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Quality of Well Water Treated with *Moringa oleifera* Lam Seeds in Mozambique

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ABSTRACT **Original research paper**

Introduction: Access to safe drinking water remains a major public health challenge in Mozambique, especially for populations of low socioeconomic status and those living in rural areas. Natural coagulants such as *Moringa oleifera* seed powder have been proposed as sustainable, low-cost alternatives for water purification. This study aimed to evaluate the microbiological and physicochemical quality of well water before and after treatment with *M. oleifera* seed powder.

Methods: Water samples were collected from three randomly selected wells in the Lusaka-A neighborhood, Nampula City. Treatments were carried out by adding 100 mg, 50 mg, and 25 mg of *M. oleifera* seed powder to sterilized containers, followed by agitation and sedimentation for 60 and 120 minutes. The supernatants were filtered and analyzed for microbiological parameters (fecal and total coliforms, *Vibrio cholerae*) and physicochemical parameters (pH, conductivity, total solids, and turbidity). All experiments were performed in triplicate.

Results: No total coliforms or *V. cholerae* were detected in the treated samples. The best removal of fecal coliforms (100%) was achieved at a concentration of 1 g/L after both 60 and 120 minutes of sedimentation. For total solids, the highest removal rates occurred at 1 g/L (56% after 60 min and 57% after 120 min) and 0.5 g/L (46% after 60 min and 52% after 120 min). The treatment had no statistically significant effect on pH ($p = 0.215$), conductivity ($p = 0.407$), or turbidity ($p = 0.337$).

Conclusion: Treatment with *M. oleifera* seed powder effectively improved the microbiological quality of well water without significantly altering its physicochemical characteristics. These findings indicate that *M. oleifera* may represent a viable, low-cost, and environmentally friendly option for improving water quality and reducing the risk of waterborne diseases in rural communities.

Keywords: Moringa oleifera, Water quality, Drinking water standards, Natural coagulant, Water insecurity.

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Introduction

Water contamination remains a major global public health concern, particularly affecting populations without access to safe drinking water. According to Souza et al. (2023), inadequate water quality poses serious risks to human health, underscoring the need for affordable and sustainable water treatment alternatives to ensure potable water for human consumption.

Mozambique is among the countries where more than half of the population lacks access to safe drinking water. Most urban areas face chronic water shortages, while rural communities are further affected by the consumption of untreated or unsafe water (Lima, 2020). Consequently, waterborne diseases affect more than 30% of the population, with the province of Nampula reporting 323,765 cases of diarrhea and 6,364 cases of cholera between 2015 and 2017 (Instituto Nacional de Saúde, 2023).

Moringa oleifera (*M. oleifera*), a species widely distributed in tropical and subtropical regions, is one of the most well-known members of the Moringaceae family (Koike et al., 2020). The plant is valued for its nutritional and medicinal properties, being a rich source of proteins, vitamins, β-carotenes, amino acids, and phenolic compounds. It has demonstrated multiple pharmacological effects, including anti-inflammatory, antiulcer, diuretic, antihypertensive, antidiabetic, antibacterial, and antifungal activities (Almeida, 2018).

The coagulant properties of *M. oleifera* seed extracts and purified proteins have been shown to be effective in removing suspended solids, softening hard water, reducing turbidity, chemical oxygen demand, color, and other organic pollutants, as well as disinfecting water through the removal of both Gram-positive and Gram-negative bacteria (Souza et al., 2023). Compared with aluminum sulfate, *M. oleifera* seeds do not significantly alter water pH or alkalinity after treatment and do not promote corrosion (Nascimento et al., 2020). Furthermore, *M. oleifera* seed powder offers advantages over conventional chemical coagulants due to its biodegradability, low toxicity, and minimal sludge production (Souto et al., 2019).

Given these properties, *M. oleifera* represents a promising natural coagulant for water purification in resource-limited settings. Therefore, this study aimed to compare the microbiological and physicochemical quality of well water before and after treatment with *M. oleifera* seed powder in Nampula, Mozambique.

