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Effectiveness of *Moringa oleifera* Defatted Cake versus Seed in the Treatment of Unsafe Drinking Water: Case Study of Surface and Well Waters in Burkina Faso

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ABSTRACT

Safe drinking water access for rural populations in developing countries remains a challenge for a sustainable development, particularly in rural and periurban areas of Burkina Faso. The study aims to investigate the purifying capacity of *Moringa oleifera* defatted cake as compared to *Moringa oleifera* seed in the treatment of surface and well waters used for populations alimentation. A total of 90 water samples were collected in sterile glass bottles from 3 dams' water reservoirs, a river, and a large diameter well, respectively. The water samples were treated in triplicate with *Moringa oleifera* seed and defatted cake coagulants. At different settling time and coagulant concentration, turbidity and pH were measured to determine the optimal conditions and factors influencing treatment with regard to sampling source. Nine physicochemical parameters (turbidity, pH, nitrates, nitrites, calcium, magnesium, total hardness, organic matter and sulfates), three bacterial fecal pollution indicators (*Escherichia coli*, fecal Coliforms and fecal Streptococcus) and parasite cysts were monitored based on laboratory standard methods. Data were analyzed using the Student's t test and XLSTAT 7.5.2 statistical software. From the results obtained, for the same concentration of coagulant, settling time providing the lowest turbidity was significantly shorter ($p < 0.0001$) with *Moringa oleifera* cake than seed. Optimum settling time with *Moringa oleifera* cake was between 15 - 60 min versus 60 - 120 min, with *Moringa oleifera* seed. Both treatments significantly reduced minerals concentration in water excepted sulfates for which the concentration reversely increased. However, only *Moringa oleifera* cake treatment reduced organic matter content in all the water samples, while it increased with *Moringa oleifera* seed one ($p < 0.0001$). The reduction of microbial pollution indicators was 92% - 100% with *M. oleifera* cake treatment and 84% - 100% with *M. oleifera* seed one. Overall, for all water samples, *Moringa oleifera* cake treatment appeared more efficient in improving drinking water quality than the *M. oleifera* seed treatment.

Keywords: Drinking Water; *Moringa oleifera*; Cake; Seed; Chemistry; Bacteriology; Parasitology

1. Introduction

Access to safe drinking-water is important as a health and development issue at national, regional and local levels. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions. This is true for major water supply infrastructure investments through to water treatment in the home [1]. However, safe drinking water access for rural populations in developing countries (DC) remains a challenge to overcome for a sustainable development. Despite appreciable efforts undertaken to achieve the Millennium Development Goals (MDG), many of these countries are still suffering from a lack of drinking water access [2,3]. In view of the increase in water demand, measures undertaken generally focused the quantitative aspect to meet the needs of populations. However, beyond the quantitative aspect, it is advisable to pay attention to the quality of water consumed by the populations.

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According to the United Nations Development Program [4], the access to safe drinking water in Burkina Faso clearly improved these years with a national rate of water access passing from 18.3% in 1993 to 66.3% in 2007. These good performances are the consequence of the efforts undertaken by the country to achieve the Millennium Development Goals (MDG). Although Burkina Faso already reached the MDG for the access to safe drinking water [4], the situation is not therefore satisfactory, in particular in rural environment where the populations are confronted with the optimal management of the water supply points [5]. Water that is aesthetically unacceptable will undermine the confidence of consumers, will lead to complaints and, more importantly and could lead to the use of water from sources that are less safe [6].

The quality of water consumed by rural populations in Burkina Faso besides the quantitative aspect is a concern because of the traditional water sources competition, the lack of hydraulic structures maintenance, the inadequate hygiene and sanitation and the lack of appropriate disinfection methods at house level [7-9]. Thus, some river and well waters continue to be used in rural areas for human consumption, particularly in the Sourou Valley [7, 10,11]. Therefore, the development and adoption of appropriate disinfection methods based on local natural substances at family level could be an efficient alternative to overcome these deficiencies.

The use of *Moringa oleifera* seeds in drinking water treatment showed some limits because of the long settling time and high concentrations of coagulant required to decrease water turbidity which unfortunately leads to the increase of water organic matter in some cases [12, 13]. In the present study, we examined the purifying capacities of *Moringa oleifera* defatted cake obtained after oil extraction and *Moringa oleifera* seed treatments applied to surface and well waters. Settling time and coagulant concentration required to decrease water turbidity, nitrates, nitrites, magnesium, calcium, organic matter, sulfates and microbial pollution indicators (*E. coli*, fecal Coliforms, fecal Streptococcus and parasite cysts) contents in water were focused throughout the study.

After the presentation of the study zone and the methodology used, the results obtained will be presented. The quality of water will be discussed with regard to the WHO standards and the *Moringa oleifera* treatment.

2. The Zone of Study

Two water sources located in the zone covered the Contract of Sourou River within the Sourou valley [14,15] namely Gana River and Boaré modern well (**Figures 1** and **2**) and 3 dams' water reservoirs in the urban and periurban zones of Ouagadougou, namely Ouaga 3, Loumbila, and Ziga (**Figure 1**) were selected for the study.

