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Moringa oleifera Seed Extracts as a Natural Coagulant for Raw Water Treatment and Improving its Quality

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Abstract
Water is one of the most important compounds on the earth. All living organisms need water for their survival and growth. Access to safe and clean drinking water is an important object. There are several chemical coagulants that are used in the treatment of water but can cause a lot of problems and are costlier. Natural coagulants such as *Moringa oleifera seeds*. *Moringa oleifera* seeds have many advantages as it is natural, completely non-toxic, eco-friendly, and locally available and it reduces the level of microorganisms in water. In the current study, the removal efficiency of turbidity was 71.77% after the treatment of raw water with *Moringa* seeds. Total dissolved solids and conductivity slightly increased after the addition of seeds to raw water. Total bacterial counts were markedly reduced to 93.51 %. The removal efficiency of total coliforms and fecal coliforms was 96.06 % and 94.88 % respectively. Bacteriological analysis of raw water revealed the isolation of 28 isolates of both Gram-positive (18) and Gram-negative (10) bacteria. Molecular techniques using 16S rDNA resulted in the identification of *Bacillus paramycoides* (strains AUMC-B468 and AUMC-B469) and *Bacillus safensis* AUMC-B470. Using the agar well diffusion method for in vitro antibacterial susceptibility test showed that the ethanol extract of *Moringa oleifera* seeds had the maximum (16 mm) antibacterial activity against isolate no 14 in comparison with the other extracts, while the aqueous extract had the minimum (12.3 mm**)** against isolate no 14. MICs of different extracts of *Moringa* seeds ranged from 25 to 400 mg ml^{-1} against the tested bacteria.
Keywords: *Moringa oleifera*, natural coagulants, seeds, antibacterial activity, 16S rRNA.

1. Introduction

Water is very important for all living organisms, as it is a required substance for all activities of humans. As human populations and economies grow, water demand has been increasing rapidly so there is a need to conserve water. Many of diseases that affect on humanity, especially in developing countries can be traced to a lack of safe water supply. Various processes and technologies are being researched to improve the quality of water **[1]**. Water quality refers to the chemical, physical, and biological characteristics of water based on the standards of its usage. Many coagulants are used in water treatment as chemical and natural coagulants **[2]**. Alum is the most common chemical coagulant used in the treatment of raw water. There are several disadvantages of it, toxic aluminum causes Alzheimer's disease when it precipitates below pH6 **[3, 4]**, production of large sludge volume, **[5]** Reduction of pH, and low efficiency in coagulation of cold water **[6]**.The natural coagulant of plant origin as *Moringa olifera* seeds has been attempted in several parts of the world to clarify water from turbidity due to the high cost of chemical treatment or non-availability [**7, 8**]. Generally, coagulants used in raw water treatment should be characterized by having a positive charge which neutralizes the negative charge of dissolved and suspended particles in the water as clay particles and microorganisms such as algae, bacteria, and protozoa [**9**]. Making a rapid mixing to ensure that the coagulant spreads throughout the water **[10]**. Attachment of small particles leads to the formation of flocs which become heavier and more stable then they can precipitate. Finally, flocs were removed from water by passing water through a filtration system which consists of filters with varying sizes of pores of sand and gravel in order to remove dissolved particles such as dust, parasites, and bacteria **[11, 12]**.

2. Materials and methods

2.1. *Moringa oleifera* seeds

Moringa oleifera seeds used in this study were provided by the National Center for Research in Cairo and kept for studies.

2.1.1. Preparation of *Moringa oleifera* seeds powder

Seeds were de-shelled and air dried at temperatures 25°C for a period of days before grinding. The white kernel was milled to a powder by using the grinder **[13]**. The fine powder obtained was stored in a sterile air-tight container in a dark place to prevent.

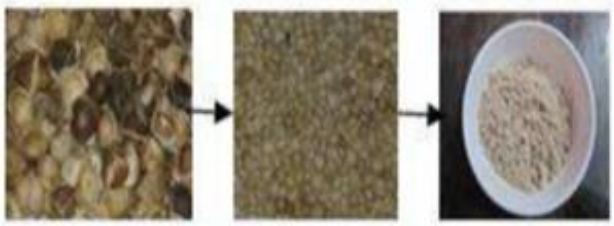

Fig. 1: Preparation of *Moringa oleifera* seeds powder

2.1.2. Preparation of *Moringa oleifera* seeds coagulant (1%)

Dissolve 1gm of *Moringa* seeds powder into 100 ml of distilled water. Suspension must be filtered through a Whatman No 1 filter paper. Using the aqueous extract of seeds instead of powder, powder of seeds increases the turbidity of raw water and does not make it clear.

