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Moringa oleifera seed as alternative natural coagulant for potential application in water treatment: A review

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ABSTRACT

Historically, there is evidence to suggest that communities in the developing countries are still using plant-based materials as one of the strategies for purifying drinking water. In this review, the coagulant properties of Moringa oleifera seeds extract were quantitatively evaluated toward suitable wastewater treatment and examining its coagulation mechanism. The seeds are rich in bio-active components and also used as a natural coagulant for effective water treatment. The seeds extract operates predominantly by bridging coagulation mechanism and operates through charge neutralization. This natural ingredient of an organic polymer is essential as it contains acrylamide monomers that are harmless to human's health and lesser expensive as compared to conventional chemicals since they are available in most rural communities. The application of this readily available natural product as part of point-of-use in water treatment technology may offer a practical, cheap, appropriate and sustainable solution for producing potable water in some developing nations.

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1. Introduction

Humans totally depend on water for their survival. Recently, water is becoming an issue of discussion in many developing nations due to an undergoing radical transformation of ecology. There is much talk of a water crisis, of which the most obvious manifestation is that 1.2 billion people lack access to safe and affordable water for their domestic use. Another worrisome issue is that large world populists are living in rural areas, have an income below the one-dollar-per-day poverty line and lack access to quality water for their livelihoods [1]. However, this problem of lacking access to quality water has major negative impacts on people's well-being such as; poverty, massive health

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effects, a shortage of safe drinking water, poor personal hygiene and a problem of sanitation. According to Rijsberman [2], it is estimated that a minimum of 7.5 litres of water is required for individual consumption, personal hygiene and preparing food. Hence; a safe, affordable, reliable and easily accessible, quality water supply is crucial for household activities, good health and agriculture. This will equally improve the individuals' life in terms of poverty reduction and other live comfortability matters. But insufficiencies in water supply affect health adversely both directly and indirectly.

Consequently, improvement in the aspects of water supply signify the important opportunities toward enhancing public well-being, provide proper and affordable treatment system [3]. Techniques that will improve water supply for humans' need should further be developed such as water and soil conservation (WSC) technique, rainwater harvesting and conservation (RWHC) techniques, Rainwater harvesting system for both water and agriculture improvement as well as suitable, sustainable and environmentally safe wastewater treatment strategy. Pieces of evidence indicated that wastewater treatment using the conventional physical method and chemical coagulants is costly and caused side effects to the health of humans and their existing environment (Fig. 1). Coagulants can either be inorganic such as aluminum-sulphate, poly-aluminum-chloride or synthetic organic polymers such as polyacrylamide derivatives [4, 5]. Considering the problem mentioned above, the use of natural materials of a plant for wastewater treatment has been adopted. However, lack of enough knowledge on the exact nature and mechanism on how these substances work toward removing impurities in water make them less likely to compete with conventional treatments. Using such natural ingredient(s) of an organic polymer is important because they contain acrylamide monomers which are the essential natural compound that has significant application and plays role in water treatment processes [6-8].

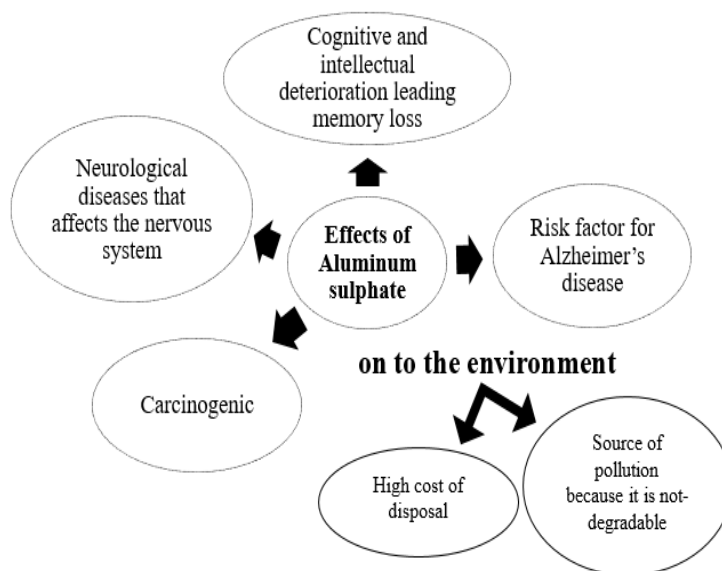


Fig. 1. Site effects of using a synthetic chemical coagulant.

Given the potential such natural coagulants as an appropriate solution to produce potable water, remarkable numbers of plants have been examined for their coagulation properties. Among the plant species studied and have shown the coagulation effect includes *Moringa oleifera* L. (*M. oleifera*), *Cactus latifaira* and *Prosopis jaliflora* [6]. To date, many researches have shown that compounds from *M. oleifera* seeds can reduce water effluent to a recommendable level. This seed was used as a primary coagulant for raw-water and synthetic turbid water purification for turbidity removal (80–

99% efficient) [9]. The seeds are biodegradable and environmentally safe to humans [6] (Fig. 2). Furthermore, the coagulation activity of the seed has been testified at industrial scale for industrial wastewater treatment such as palm oil mill effluent (POME) and a high effluent reduction was revealed [10, 11]. In addition, *M. oleifera* seeds possess other effects such as antimicrobial, buffering capacity (Fig. 2) [12, 13] and also contains natural antioxidant compounds which are essential to the human's system [14]. All the above-mentioned factors are useful contributors for wastewater remediation by removing microorganism, suspended particles and high turbidity [15, 16]. Therefore, the goal of this review is to provide an insight into the utilization of *M. oleifera* seeds material as an alternative natural coagulant for water purification as well as clarifying on its coagulation mechanism (coagulation activity assay).