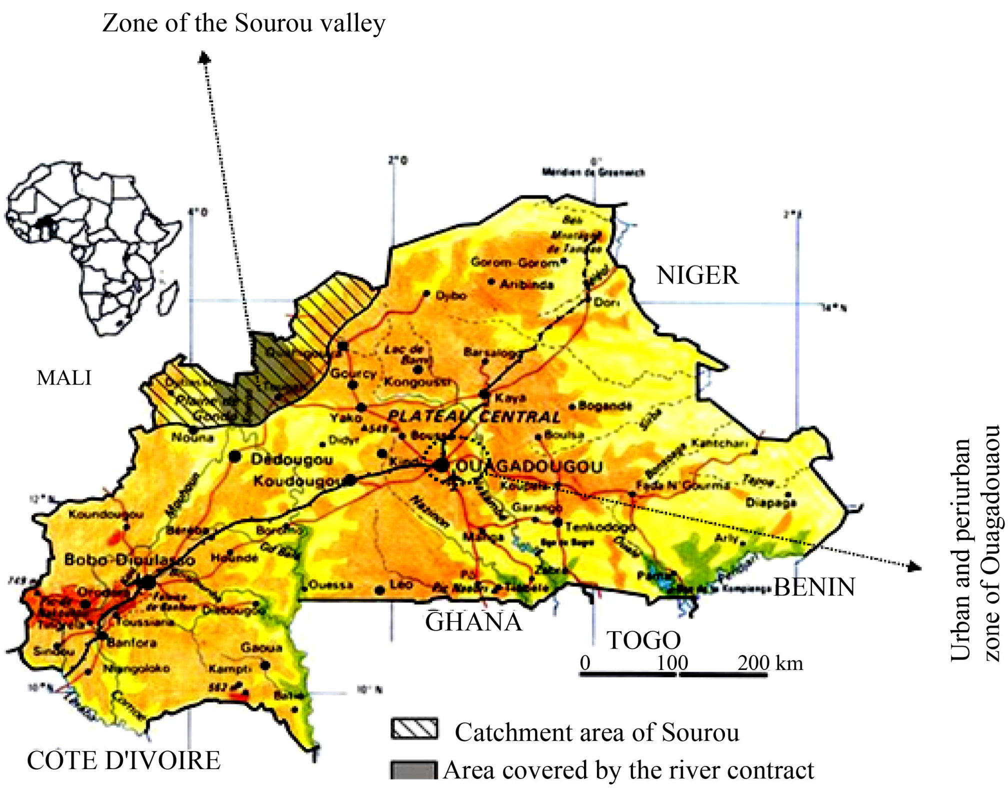

Figure 1. Location of the study zones [15,20].

Figure 2. Aspects of drinking water at the sites of Gana and Boaré in the Sourou valley during the study period. Water sample from Gana River (a) and the modern well of Boare (b).

The Sourou valley is located in the North-West of Burkina Faso, in the area of the Mouhoun loop and constitutes an important agrarian production zone benefitting the whole country [8]. Drinking water access for a Sourou population is possible from various sources of supply including drillings, modern and traditional wells, and surface waters as well [7,14,16]. Access to safe drinking water is particularly problematic for some rural populations which feed on mainly from surface waters and wells.

In the urban and periurban zone of Ouagadougou, surface waters were used to supply drinking water to populations through treatment plants and for agriculture, recreational activities and in some cases as direct source of drinking water as well [17,19]. Loumbila and Ziga dams are located at 15 and 50 Km of Ouagadougou, respectively while Ouaga 3 is within the city.

3. Material and Methods

For this study, *Moringa oleifera* seed and defatted cake coagulants were used to treat unsafe drinking water samples. The treatment efficiency was assessed by comparing the physico-chemical and microbiological characteristics of treated and untreated water samples with the WHO standards for drinking water.

3.1. *Moringa oleifera* Seed and Defatted Cake Coagulants Preparation

Moringa oleifera seeds were obtained from the National Forest Seed Centre (NFSC). To obtain *Moringa oleifera* defatted cake, the seeds were sorted and pressed with a press machine (ZX10) to remove about 30% oil. The defatted cake obtained was dried and crushed using the procedure described by Folkard *et al.* [20]. To prepare the *Moringa oleifera* seed powder, the hulls and wings from the kernels were removed. The kernels were then crushed and ground to a medium fine powder according to Folkard *et al.* [20].

The coagulants from the cake and seed powders were then prepared following the procedure of Folkard *et al.* [20]. Appropriate quantities of *Moringa oleifera* seed or cake powder were placed into bottles that contained 500 ml of sterilized distilled water, giving 20 g/l and 100 g/l concentrated stock solutions, respectively. The mixtures were stirred for one hour to extract the active protein of *Moringa oleifera* prior to water samples treatment.

3.2. Water Sampling

Water samples were collected aseptically in triplicate into sterile glass bottles at the field. A total of 90 samples were collected at the field, preserved at 4˚C in cool boxes, carried to the laboratory and stored in a refrigerator at 4˚C before treatment and analysis.