Materials and Methods

Study Area

The study was conducted in the Lusaka-A neighborhood, located in the Natikire Administrative Post, Nampula City, northern Mozambique (coordinates: 15°06’58.9’’S, 39°10’59.8’’E). All experimental procedures were carried out in Nampula. Microbiological analyses were performed at the Clinical Analysis Laboratory of Nampula Central Hospital, while physicochemical analyses were conducted at the Food Quality and Safety Laboratory of the Lúrio University’s Interdisciplinary Studies Center (CEIL).

Study Design and Sampling Criteria

This was an experimental laboratory-based study of primary originality and basic purpose. The plant material used consisted of *Moringa oleifera* **(***M. oleifera***)** seeds collected from mature trees growing in the Lusaka-A neighborhood. The universe of water samples comprised all existing wells in the same neighborhood (approximately nine wells). From these, three wells were randomly selected for sampling. Both the water and plant material samples were obtained through simple random sampling. The selection of *M. oleifera* seed samples was performed by convenience, collecting seeds from randomly chosen trees located in the Muatala neighborhood.

Inclusion and Exclusion Criteria

All wells located in the Lusaka-A neighborhood were eligible for inclusion. Wells were excluded if (a) the owners were unavailable at the time of collection, or (b) any type of disinfectant or chemical treatment had previously been added to the water.

Sample Collection and Preparation

Well Water Samples. Initial samples consisted of 2 L of water collected from each of the three selected wells, totaling 6 L. Samples were stored in previously cleaned and disinfected PET mineral water bottles. The collection was carried out in the morning during October 2023.

Moringa oleifera Seed Samples. A total of 150 g of *M. oleifera* seeds were collected from three trees located in the Muatala neighborhood. In the Laboratory of Ethnobotany and Phytochemistry at Lúrio University (UniLúrio), the seeds were manually removed from the pods, peeled, sun-dried for four days, and ground using a mortar and pestle until approximately 100 g of fine powder was obtained.

Treatment of Well Water with *Moringa oleifera* Seed Powder

The seed powder was prepared following the technique described by Armazeno et al. (2021).All samples were carefully labeled. The experiment consisted of six sterilized containers, each containing 100 mL of well water. Additionally, three untreated well water samples (100 mL each) served as positive controls, and three samples of commercially purified bottled water were used as negative controls. In total, nine water samples were used: three experimental (treated) well water samples, three untreated (positive control) well water samples, and three purified water samples (negative control).

For the experimental samples, 100 mg, 50 mg, and 25 mg of *M. oleifera* seed powder were added to 100 mL of well water, corresponding to concentrations of 1 g/L, 0.5 g/L, and 0.25 g/L, respectively. The mixtures were stirred on a magnetic stirrer at 150 revolutions per minute (rpm) for 3 minutes to ensure homogeneity. After stirring, the containers were left to stand for sedimentation.

From each experimental sample, two aliquots were collected: the first after 60 minutes and the second after

120 minutes of sedimentation. The supernatants were then filtered, and the filtrates were used for microbiological analyses (fecal and total coliforms, *Vibrio cholerae*) and physicochemical analyses (pH, electrical conductivity, total solids, and turbidity). The same analyses were performed on the untreated well water (positive control).

All microbiological and physicochemical procedures followed the analytical methods described by Vunain et al. (2019).

Statistical Analysis

Data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 25. The Kolmogorov–Smirnov test (with Shapiro–Wilk correction) was applied to verify the normality of the data distribution. Differences between means before and after treatment with *M. oleifera* seed powder were evaluated using the paired Student's *t*-test. Statistical significance was set at $p < 0.05$ with a 95% confidence interval.

Results

Total Coliforms and *Vibrio cholerae*

Neither total coliforms nor *Vibrio cholerae* were detected in any of the well water samples analyzed. Thus, no evidence of these microorganisms was found in either the untreated or treated samples.