2.1.3. Extraction of *Moringa oleifera* seeds with different solvents

Different extracts of seeds were prepared by soaking 10 grams of powder of seeds with 100 ml of different solvents ethanol, methanol, acetone, and water. Placed on a shaker for 24 hrs. The crude preparation was left overnight in the shaker at room temperature .The extract was then filtered using sterile Whatman filter paper followed by centrifugation at 4000 rpm for 20 min. Transfer the supernatant of the extract to a pre-weighed beaker and evaporate the solvent at 40°C **[14]**. Different concentrations of these extracts were made by dissolving them in a known volume of dimethyl sulphoxide (DMSO), stored in the refrigerator at 4°C **[15]**.

2.1.4. Jar Test

It was carried out in a chemical laboratory of Sohag Water Company. It was used to determine the optimum dose of coagulant in water treatment [16]. A brand PHIPPS PB700, Jartester equipment consists of a number six rotating paddles and six beakers was used. Raw water samples were taken in beakers and different doses of the *Moringa* seeds (12 mg/ml, 13 mg/ml, 14 mg/ml, 15mg/ml, 16 mg/ml, and 17 mg/ml) were added to all the jars **[17,18]**, control was a sample of raw water without seeds extract. The paddles were be rotated at 200 rpm to the flash mixing and slow mixing in the flocculation. After 5 minutes settling, supernatant will be taken carefully from all the jars to measure turbidity, pH, TDS, conductivity, total bacterial counts, total coliforms, fecal coliforms, and total algal count.

Fig. 2: Jartester equipment

2.1.4.1. Determination of turbidity

Turbidity was measured by a 2100N turbidimeter from Hach company, Canada. It is based on measuring the clarity of the sample through an amount of light that is scattered by particles in water samples when a light is shined [19].

2.1.4.2. Measurement of pH

Measure pH for the samples by using the pH meter model Orion Star from USA company. The probe of the pH meter was inserted into the sample. The value of pH was taken from the LCD after it was stabilized [20].

2.1.4.3. Determination of total dissolved solids

Total Dissolved Solids are the sum of the cations and anions such as calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, fluoride, sulfate, phosphate, and nitrate in water. TDS was measured by WTW-Germany meter by inserting the probe in samples [21].

2.1.4.4. Measuring of conductivity

Conductivity is related to the ability of a solution to carry electric current. The conductivity of the samples was measured by benchtop conductivity meter Cond720, WTW-Germany [22].

2.1.4.5. Estimation of total bacterial count

The total bacterial count was estimated by the pour plate method [23].

2.1.4.6. Estimation of total and fecal coliforms

Total and fecal coliforms were estimated by multiple tube fermentation technique (MTF), also called the Most Probable Number (MPN) procedure in 96 hours based on the production of gas and acid from the fermentation of lactose [24].

2.1.4.7. Determination of total algal count

Total algae for all samples with different doses were counted on optical microscope model CX43RF in a Sedgewick Rafter counting chamber after preservation of samples in Lugol's iodine.

2.2. Isolation of bacteria from raw water

Isolation, Purification, maintenance, and preservation of bacterial isolates throughout the duration of the study then identification of some selected bacterial isolates. Identification was confirmed by 16S rRNA gene sequencing by sending bacterial isolates to a macro gen lab in South Korea to be identified by 16S rRNA encoding gene of the isolates were PCR amplified and sequenced The resulting nucleotide sequence were compared to available sequence in the databases. Further identification at the species level was carried out by 16S rRNA analysis. All the sequences reported by the BLAST program revealed that 16S rDNA sequences of bacterial isolates.

2.3. Determination of the antibacterial activity of *Moringa* seed extracts by agar well diffusion method [25]

Bacter

Bacterial isolates were used to observe the antibacterial potentiality of different extracts of *Moringa* seeds. From each culture of selected isolates, pure colonies were transferred with a sterile inoculating loop to a tube containing sterile normal saline and vortexed them, then compared to 0.5 McFarland standard which is equivalent to 1.5 x 108 CFU/ml. Inoculum suspension was dipped with a sterile cotton swab**[26]**. The swab was then streaked over the entire surface of the nutrient agar plates three times. After swabbing, the plates were let to dry for five minutes. Wells about 6 mm in diameter were punched with a sterile cork borer **[27]**. The extracts were reconstituted in 20% DMSO for the analysis **[28]**. 100 µl of tested extracts in different concentrations (50, 100, 200, 400) mg ml^{-1} were applied into the wells using a micropipette. The

dishes were then let for 2 hrs at environmental conditions until the extracts were diffused into the medium and then incubated for 24 hrs at 37°C **[29]**. DMSO is considered as the negative control. The antibacterial activity was indicated by an inhibition zone surrounding the wells, it was recorded if the inhibition zone was ≥ 7 mm diameters around the wells as a significant susceptibility of the isolates to the extract **[30]**. The experiment was performed in triplicates.