3.3. Water Samples Treatment

Water samples were treated in the laboratory in triplicate. Increased concentrations of *Moringa oleifera* seed and defatted cake coagulants were used to treat water samples according to Folkard *et al.* [20] in order to determine the appropriate concentrations for an optimum clarification of water samples. Experiments were carried out using the jar test (FC6S Velp Scientifica Jar-Test). The test involved a rapid mixing, followed by a slow mixing then, sedimentation for 15 min, 30 min, 60 min and 120 min, respectively. For each sedimentation period, 20 ml of supernatant were taken for turbidity and pH measurements using a WTW 550 IR turbidity meter and a WTW 330i pH meter with a Sen Tix 41 electrode, respectively in order to determine the optimal conditions and factors influencing treatment. For each water sample, the treatment that gave the lowest turbidity determined the optimum treatment conditions.

3.4. Physicochemical and Microbiological Characteristics of Coagulants and Water Samples

The physicochemical and microbiological characteristics of water samples were determined before and after treatment at optimum processing conditions to evaluate the treatment effect. Analyzes were at the National Office of Water and Sanitation and the Institute for Research in health Sciences.

Physicochemical parameters which enclosed turbidity, nitrates, nitrites, calcium, magnesium, sulfates, total hardness, and organic matter, were determined by the standard methods described by Rodier [21]. Organic matter was determined by the method of weight loss after ignition of dry matter (French standard NF 90-105). Calcium, magnesium, and total hardness were determined by titrimetric methods according to the French standards NF T 90-016 for calcium-magnesium, and NF T 90-003 for total hardness. For nitrates, nitrites and sulfates determination, proportioning was carried out by molecular absorption spectrophotometry with a spectro Hach Lange DR 3800 according to the methods 8051, 8039, 8507 respectively for sulfates, nitrates and nitrites.

Three (3) bacterial indicators of fecal contamination namely *Escherichia coli*, fecal Coliforms, fecal Streptococcus were determined by the method of membrane filtration technique [22]. Bacterial cells were concentrated on a 0.2 μm Millipore Membrane Filter followed by culture on the chromogenic RAPID E. COLI 2 AGAR (BIO RAD) medium which contains 2 substrates specific to the *β*-D-Glucuronidase (Gluc) and *β*-D-Galactosidase (Gal) en-zymes, respectively. Incubation was performed at 44.5˚C for 24 h. Colonies of *E. coli* (Gal+/Gluc+) appear violet to pink while other coliforms colonies stain blue. On the Bile-Esculine-Azide medium, Gram positive cells able to reduce Esculine as fecal Streptococcus stain black after 24 h incubation period at 37˚C, while Gram negative and other Gram positive cells are inhibited by sodium Azide.

Parasite eggs and/or cysts were identified and enumerated according to Ritchie [23] and consisted of a concentration of parasites with Formalin and Ether followed by a microscopic observation of the precipitate using lens 10 and 40 for the detection of parasite eggs or larva, and lens 100 with immersion oil after addition of two drops of a Iodine-Potassium iodide solution for the research of protozoa cysts.

3.5. Statistical Analysis

Data obtained were analyzed for water source and sampling period variations using the Student's t-test and XLSTAT 7.5.2 statistical software. Mean parameters concentrations were compared according to the Newman Keuls' test.

4. Results and Discussion

4.1. Physicochemical Parameters of Coagulants

The physicochemical parameters of *Moringa oleifera* seed and defatted cake coagulants are shown in **Table 1**. The concentration of nitrates, nitrites, sulfates and organic matter in *Moringa oleifera* seed coagulant appears more important than in the defatted cake one. Thus, the treatment with *Moringa oleifera* cake coagulant could induce less organic matter and minerals in some treated water compared to *Moringa oleifera* seed coagulant.

4.2. Water's Turbidity and pH with Regard to Concentration of Coagulant and Settling Time

Table 2 presents the variance of turbidity and pH of water samples in relation to sampling site, *Moringa oleifera* treatment, settling time and coagulant concentration. The Student's t-test revealed that water turbidity and pH were significantly related to the sampling site ($p < 0.0001$), treatment ($p < 0.0001$), settling time ($p < 0.0001$ and $p = 0.000$, respectively) and concentration of coagulant ($p < 0.0001$).

The mean turbidity and pH characteristics are shown in **Tables 3(a)** and **(b)**. Globally, both treatments removed significantly water turbidity. Overall, for all water samples, statistical analysis showed that *Moringa oleifera* cake treatment was more efficient in decreasing water turbidity (5.7 NTU) than *M. oleifera* seed (11.8 NTU). Moreover, water clarification with *Moringa oleifera* cake required a shorter settling time than *Moringa oleifera* seed (15 - 60 min and 60 - 120 min, respectively). However, both treatments efficiency was influenced by the water samples' characteristics.

For water samples from Loumbila, turbidity values in agreement the WHO standard were obtained after 30 min settling period with *Moringa oleifera* cake (4.83 NTU) and 60 min with *Moringa oleifera* seed (4.22 NTU) (**Table 3(a)**). Concerning water samples from Ouaga 3, optimum settling time leading turbidity values feting the WHO standard was 15 min for *Moringa oleifera* cake versus 1 hour for *Moringa oleifera* seed (**Table 3(a)**). Optimum settling time for water samples from Gana with *Moringa oleifera* cake treatment was 1 hour. For this settling time, turbidity of water treated with *Moringa oleifera* seed was over the WHO guideline value (**Table 3(a)**). Concerning water samples from Ziga and Boaré, optimum settling time was superior to 2 hours for both treatments. However, *Moringa oleifera* cake treatment gave turbidity values close to the WHO guideline value (**Table 3(b)**) [24,26,27].