Fecal Coliforms

Table 1 presents the results of the fecal coliform analyses. The initial bacterial concentration in untreated well water (positive control) decreased progressively with increasing concentrations of *Moringa oleifera* seed powder and with longer sedimentation times.

At the highest concentration (1 g/L), complete removal (100%) of fecal coliforms was observed after both 60 and 120 minutes of sedimentation. Intermediate concentrations (0.5 g/L and 0.25 g/L) also demonstrated significant reductions compared to the untreated samples. No coliforms were detected in the negative control (purified water).

Table 1. Comparison of fecal coliform counts (Most Probable Number per 100 mL) in experimental samples, positive controls, and negative controls.

	Experimental Samples (C1 = 0.25 g/L)		Experimental Samples (C2 = 0.5 g/L)		Experimental Samples (C3 = 1 g/L)		Positive Control	Negative Control
Wells	t=60min	t=120min	t=60min	t=120min	t=60min	t=120min		
1	28	23	18	0	0	0	103	0
2	33	23	2	0	0	0	71	0
3	38	27	16	1	0	0	109	0
Mean	33	24	12	0.3	0	0	94	0

Reference value: 0 MPN/100 mL (Most Probable Number per 100 mL). Statistical test: Paired Student's t-test, 95% Confidence Interval (CI). C = concentration; g/L = grams per liter.

On average, the untreated water samples showed a concentration of 94 MPN/100 mL (Most Probable Number per 100 mL). In contrast, samples treated with *Moringa oleifera* seed powder at a concentration of 1 g/L achieved 100% removal of fecal coliforms after both 60 and 120 minutes of sedimentation.

For samples treated with 0.25 g/L, fecal coliform counts were 33 MPN/100 mL after 60 minutes and 24 MPN/100 mL after 120 minutes, indicating a moderate reduction compared with the untreated control. Statistical analysis revealed a significant difference between the mean bacterial concentrations before and after treatment ($p = 0.017$), confirming the effectiveness of *M. oleifera* seed powder in reducing fecal contamination.

Total Solids

Table 2 summarizes the results of total solids analysis for both untreated and treated well water samples at different *Moringa oleifera* seed powder concentrations and sedimentation times.

A significant reduction in total solids was observed after treatment ($p = 0.05$), indicating that *M. oleifera* seed powder effectively improved water quality by reducing particulate and dissolved matter.

At the highest concentration (1 g/L), total solids decreased from an average of 962 mg/L in untreated water to 419 mg/L and 420 mg/L after 60 and 120 minutes of sedimentation, respectively, representing an average reduction of approximately 56–57%. Intermediate concentrations (0.5 g/L and 0.25 g/L) also demonstrated a progressive reduction compared to the control. All treated samples remained below the reference limit of 1000 mg/L, in accordance with international water quality standards.

Table 2. Comparison of total solids (mg/L) in experimental, positive control, and negative control samples.

	Experimental Samples (C1 = 0.25 g/L)		Experimental Samples C_2=0.5g/L		Experimental Samples C_3=1g/L		Positive Control	Negative Control
Wells	t=60min	t=120min	t=60min	t=120min	t=60min	t=120min		
1	587	560	512	494	462	453	815	0
2	389	367	359	259	257	232	832	0
3	668	618	613	612	539	575,4	1240	0
Mean	**548**	**515**	**495**	**455**	**419**	**420**	**962**	**0**

Reference value: 1000 mg/L. Statistical test: Paired Student's t-test, 95% Confidence Interval (CI). C = concentration; g/L = grams per liter.

Turbidity

Table 3 presents the turbidity results for untreated and treated well water samples at different *Moringa oleifera* seed powder concentrations and sedimentation times.

Although a slight reduction in turbidity was observed after treatment, no statistically significant difference was found between the mean turbidity values of untreated and treated samples ($p > 0.05$). These findings suggest that *M. oleifera* seed powder, under the tested conditions, had no significant effect on water turbidity, despite improvements in other physicochemical parameters.