2.3.1.Determination of minimum inhibitory concentration (MIC)

By broth dilution method, MIC was determined for the extracts that showed inhibition zone ≥ 7 mm diameter growth. The test was performed using a broth dilution method. A serial of twofold dilution of the extract was prepared in nutrient broth. The extract solution with a concentration of 400 mg/mL was serially diluted as 1:2, 1:4, 1:8, and 1:16 to bring 200, 100, 50, and 25 mg/mL concentrations, respectively **[31, 32]**. These concentrations were added to the tubes containing nutrient broth with the final inoculum count of 5×10^5 CFU/ml. After 24 hrs from the incubation of bacterial isolates at 37°C. The lowest concentration which inhibits the visible growth of bacteria in the liquid medium is defined as MIC.

2.3.2. Determination of the minimum bactericidal concentration (MBC)

The lowest concentration of the tested extract kills the tested isolates. Fifty µl from each tube with no visible growth in the MIC test was collected, sub-cultured in nutrient agar plates, and incubated for 24 hrs at 37°C. The lowest concentration that yielded no single bacterial colony and showed no visible growth after incubation was taken as the MBC **[33, 34]**.

2.4.Statistical analysis

Data were analyzed for variance using the PROC GLM procedure in SAS software. (SAS ver. 9.2). The least significant differences (LSD) between means were estimated at 5% and 1% significant levels for studied treatments [35].

3. Results and Discussion:

3.1.Effect of *Moringa* seeds on physicochemical properties

3.1.1. Effect of *Moringa* seeds coagulant on turbidity

Aqueous extract of *Moringa* seeds at a concentration of 1ppm rapidly reduced turbidity from 5.35 NTU (control sample) to 1.51 NTU with a removal efficiency of 71.77 % at the optimum dose of 16 mg/l after a five minute sedimentation time (**Table 1**). Comparison results with alum showed that turbidity was reduced to 1.94 NTU with a removal efficiency of 63.73% at the optimum dose of 15 mg/l. This observation came in harmony with previous reports **[23, 36, 37]**.

3.1.2.Effect of *Moringa seeds* on total dissolved solids

Increasing doses of *Moringa oleifera* seeds lead to a slight increase in the content of the total dissolved solids from 215 mg/ml to 221 mg/ml at the optimum dose of 16 mg/ml (**Table 2**). These increases showed no effect on TDS levels of water, it is within the WHO value of 1000mg/L for drinking water **[38]**.

Table 1: Effect of *Moringa seeds* coagulant on turbidity

Doses (mg/ml)	Turbidity (NTU) ± SD	Removal Efficiency (%)
Control	5.35±0.00	0
12	1.98±0.017	62.99
13	2.21±0.02	58.69
14	2.6±0.05	51.40
15	2.09±0.09	60.93
16	1.51±0.01	71.77
17	3.06±0.017	42.80

Table 2: Effect of *M. oleifera* seeds on TDS

Treatment by	Doses (mg/ml)	TDS (mg/l)
Moringa oleifera seeds	Control	215
	12	217
	13	218
	14	219
	15	219
	16	221
	17	222

3.1.3. Effect of *Moringa oleifera* seeds coagulant on pH

PH was found to be 8.1 before water treatment with *Moringa* seeds (**Table 3**). After treatment with a coagulant, it did not show any remarkable change for all samples treated with different doses This observation came in harmony with previous reports. This observation came in harmony with previous reports **[39]**.

Table 3: Effect of *M. oleifera* coagulant on pH**.**

Treatment by	Doses (mg/ml)	pH
Moringa olifera seeds	Control	8.1±0.00
	12	7.6±0.01
	13	7.51±0.01
	14	7.41±0.02
	15	7.6±0.02
	16	7.51±0.0
	17	7.4±0.02

3.1.4.Effect of *Moringa* seeds on Conductivity

Generally, it was observed that conductivity increases slightly from 353 µs/cm to 361 µs/cm at the optimum dose 16 mg/ml (**Table 4**). This increase might be due to the nature of *M. oleifera* seeds which contain many ions and lower molecular weight water soluble proteins that carry positive charges that induce the conduction of electric current. These results are in harmony with some previous reports **[40]**.