Table 1. Physicochemical characteristics of *Moringa oleifera* seed and defatted cake coagulants.

Type of *M. oleifera* coagulant	Nitrates (mg/l)	Nitrites (mg/l)	Calcium (mg/l)	Magnésium (mg/l)	Sulfates (mg/l)	Total hardness	Organic matter (mg/l)
Seed	34	4	0	0	47	0	14,000
Defatted cake	19	1	0	0	10	0	200

Table 2. Variance of water's turbidity and pH in relation to the sampling site, *M. oleifera* treatment, settling time and concentration of coagulant.

Source of variation	df	Turbidity (NTU)		pH	
		MS	P	MS	P
Site	4	23110114.2	<0.0001**	1.816	<0.0001**
Treatment	2	18922.4	<0.0001**	4.103	<0.0001**
Settling time	3	29309.5	<0.0001**	0.289	0.000**
Concentration	18	40150923.8	<0.0001**	0.523	<0.0001**

MS: Mean square; **significant $p < 0.01$.

The effectiveness of both treatments was also related to the coagulant concentration. Beyond optimal concentration of coagulant, turbidity of treated water increased (**Tables 3(a)** and **(b)**).The purifying activities of *Moringa oleifera* are based on the electrostatic patch charge mechanism [28]. Elimination of fat matter in *Moringa oleifera* seeds could reduce interactions between lipids and active proteins and could explain the effectiveness of defatted cake in water treatment.

Concerning pH, both treatments decreased significantly ($p < 0.0001$) this parameter. Overall, it appeared that *Moringa oleifera* seed treatment reduced more pH than *Moringa oleifera* cake (7.1 and 7.3, respectively). However, pH values of all water samples (treated or not) were in agreement with the WHO guideline value [24,25] (**Tables 3(a)** and **(b)**).

4.3. Physicochemical Parameters of Water Treated with *Moringa oleifera* Defatted Cake and Seed Coagulant.

The results of the statistical analysis on the data obtained before and after treatment at optimum processing conditions are presented in **Tables 4(a)** and **(b)**. The Student's t-test revealed that all the characteristics of water were significantly related to the sampling site and treatment, respectively ($p < 0.0001$). The joined effects of site and treatment affected also significantly ($p < 0.0001$) these parameters.

Globally for all water samples, *Moringa oleifera* cake treatment reduced more significantly turbidity, nitrates and organic matter contents than *Moringa oleifera* seed treatment (5.7, 1.19 and 5.8 mg/l against 11. l, 2.5 and 75.4 mg/l, respectively). However, *Moringa oleifera* seed treatment induced more sulfates (21.2 mg/l) in treated water than *Moringa oleifera* cake (15.9 mg/l).

For calcium, magnesium and total hardness, it appeared that *Moringa oleifera* seed is more efficient to reducing the concentration of theses parameters (14.1 mg/l, 11.1 mg/l and 25.1 mg/l, respectively) than *Moringa oleifera* cake (15.1 mg/l, 12.3 mg/l and 27.4 mg/l, respectively).

The mean turbidity values in the water samples ranged from 61 to 6348 NTU (**Table 5**). This parameter varied significantly with the sampling site ($p < 0.0001$) and *M.oleifera* treatment as well ($p < 0.0001$). Significant reductions of 98%, 91.8%, 96.25%, 96.6% 99.9% were observed for Loumbila, Ouaga3, Ziga, Boaré and and Gana water samples, respectively after *M. oleifera* cake treatment against 96.53%, 90.8%, 92.8%, 91.5% and 99.9%, respectively with *Moringa oleifera seed* treatment. The efficiency revealed for *Moringa oleifera* cake was closely related to the initial turbidity of the water sample.

The mean pH of the water samples ranged from 7.34 to 8.01 (**Table 5**). Both treatments reduced significantly this parameter ($p < 0.0001$). Optimum values of treated water fitted the WHO guideline value [24,25]. Although pH usually has no direct impact on consumers, high or low pH can affect the palatability. No health based guideline value has been proposed for pH.

The mean nitrates concentration in water samples ranged from 0 to 200.3 mg/l (**Table 5**). This parameter varied significantly with the sampling source ($p < 0.0001$), *M. oleifera* treatment ($p < 0.0001$) and their joined effects as well ($p < 0.0001$). The higher reduction was obtained for Gana water samples: 98.5% with *Moringa oleifera* seed versus 99.5% with *Moringa oleifera* cake. Although both treatments increased nitrates content in water from Loumbila and Ouaga 3, concentrations issued fitted the WHO and USEPA guide line value

Table 3. (a) Means turbidity and pH of water samples from Loumbila, Ouaga 3 and Gana, treated or not with *Moringa oleifera* cake (1) or seed (2) coagulant; (b) Means turbidity and pH of water samples from Ziga and Boaré, treated or not with *Moringa oleifera* cake (1) and seed (2) coagulant.

