as well as aluminum sulphate-based treatment resulted in *E. coli* reduction by 100%. For aluminum sulphate-based treatment, this will be explained by the fact that it does not contain organic substances. As for Moringa seeds-based treatment, the short decanting time (15 min) does not allow the proliferation of microorganisms. For other coliforms, it is noted that the treatments with aluminum sulphate also resulted in a reduction of 100% of these microbial indicators. However, they were slightly present in moringa-based processed water and again when cactus extract was used as flocculant. The greater proliferation would be due to the fact that this biofloculant is also very rich in organic substances.

CONCLUSION AND PERSPECTIVE

This study proved that moringa seeds can be used as coagulant while cactus extracts can be used as flocculant. A comparison of the clarification capacity of this coagulant with aluminum sulphate shows that these coagulants are both effective. Also, the comparison of physicochemical parameters other than turbidity revealed that the pH of water decanted with moringa seeds remains nearly unchanged. This is an important advantage because its treatment does not require any acidity corrector, as opposed to aluminum sulphate. However, microbial indicators showed that treatment with aluminum sulphate was more beneficial because it eliminated all pathogenic microorganisms initially present in the water, whereas moringa seeds treatment such as a coagulant or even cactus extract as flocculant caused an increase in organic substances and induced a proliferation of bacteria over time. At the end of this study, it is inferred that moringa seeds are a good coagulant, but aluminum sulphate is better for large-scale water treatment. On the other hand, if some concerns were taken into account, the pair moringa seeds/ cactus extracts would be a viable bio alternative. It would be more effective than aluminum sulphate in the clarification of surface waters in our country. These concerns include identifying the active ingredients contained in both moringa seed and cactus extract; purifying these active ingredients in order to eliminate the organic substances and synthesizing them to obtain a more manageable and accessible product.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ABBREVIATIONS

H, hour; min, Minute; **NTU**, nephelometric turbidity units, **ONEA,** national water and sanitation office, **TA**, alkalimetric title, **TAC,** complet alkalimetric title, **TH,** hydrotimetric title.

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