Table 3. Comparison of turbidity (NTU) in experimental, positive control, and negative control samples.

	Experimental Samples C_1=0.25g/L		Experimental Samples C_2=0.5g/L		Experimental Samples C_3=1g/L		Positive Control	Negative Control
Wells	t=60min	t=120min	t=60min	t=120min	t=60min	t=120min		
1	14.2	14	13.5	13	13	12.8	15.1	0
2	17.8	14.4	12.6	10.9	8.9	6.5	48.9	0
3	29	28.7	25.8	24	23	22.4	267.7	0
Mean	**20**	**19.04**	**17.34**	**15.94**	**14.99**	**13.96**	**110.57**	**0**

Note: Values not provided in the original dataset. NTU = Nephelometric Turbidity Units. Statistical test: Paired Student's t-test, 95% Confidence Interval (CI). C = concentration; g/L = grams per liter.

pH

Table 4 presents the pH results for untreated and treated well water samples at different concentrations of *Moringa oleifera* seed powder and sedimentation times.

No significant difference was observed between the mean pH values of untreated and treated samples (p = 0.215), indicating that *M. oleifera* seed powder did not significantly alter the acidity or alkalinity of the well water. The pH values of all samples remained within the acceptable range for drinking water as defined by international standards (typically 6.5–8.5).

Table 4. Comparison of pH values in experimental, positive control, and negative control samples.

	Experimental Samples C_1=0.25g/L		Experimental SamplesC_2=0.5g/L		Experimental SamplesC_3=1g/L		Positive Control	Negative Control
Weels	t=60min	t=120min	t=60min	t=120min	t=60min	t=120min		
1	6.9	6.9	7.1	7	7.1	6.9	7	7
2	6.8	6.9	7	7	7	7	6.9	7
3	6.8	6.9	6.8	7	7.1	6.7	7	6.8
Mean	**6.8**	**6.9**	**6.9**	**7**	**7**	**6.8**	6.7	7

Reference value: 6.5–8.5. Statistical test: Paired Student's t-test, 95% Confidence Interval (CI). C = concentration; g/L = grams per liter.

Electrical Conductivity

Table 5 summarizes the results of electrical conductivity analyses for untreated and treated well water samples at different *Moringa oleifera* seed powder concentrations and sedimentation times.

No statistically significant difference was observed between the mean electrical conductivity values of untreated and treated samples (p = 0.407). This indicates that the addition of *M. oleifera* seed powder did not significantly affect the ionic composition or the concentration of dissolved minerals in the well water.

The conductivity values remained within the acceptable limits for drinking water established by international guidelines (typically ≤1500 µS/cm), confirming that the treatment did not compromise water quality.

Table 5. Comparison of electrical conductivity (µS/cm) in experimental, positive control, and negative control samples.

	Experimental Samples C_1=0.25g/L		**Experimental Samples C_2=0.5g/L**		**Experimental Samples C_3=1g/L**		**Positive Control**	**Positive Control**
Wells	t=60min	t=120min	t=60min	t=120min	t=60min	t=120min		
1	509	506	508	509	509	**506**	510	1852
2	1288	1296	1297	1287	1289	1280	1298	1798
3	957	937	945	910	923	913	1879	1801
Mean	**918**	**913**	**914**	**902**	**804**	**899.6**	**1229**	**1817**

Reference value: 50–2000 µS/cm. Statistical test: Paired Student's t-test, 95% Confidence Interval (CI). C = concentration; g/L = grams per liter.

Discussion

The present study evaluated the efficiency of *Moringa oleifera* seed powder in improving the microbiological and physicochemical quality of well water. The results demonstrated that treatment with *M. oleifera* at a concentration of 1 g/L achieved complete (100%) removal of fecal coliforms, while also reducing total solids to levels within the limits established by Mozambican legislation (Law No. 16/91 of August 3, 2004).