(a)

Sampling site	Treatment	Concentration of coagulant (mg/l)	Turbidity (NTU)			pH		
			Settling time (min)			Settling time (min)		
			15	30	60	15	30	60
Loumbila	Untreated	0	158.67^{a}	158.67^{a}	158.67^{a}	7.53^{a}	7.53^{a}	7.53^{a}
	1	400	11.01^{c}	8.35^{cde}	2.94^{f}	7.33^{bc}	7.32^{bc}	7.307^{c}
		500	8.29^{cde}	5.59^{def}	2.23^{f}	7.35^{bc}	7.35^{bc}	7.34^{bc}
		600	7.98^{cde}	4.82^{def}	1.78^{f}	7.36^{bc}	7.35^{bc}	7.35^{bc}
	2	400	20.97^{b}	9.1^{cd}	4.22^{def}	7.24^{c}	7.24^{c}	7.23^{c}
		500	17.12^{b}	8.57^{cde}	3.89^{ef}	7.25^{c}	7.25^{c}	7.23^{c}
		600	18.29^{b}	9.04^{cd}	3.69^{ef}	7.26^{c}	7.24^{c}	7.24^{c}
Ouaga3	Untreated	0	61.53^{a}	61.53^{a}	61.53^{a}	7.63^{a}	7.63^{a}	7.63^{a}
	1	300	9.82^{e}	6.98^{fgh}	5.29^{hij}	7.3^{cde}	7.3^{cde}	7.28^{e}
		350	6.63^{ghi}	4.45^{ijk}	2.64^{kl}	7.31^{bcde}	7.3^{cde}	7.3^{cde}
		400	4.32^{ijkl}	2.97^{jkl}	1.9^{l}	7.34^{bc}	7.33^{bcd}	7.32^{bcde}
	2	300	19.61^{c}	9.91^{e}	5.47^{hi}	7.23^{f}	7.21^{f}	7.21^{f}
		350	17.51^{c}	8.47^{efg}	5.26^{hij}	7.29^{de}	7.31^{bcde}	7.297^{cde}
		400	13.23^{d}	9.12^{ef}	4.4^{ijk}	7.34^{b}	7.31^{bcde}	7.31^{bcde}
Gana	Untreated	0	6360^{a}	6360^{a}	6360^{a}	7.7^{a}	7.7^{a}	7.7^{a}
	1	9000	13.4^{b}	8.69^{b}	6.1^{b}	7.35^{b}	7.35^{b}	7.343^{b}
		10,000	9.56^{b}	6,07^{b}	4,13^{b}	7.36^{b}	7.35^{b}	7.35^{b}
		11,000	20.9^{b}	17.07^{b}	9.6^{b}	7.36^{b}	7.36^{b}	7.34^{b}
	2	9000	64.47^{b}	52.37^{b}	27.067^{b}	6.85^{d}	6.77^{c}	6.67^{c}
		10,000	67.4^{b}	33.1^{b}	18.4^{b}	6.36^{d}	6.35^{d}	6.35^{d}
		11,000	62.47^{b}	31.9^{b}	23.3^{b}	6.36^{d}	6.36^{d}	6.34^{d}
Guideline values [24,25]				≤5 NTU			6.5 - 8.5	

For a site, means with a same letter within a column are not significantly different according to Newman Keuls' test $p < 0.05$. 1: Treated with *Moringa oleifera* cake coagulant 2: Treated with *Moringa oleifera* seed coagulant.

(b)

Sampling site	Treatment	Concentration of coagulant (mg/l)	Turbidity (NTU)				pH			
			Settling time (min)				Settling time (min)			
			15	30	60	120	15	30	60	120
Ziga	Untreated	0	180.3^{a}	180.3^{a}	180.3^{a}	180.3^{a}	7.97^{a}	7.97^{a}	7.97^{a}	7.97^{a}
	1	600	50.87^{f}	35.17^{i}	21.6^{l}	11.23^{n}	7.3^{ghi}	7.27^{hij}	7.24^{ijk}	7.23^{jkl}
		700	35.27^{i}	25.77^{jk}	13.2^{mn}	7.04^{o}	7.26^{hijk}	7.22^{jkl}	7.2^{jklm}	7.2^{klm}
		800	78.33^{b}	64.27^{c}	40.2^{gh}	27.77^{j}	7.22^{jkl}	7.2^{klm}	7.16^{lm}	7.15^{m}
	2	600	57.74^{de}	43.21^{g}	23.33^{kl}	11.03^{n}	7.5^{b}	7.45^{bc}	7.43^{cd}	7.4^{cde}
		700	54.17^{ef}	37.04^{hi}	15.69^{m}	10.67^{no}	7.45^{bc}	7.42^{cd}	7.403^{cd}	7.373^{def}
		800	59.59^{d}	37.51^{hi}	23.24^{kl}	12^{mn}	7.38^{def}	7.34^{efg}	7.32^{fgh}	7.29^{ghi}
Boaré	Untreated	0	277^{a}	277^{a}	277^{a}	277^{a}	7.277^{a}	7.28^{a}	7.28^{a}	7.28^{a}
	1	700	46.27^{f}	30.8^{jk}	16.01^{m}	9.63^{n}	7.23^{bc}	7.2^{bcde}	7.2^{bcde}	7.2^{fghij}
		800	41.73^{g}	32.67^{ij}	16.4^{m}	9.95^{n}	7.22^{bcd}	7.2^{bcdefg}	7.2^{bcde}	7.17^{hijk}
		900	47.83^{f}	37.17^{h}	15.39^{m}	9.35^{n}	7.2^{bcdef}	7.2^{cdefgh}	7.19^{efghi}	7.16^{ijk}
	2	700	79.33^{c}	63.67^{d}	45.6^{fg}	25.17^{l}	7.23^{b}	7.2^{cdefgh}	7.17^{ghijk}	7.15^{jkl}
		800	77.1^{c}	66.67^{d}	52.27^{e}	26.9^{kl}	7.23^{b}	7.2^{defghi}	7.15^{jkl}	7.13^{l}
		900	84^{b}	66.43^{d}	44.3^{fg}	35.17^{hi}	7.2^{bcde}	7.2^{defghi}	7.19^{efghi}	7.14^{kl}
Guideline values [24,25]				≤5 NTU					6.5 - 8.5	