Table 4: Effect of *Moringa* seeds on conductivity

Treatment by	Doses(mg/ml)	Conductivity(µs/cm)
Moringa olifera seeds	Control	353
	12	357
	13	358
	14	358
	15	360
	16	361
	17	363

3.2.Effect of *Moringa* seeds on bacteriological properties

3.2.1. Effect of *Moringa* seeds on total bacterial counts

There was a significant reduction in total bacterial counts after the addition of *Moringa* seeds to samples of raw water. It was observed that the control sample contained about 1850 CFU/ml. The optimum dose of 16 mg/ml reduces total bacterial counts to 120 CFU/ml at a range 93.51% (**Table 5**). Comparison results with alum showed that total bacterial counts reduced to 180 CFU/ml at a dose of 15 mg/ml with efficiency of 90.27%. These results are in harmony with some previous reports **[41]**.

Table 5: Effect of *Moringa* seeds on total bacterial counts.

Doses (mg/l)	TBC (CFU/ml) ±SD	Removal efficiency (%)
Control	1850±0.0	0
12	260±11.1	85.94
13	680±12.5	63.24
14	730±4.5	60.54
15	420±7.2	77.29
16	120±11.1	93.51
17	920±11.1	50.27

3.2.2. Effect of *Moringa* seeds on total coliform bacteria

Total coliform counts show a significant variation after the addition a different dose of *Moringa* seeds coagulant to raw water. The total coliform for the control sample was greater than 1600 TC/100 ml. The lowest MPN was 63 at a dose 16 mg/ml with a removal efficiency of 96.06 % as shown in (**Table 6**). Comparison results with alum showed that total coliform bacteria reduced to 79 MPN/100 ml at a dose of 15 mg/ml with a removal efficiency of 95.06 %. These results are in harmony with some previous reports [42].

Table 6: MPN test of total coliform after the addition *Moringa* seeds to water.

Doses (mg/l)	Positive tubes	Total coliform (MPN)	Removal efficiency (%)
Control	5-5-5	> 1600	0
12	5-2-1	70	95.62
13	5-5-0	240	85
14	5-4-4	350	78.12
15	5-3-1	140	91.25
16	5-2-1	63	96.06
17	5-5-4	430	73.12

3.2.3. Effect of *Moringa* seeds on fecal coliform

The MPN test for the control sample was greater than 900 FC/100 ml (**Table 7**). There is a reduction of fecal coliform counts after the addition of different doses of *Moringa* seeds coagulant as MPN of fecal coliform reduced to 46 MPN/100 ml at dose 16 mg/l with removal efficiency 94.88%. Comparison results with alum showed that fecal coliform bacteria reduced to 49 MPN/100ml at a dose 15 mg/ml with a removal efficiency of 94.55%. These results are in harmony with some previous reports.

Table 7: MPN test of fecal coliform after addition of *Moringa* seeds.

Doses (mg/ml)	Positive tubes	Fecal coliform (MPN)	Removal efficiency (%)
Control	5-5-3	900	0
12	5-2-0	49	94.55
13	5-4-3	280	68.88
14	5-4-4	350	61.11
15	5-2-1	70	92.22
16	5-1-1	46	94.88
17	5-5-2	540	40

3.2.4. Effect of *Moringa* seeds on total algal count

Generally, algae count shows a significant variation after the addition a different dose of *Moringa* seeds coagulant to raw water. The algae count for the control sample was 2432 org/ml reduced to 485 org/ml at a dose of 16 mg/ml with a removal efficiency of 80.05% as shown in (**Table 8**). Comparison results with alum showed that the total algal count reduced to 601 org/ml at a dose of 15 mg/ml with a removal efficiency of 75.28 %.