Removal of Fecal Coliforms

The total elimination of fecal coliforms observed at 1 g/L and sedimentation times of 60 and 120 minutes is consistent with the limits established by Mozambican drinking water standards (Law No. 16/91). These findings are also in agreement with those of Armazeno et al. (2021) in Quelimane, Mozambique, who reported 100% removal of fecal coliforms at a concentration of 0.5 g/L after 120 minutes of sedimentation. Similarly, Andrade (2021) in Brazil observed >99% bacterial removal when water samples were treated with 600 mg/L of *M. oleifera* seed powder.

Incomplete removal at lower concentrations in the present study may be attributed to the higher turbidity observed in the untreated well water samples. According to Nunes et al. (2019), turbidity is closely related to microbial contamination, as suspended particles—composed of clay, sand, and organic matter—can serve as protective carriers for microorganisms, reducing the efficacy of coagulation and sedimentation processes.

Reduction of Total Solids

The significant reduction in total solids following treatment confirms the coagulating efficiency of *M. oleifera*. All post-treatment values remained within the limits defined by Law No. 16/91. These results differ from those of Fevereiro (2018) in Maputo, who observed increases of 39% and 52% in total solids when treating water with 5 g and 7.5 g of *M. oleifera* seed powder, respectively. Conversely, Andrade (2021) reported a 69 ± 8% reduction in total solids in treated water samples in Brazil. Such differences may be associated with variations in initial water composition, dosage, and seed preparation methods used across studies.

Turbidity Reduction

Although the reduction in turbidity observed in this study was not statistically significant, treated samples exhibited visibly lower turbidity levels than the untreated controls. The final values did not meet the standards set by Law No. 16/91; however, the trend toward lower turbidity aligns with results reported by Ribeiro et al. (2019), who demonstrated that turbidity removal efficiency depends on pH and dosage. Their study showed that high pH values (>8.5) reduced coagulation efficiency, while lower pH values favored turbidity reduction at lower doses of *M. oleifera* powder. Similarly, Michelam et al. (2021) reported maximum water clarification after 30 minutes of sedimentation, achieving efficiencies of 90.9% (without husk) and 92.7% (with husk) at a dosage of 300 mg/L.

pH and Electrical Conductivity

The results for pH and electrical conductivity remained within the acceptable limits of Law No. 16/91 and Ministerial Decree No. 188/2004 (Regulation on Drinking Water Quality). No statistically significant differences were found between treated and untreated samples, confirming that *M. oleifera* does not significantly alter these parameters. These findings corroborate those of Souza et al. (2023) and Othomani et al. (2020), who also reported that *M. oleifera*-based water treatments did not affect pH values.

This stability is considered an important technological advantage of *M. oleifera* over synthetic coagulants such as aluminum sulfate, which can lower pH, increase water corrosivity, and damage pipelines (Chales, 2022). Moreover, *M. oleifera* generates biodegradable sludge and avoids residual aluminum accumulation, making it a safer and more sustainable alternative for rural water purification (Chales, 2022).

Conclusion

Treatment of well water with *Moringa oleifera* seed powder achieved compliance with official potability standards in terms of fecal coliform removal. A statistically significant reduction was also observed in total solids, confirming the coagulant efficiency of the seed powder. In contrast, no significant changes were detected in pH, electrical conductivity, or turbidity, indicating that *M. oleifera* does not alter the physicochemical stability of the water.

Although *M. oleifera* effectively reduced suspended particles and microbial load, further studies are needed to assess its capacity for removing total coliforms and *Vibrio cholerae* under varying environmental and operational conditions.

Overall, the results demonstrate that *Moringa oleifera* seed powder represents a viable, low-cost, and environmentally safe alternative for improving the quality of well water. Its use can contribute to the mitigation of waterborne diseases and to the promotion of safe drinking water access in resource-limited regions such as northern Mozambique.

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