For a site, means with a same letter within a column are not significantly different according to Newman Keuls' test $p < 0.05$. 1: Treated with *Moringa oleifera* cake coagulant 2: Treated with *Moringa oleifera* seed coagulant.

Table 4. (a) Variance of physicochemical characteristics of water from Ouaga3, Loumbila, Ziga, Boaré and Gana with regard to sampling site and treatment at optimal processing conditions; (b) Variance of physicochemical characteristics of water from Ouaga3, Loumbila, Ziga, Boaré and Gana with regard to sampling site and treatment at optimal processing conditions.

(a)

Source of variation	df	Turbidity (NTU)		Nitrates (mg/l)		Nitrites (mg/l)		Calcium (mg/l)	
		MS	P	MS	P	MS	P	MS	P
Sampling site	4	7,625,681	$<0.0001^{**}$	7858	$<0.0001^{**}$	0	$<0.0001^{**}$	19,119	$<0.0001^{**}$
Treatment	2	9,792,804	$<0.0001^{**}$	8711	$<0.0001^{**}$	0	$<0.0001^{**}$	21,979	$<0.0001^{**}$
Site x treatment	8	7,636,419	$<0.0001^{**}$	7695	$<0.0001^{**}$	0	$<0.0001^{**}$	18,567	$<0.0001^{**}$

^{MS}mean square; **significant $p < 0.01$.

(b)

Source of variation	df	Magnesium (mg/l)		Total hardness (mg/l)		Sulfates (mg/l)		Organic matters (mg/l)	
		MS	P	MS	P	MS	P	MS	P
Sampling site	4	64670.7	$<0.0001^{**}$	153554.2	$<0.0001^{**}$	161	$<0.0001^{**}$	1,502,776	$<0.0001^{**}$
Treatment	2	66982.1	$<0.0001^{**}$	167443.4	$<0.0001^{**}$	484	$<0.0001^{**}$	846,001	$<0.0001^{**}$
Site x treatment	8	66197.6	$<0.0001^{**}$	156186.1	$<0.0001^{**}$	237	$<0.0001^{**}$	915,008	$<0.0001^{**}$

^{MS}mean square; **significant $p < 0.01$.

Table 5. Mean physicochemical characteristics of water from Loumbila, Ouaga3, Ziga, Boaré and Gana treated or not with *Moringa oleifera* cake coagulant (1) and *Moringa oleifera* seed coagulant (2) at optimal processing conditions.