Table 8: Total Algal count after the addition of *Moringa* seeds**.**

Doses (mg/l)	Algae count (org/ml)	Removal efficiency %
Control	2432	0
12	675	72.24
13	642	73.60
14	615	74.71
15	560	76.97
16	485	80.05
17	709	70.84

3.3. Identification of selected isolates of bacteria

Gram staining and microscopic examination of bacterial isolates revealed that eighteen isolates were gram-positive (12 cocci and 6 bacilli) and ten isolates were Gram-negative short rods. Identification of bacterial isolates using 16S rRNA By sending bacterial isolates no (3,14 and 15) to a macrogen lab in South Korea to be identified by 16S rRNA. All the sequences of isolates no(3 and 14) showed 99.93% -100% identity and 99% - 100% coverage with several strains of the same species including the type strain *B. paramycoides* MCCC1A04098. Furthermore,16S rDNA sequences of bacterial isolate no(15) had 99.63% -100% identity and 99% - 100% coverage with several strains of the same species including the type strain *B. safensis* NBRC100820. The 16S rRNA sequences of bacteria reported in this study have been deposited in the GeneBank database under accession numbers: OP315512 as (*B.paramycoides* AUMC-B468), OP315572 as (*Bacillus paramycoides* AUMC-B-469) and OP315630 as (Bacillus safensis AUMC-B-470), which doi is http://www.ncbi.nlm.nih.gov/nuccore.

3.4. Antibacterial activity of *Moringa oleifera* seed extracts

Seed extracts of *Moringa oleifera* were assayed for antibacterial activity by agar well diffusion method **[43]**. The negative control DMSO did not inhibit the growth of the tested bacteria. From the agar well diffusion result, It was found that isolates no 3, isolate no 14, and isolate no 15 were significantly susceptible to all extracts of *Moringa* seeds. However, the ethanol extract of *Moringa* seeds had the maximum (16.0 mm) antibacterial activity against isolate no 14 in comparison with the other extracts, while the aqueous extract of *Moringa* seeds had the minimum (12.6 mm**)** against isolate no3 (**Table 9**). These findings are nearly similar to those reviewed by some researchers **[44]**. Among the different *M. oleifera* seeds extracts, the ethanolic extract showed the highest (16.0 mm) antibacterial activity against isolate no 14, followed by acetone extract (15.6 mm), methanol (13.00 mm) and aqueous extract (12.3 mm). For isolate no 3, the ethanol extract has shown a maximum inhibitory effect (15.0 mm) followed by the methanol (14.6 mm), acetone (14.3 mm), and aqueous (12.6 mm) extracts. In the case of isolate no.15, the acetone extract was found to have the highest activity (13.0 mm) followed by ethanol (11.6 mm), methanol (10.6 mm), and then the aqueous (7.0 mm) extract as in (**Table 10)** and then the aqueous (7.0 mm) extract. In the case of isolate 2, the ethanolic extract showed the highest (11.3 mm) antibacterial activity followed by acetone (10.3 mm) and then methanol (7.00 mm) as in (**Table 11).** Aqueous extract of M. *oleifera* was ineffective against bacterial isolate no. 2 . Among the different plant extracts, only ethanolic extract was active (7.6 mm) against isolate 1. Aqueous extracts of *Moringa* seeds do not have much activity against bacteria (**Table 12)**. The reason might be that aqueous extract is different from other solvent extracts due to having myriads of compounds that may interact antagonistically in their overall activities. It is also suggested that the active constituents from plant materials are not readily extractable in water. These findings and suggestions came in harmony with previously reported data given by some investigators [**45, 46**].

Table 9: Antibacterial activity of ethanolic extract of *Moringa* seeds.

Zone of inhibition (mm) ± SD				
	Conc.(mg/ml)			
no of isolates	50	100	200	400
1	0	0	0	7.6±0.05
2	0	8.6±0.15	10.6±0.15	11.3±0.15
3	9.3±0.2	10.0±0.0	13.3±0.23	15.0±0.17
14	11.3±0.15	12.3±0.11	13.3±0.11	16.0±0.0
15	0	7.0±0.0	9.6±0.15	11.6±0.15

Table 10: Antibacterial effect of methanolic extract of *Moringa* seeds

Zone of inhibition (mm) ± SD				
	Conc.(mg/ml)			
no of isolates	50	100	200	400
1	0	0	0	0
2	0	0	0	7.0+0.17
3	0	9.0±0.1	12.3±0.11	14.6+0.15
14	0	9.3±0.15	11.0±0.2	13.0+0.1
15	0	8.3±0.05	9.3±0.05	10.6±0.15

Table 11: Antibacterial effect of acetone extract of *Moringa* seeds.