Sampling site	Treatment	Turbidity (NTU)	pH	Nitrates (mg/l)	Nitrites (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sulfates (mg/l)	Total hardness (mg/l)	Organic matter (mg/l)
Loumbila	Untreated	159.7^{d}	7.46^{c}	0^{h}	0.001^{fg}	4.27^{i}	12.2^{g}	9.1^{g}	16.45^{gh}	12^{i}
	1	2.9^{f}	7.31^{e}	1.67^{fg}	0.002^{fg}	6.1^{gh}	8.37^{hi}	16.67^{e}	14.13^{h}	2^{j}
	2	5.5^{f}	7.22^{f}	1.87^{ef}	0.004^{ef}	5.33^{hi}	8.13^{ij}	21.13^{c}	13.47^{h}	25^{g}
Ouaga3	Untreated	60.6^{e}	7.61^{b}	0^{h}	0.013^{d}	31.23^{d}	13.5^{ef}	9.67^{f}	44.743^{b}	6^{ij}
	1	4.9^{f}	7.4^{cd}	1.33^{fg}	0.033^{b}	36.1^{c}	9.34^{h}	13.4^{f}	45.44^{b}	2^{j}
	2	5.7^{f}	7.3^{e}	1.1^{g}	0^{g}	30.49^{d}	5.29^{k}	14.2^{f}	35.78^{c}	14^{h}
Ziga	Untreated	187^{c}	8.01^{a}	7.12^{c}	0.004^{ef}	7.287^{g}	18.9^{c}	16^{e}	26.21^{e}	47^{e}
	1	7.04^{f}	7.2^{f}	0^{h}	0.029^{c}	7.32^{g}	14.3^{e}	22^{c}	21.63^{f}	5^{ij}
	2	13.3^{f}	7.41^{cd}	2.3^{e}	0.007^{e}	6.55^{gh}	12.4^{fg}	34^{a}	18.95^{fg}	60^{d}
Boaré	Untreated	285.67^{b}	7.13^{f}	9.9^{b}	0.042^{a}	38.87^{b}	7.12^{j}	11.97^{f}	45.59^{b}	36^{f}
	1	9.63^{f}	7.18^{f}	1.57^{fg}	0.004^{ef}	13.6^{ef}	22.3^{b}	14.23^{f}	35.86^{c}	9^{i}
	2	24.03^{f}	7.15^{f}	3.9^{d}	0.006^{e}	13.12^{f}	17.4^{d}	31^{b}	30.56^{d}	62^{c}
Gana	Untreated	6348.3^{a}	7.34^{g}	200.8^{a}	0^{g}	322.73^{a}	586^{a}	0^{h}	913.3^{a}	1800^{a}
	1	4.1^{f}	7.05^{de}	1.4^{fg}	0.005^{ef}	12.38^{f}	7.6^{ij}	19.5^{cd}	19.98^{fg}	11^{i}
	2	10.6^{f}	6.35^{h}	3.3^{d}	0.005^{ef}	14.83^{e}	12.3^{fg}	18.67^{d}	26.98^{de}	253^{b}
Guideline values [24,25]		≤5	6.5 - 8.5	50	3	-	-	≤500	≤0.3	-

For a site, means with a same letter within a column are not significantly different according to Newman Keuls' test $p < 0.05$. 1: Treated with *Moringa oleifera* cake coagulant 2: Treated with *Moringa oleifera* seed coagulant

(≤50 mg/l) [6,29] (**Table 5**). Nitrates concentration in drinking water is more focused because high level can be hazardous to infants. The nitrates itself is not a direct toxicant but is a health hazard because of its conversion to nitrite, which reacts with blood haemoglobin to cause methaemoglobinaemia.

Mean calcium and magnesium concentrations ranged from 4 to 322 mg/l and 7 to 586 mg/l, respectively (**Table 5**). Both parameters varied significantly with the water source ($p < 0.0001$) and treatment ($p < 0.0001$) (**Tables 4(a)** and **(b)**). The highest reductions in calcium and magnesium contents were obtained for Gana and Boaré water samples: 95% - 98% and 66% - 59%, respectively with *Moringa oleifera* seed versus 96% - 98.8% and 67% - 88%, respectively with *Moringa oleifera* cake. There is no evidence of adverse health effects from calcium or magnesium in drinking water; both ions contribute to water hardness. Therefore, guideline values are not proposed [24,25,30].

Total Hardness values of the water samples ranged from 16 to 913 mg/l. This parameter varied significantly with the sampling source ($p < 0.0001$) and treatment ($p < 0.0001$). Both treatments reduced significantly total hardness. However, the highest reduction was obtained with *Moringa oleifera* seed treatment for all the water samples (**Table 5**). The hardness of drinking water is important for aesthetic acceptability by consumers. Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. Consumers are likely to notice changes in hardness. In some cases, consumers tolerate water hardness in excess of 500 mg/l [6]. For this parameter the results obtained were in agreement with the WHO guideline value.

Coagulation with *Moringa oleifera* seeds is based on the adsorption and neutralization of negative particles (colloids) and metals by the positive charges of the active proteins contained in *Moringa oleifera* coagulant [31]. This mechanism could explain the removal of nitrates, calcium, magnesium and total hardness with colloids for these samples (**Table 5**).

Mean Sulfates concentration in the water samples ranged from 0 to 16 mg/l (**Table 5**). Concentrations were significantly related to the sampling site and treatment ($p < 0.0001$, **Table 4(b)**). Both treatments increased sulfates content in treated water, although within the range of the WHO guideline value (250 mg/l).

Moringa oleifera seed coagulant lead to an increase in organic matter for all samples except those of Gana river for which a decrease from 1800 mg/l to 253 mg/l was recorded with 10 g/l of *Moringa oleifera* seed coagulant (**Table 5**). For water samples from Loumbila, Ouaga3, Boaré and Ziga, *Moringa oleifera* seed treatment increased the concentration of 100%, 125%, 98% and 100%, respectively. Comparatively, *Moringa oleifera* cake coagulant reduced organic matter content in all water samples (**Table 5**). Because of the high concentration of organic matter in *Moringa oleifera* seed coagulant (**Table 1**), the treatment increased organic matter in the treated water as also observed Jacques *et al.* [12] and Kaboré *et al.* [13]. The provision of drinking-water that is not only safe but also acceptable in appearance, taste and odor is of high priority [6].

4.4. Microbiological Parameters of Water Treated with *Moringa oleifera* Seed and Cake Coagulants

The microbiological parameters examination of the water samples are presented in **Tables 6** and **7**. The Student's t-test (**Table 6**) revealed that all the microbial characteristics of water samples were significantly related to the sampling site ($p < 0.0001$) and *M. oleifera* treatment ($p < 0.0001$). The joined effects of site and treatment affected also significantly ($p < 0.0001$) these characteristics.

For all water samples, mean concentrations of microbial pollution indicators (**Table 7**) were significantly higher ($p < 0.0001$) in untreated water than in the treated one. Globally, both treatments removed significantly concentrations of microbial pollution indicators (**Table 7**). However, the highest reduction was recorded with *Moringa oleifera* seed treatment: 99.92% for fecal Coliforms, 99.92% for *E.coli* and 100% for fecal Streptococcus versus 99.3%, 99.76% and 98% for these indicators, respectively with *Moringa oleifera* cake treatment. However, the reductions obtained for the both treatments significantly differed through water samples (**Tables 6** and **7**). Thus, for Loumbila and Gana water samples both treatments reduced 100% all microorganisms while 84% - 95%, 92% - 100% and 100% of fecal Coliforms, *E. coli* and fecal Streptococcus reductions, respectively were recorded for Ouaga 3 samples (**Table 7**).

From the microbial characteristics of Ouaga3, Ziga and Boaré, water samples, it appeared at optimal processing conditions, that *Moringa oleifera* seed treatment is more efficient than *Moringa oleifera* cake one. However, the addition of organic matter brought by the seed can cause bacteria's growth in the treated water. Indeed, the bacteria abundance in water depends on the amount of nutrients in form of organic carbon (sugar, amino acids, organic acids, etc.). Drinking water should contain 0.5 to 2 mg/l of dissolved organic carbon in order to ensure the microbiological stability [32]. Thus we can conclude that the treated water with *Moringa oleifera* cake could be more stable than those treated with *Moringa oleifera* seed. This parameter is very important because it influences the quality preservation of treated water.

Table 6. Variance of microbiological characteristics of water samples with regard to sampling site and *Moringa oleifera* treatment.

Source of variation	df	Fecal coliforms (CFU/100 ml)		*Escherichia coli* (CFU/100 ml)		Fecal streptococcus (CFU/100 ml)		Parasite cyst (eggs/l)	
		MS	P	MS	P	MS	P	MS	P
Sampling site	4	9,540,887	<0.0001**	2,707,337	<0.0001**	670,383	<0.0001**	304,222	<0.0001**
Treatment	2	29,809,722	<0.0001**	3,646,587	<0.0001**	1,353,749	<0.0001**	304,222	<0.0001**
Site x treatment	8	9,555,408	<0.0001**	2,714,545	<0.0001**	673,618	<0.0001**	304,222	<0.0001**

MSmean square; **significant $p < 0.01$.

Table 7. Means concentrations of *E. coli*, fecal Coliforms, fecal Streptococcus and parasite cysts of water from Ouaga3, Loumbila, Ziga, Boaré and Gana, treated or not with *Moringa oleifera* cake coagulant (1) and *Moringa oleifera* seed coagulant (2) at optimal processing conditions.

Sampling site	Treatment	Fecal coliforms (CFU/100 ml)	*E. coli* (CFU/100 ml)	Fecal streptococcus (CFU/100 ml)	Parasite cysts (eggs/l)
	Untreated	147[c]	43[b]	23[c]	0[b]
Loumbila	1	0[d]	0[c]	0[d]	0[b]
	2	0[d]	0[c]	0[d]	0[b]
	Untreated	203[c]	120[b]	10[c]	0[b]
Ouaga3	1	33[cd]	10[c]	0[d]	0[b]
	2	10[d]	0[c]	0[d]	0[b]
	Untreated	237[c]	180[b]	90[c]	0[b]
Ziga	1	20[d]	3[c]	0[d]	0[b]
	2	20[d]	0[c]	0[d]	0[b]
	Untreated	567[b]	133[b]	550[b]	0[b]
Boaré	1	33[d]	0[c]	0[d]	0[b]
	2	0[d]	0[c]	0[d]	0[b]
	Untreated	6000[a]	3800[a]	1933[a]	22833[a]
Gana	1	0[d]	0[c]	0[d]	0[b]
	2	0[d]	0[c]	0[d]	0[b]
Guideline values [24,25]		0	0	0	0

Means with a same letter within a column are not significantly different according to Newman Keuls' test $p < 0.05$.

5. Conclusion

Unhygienic water causes waterborne diseases which have proven to be the biggest health threat worldwide and they contribute between 70% - 80% of health problems in developing countries [1,33]. These diseases continue to be a major cause of human mortality and morbidity. Diarrheal diseases remain a leading cause of illness and death in the developing world which alone causes 2.2 million of the 3.4 million water-related deaths per year, 90% of these deaths involving children of less than five years [1,33]. Water treatment with *Moringa oleifera* seed is an economical method that can purify drinking water in rural areas. This study showed that *Moringa oleifera* cake possessed a very large purifying capacity. Moreover, *Moringa oleifera* oil is of great interest and an income generating source. The promotion of this method could contribute greatly to sustainable human development and the MDG achievement in developing countries.

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