Zone of inhibition (mm) ± SD				
	Conc.(mg/ml)			
no of isolates	50	100	200	400
1	0	0	0	0
2	0	7.3±0.05	9.0±0.1	10.3±0.05
3	0	8.6±0.05	12.0±0.1	14.3±0.05
14	7.0±0.0	10.0±0.1	13.0±0.1	15.6±0.25
15	0	7.3±0.05	12.3±0.11	13.0±0.1

Table 12: Antibacterial effect of aqueous extract of *Moringa* seeds.

Zone of inhibition (mm) ± SD				
	Conc.(mg/ml)			
no of isolates	50	100	200	400
1	0	0	0	0
2	0	0	0	0
3	0	9.6±0.15	11.0±0.11	12.6±0.15
14	9.6±0.15	10.6±0.05	11.6±0.05	12.3± 0.05
15	0	0	0	7.0±0.0

3.4.1. Minimum Inhibitory Concentration (MIC)

MIC of the different extracts of *Moringa* seeds ranged from 25-400 mg ml^{-1}. MICs of ethanol extract from *Moringa* seeds range from 25 to 400 mg ml^{-1}. The lowest MIC value was recorded for ethanol 25 mg ml^{-1} against isolate no 14, 50 mg ml^{-1} against isolate no 3, 100 mg ml^{-1} against (isolate no 2 and isolate no 15) and 400 mg ml^{-1} against isolate no1. MICs of acetone extracts from *Moringa* seeds range from 50 to 100 mg ml^{-1}. The lowest MIC value recorded for acetone was 50 mg ml^{-1} against (isolate no 14) and 100 mg ml^{-1} against (isolate no 2, isolate no 3, and Isolate no 15). Isolate no 1 was resistant to the acetone extract of *Moringa* seeds.

3.4.2. Minimum Bacteriocidal Concentration (MBC)

The antibacterial activity of different extracts of *Moringa* seeds with the MBC test was confirmed by the absence of bacterial growth on solid agar media. The minimum bacteriocidal concentration of ethanol extract of *Moringa* seeds was 50 mg ml^{-1} against isolate no 14, 100 mg ml^{-1} against isolate no 3, 200 mg ml^{-1} against (isolate no 2and isolate no 15) and there is no bacteriocidal effect against isolate no1. Methanol extract of *Moringa* seeds presented activity against(isolate no 3 and isolate no 14) with MBC 200 mg ml^{-1}, 400 mg ml^{-1} against isolate no 15 was recorded, and no activity against isolate no 2 and isolate no 1. The acetone extract of *Moringa* seeds showed bacteriocidal activity against isolate no 14 with MBC of 100, and 200 mg ml^{-1} against (isolate no 3 and isolate no 15), respectively while MBC reached 400 mg ml^{-1} against isolate no 2. There is no activity against isolate no 1. The minimum bactericidal concentration of aqueous extract of *Moringa* seeds was 100 mg ml^{-1} against isolate no 14,200 mg ml^{-1} against isolate no 3 and there is no activity against isolate no 1, isolate no 2, and isolate no 3.

4. Conclusion

Moringa oleifera is an effective natural coagulant that can be used in improving the physicochemical and bacteriological parameters of water including pH, turbidity, TDS,

conductivity, Total bacterial count (TBC), Total coliform (TC) and fecal coliform(FC). The results obtained show that seeds of *M. oleifera* have some coagulating properties with optimal doses of 16 mg/l since it's environmentally friendly and cheaper. *M. oleifera* seeds powder did not significantly lower or raise the water pH. Increasing doses of *Moringa oleifera* seeds coagulant leads to increasing the percent of the total dissolved solids at the optimum dose of 16 mg/ml, this increase is due to containing of these seeds on many minerals and amino acids. However, the measured TDS levels of water were within the WHO regulations. The increase in conductivity is often correlated with ions and lower molecular weight water-soluble proteins found in *Moringa oleifera* seeds. Treatment of raw water with *M. oleifera* seeds powder resulted in a reduction in turbidity and bacterial counts. The results of the current investigation introduce environmentally friendly and cheaper solutions to improve the quality of raw water and to get access to clean and safe drinking water.

CRediT authorship contribution statement:

Conceptualization, M.A. and A.M.; methodology, A.M.; software, A.M.; validation, M.A., M.M. and A.M.; formal analysis, A.M.; investigation, A.M.; resources, A.M.; data curation, A.M.; writing—original draft preparation, A.M..; writing—review and editing, A.M.; visualization, A.M.; supervision, M.A.; project administration, A.M.; funding acquisition, All authors have read and agreed to the published version of the manuscript."

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

Declaration of competing interest

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

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