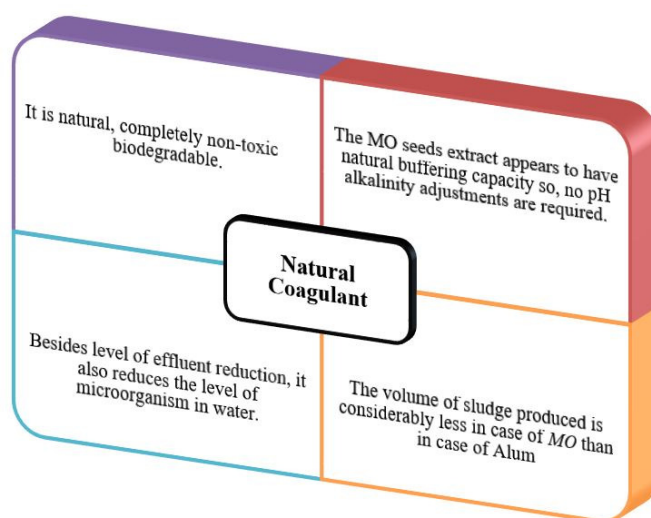


Fig. 2. Reason for use of *M. oleifera* seeds as natural coagulant.

2. Moringa oleifera tree (brief morphological description)

M. oleifera species is cultivated across the globe, because of its medicinal and nutritional value. This species belongs to the single-generic family called Moringaceae, genus *Moringa* with 14 species which comprises of shrubs and trees. Ramachandran, Peter and Gopalakrishnan [17] reported that genus *Moringa* has two common species which includes *Moringa concanensis* and *Moringa oleifera*. *Moringa oleifera* Lam is the actual botanical name of the species of interest. The tree has many other names including Ben oil tree (because of the 'Ben oil' produce from its seeds), Horseradish tree (because of horseradish mild taste of its leaf) and Drumstick tree (drumsticks fruit resemblance) [6, 14, 18].

The *M. oleifera* species is medium-sized of about 20 - 25 m height, with back corky, fissured, glabrous, soft and tuberous roots. The leaves are compound, longitudinally cracked, spirally arranged with length 25 - 45 cm long (main axis 30 - 75 cm long), crowded at the end of its branches [21]. It possesses a long petiole and tri-pinnate leaves in rachises (tip of its branches) as shown in Fig. 3a. Leaflets stalk, obovate/ovate, base acute-obtuse (of 90 °), imarginate or rounded [19-21]. Other features include ramal phytotaxy, smooth leaf surface, unicostate leaf venation, opposite leaf arrangement, entire leaf margin and petiolated leaf attachment as earlier reported by Zhigila, Mohammed, Oladele and Sawa [21]. The species flower is white in colour, produces fragrant smells, bisexual (attractive to both sexes) in nature, oblique in perpendicular stalked and united into erect auxiliary. The flower has abundant panicles (Fig. 3b). The inflorescence comprises of the yellowish

petal, calyx in angular/sharply defined and stamen with tightly base or densely pilose. The ovary has long appressed hairs and terete with 3 longitudinal furrows, single-celled and 3 placentas bearing rows of ovules and pendulous capsule [19, 22].

The quantitative features of *M. oleifera* fruit pod have been mentioned [21]. The highest pod length ranges 414.5 (495.0) 573.2 mm and fruit stalk length of 96.70 (111.41) 119.50 mm by operational taxonomic units (OTU) 26 and 20 respectively. The highest average pods width was 25.59 mm and the highest number of seeds are 26 with the mean of 23.40. The pod index is relatively 5 highest and lowest is 2. The seed length ranges from 9.12 mm – 16.21 mm [21]. Two different seed shapes; ovate and isodiametric were recognized with prominent or less prominent wing form and the colour was varied from tan to cream. Such seed shape patterns appear to mark different evolutionary levels inside many taxonomic groups and variation of the seed characters is sufficient to distinguish taxa at sectional level [21, 23]. Furthermore, evidences indicated that almost all parts of the tree are useful. For that, the species is titled 'MIRACLE TREE' [6, 14, 18].



Fig. 3. a) *M. oleifera* compound leaf; tri-pinnate, paler lower surfaces of leaflets and b) flower panicle; whitish-yellow [6, 21].

3. Moringa Oleifera seeds as alternative natural coagulant for water treatment

The practice of using natural material from plant as coagulants for water purification has been reported [6, 24-29]. Asia and Africa's countries have been using such products for a few decades to reduce water turbidity. They include *Moringa oleifera* seeds powdered. Apart from *Moringa oleifera*, other species such as *Cactus latifera* and *Prosopis juliflora* have shown that coagulation effect. The plant organs viz. seed, root or leaf is normally used. Water purification by these species is essential because they contain acrylamide monomers that are harmless to humans and their existing environment. The use of such conventional chemicals attracts extra cost and are rarely found. Whereas, natural seeds coagulant are mostly availability in most rural communities, these make it less expensive compared to ones. Hence, these natural products have potential for commercialization in near future due to their abundance and other valuable properties that are health and environmentally sound [8].

M. oleifera seed was found to be an effective purifier towards removing suspended materials such as suspended solids, turbidity and other waste products. As earlier stated, due to the non-existence of enough knowledge on how such natural material works, the use of chemical coagulants

in water treatment become more common. The mostly used chemicals are; alum (Aluminum sulphate), synthetic organic polymer, synthetic polymeric derivatives and inorganic coagulant which are all a threat to humans' health and environment (Fig. 1) [30, 31], as well as WHO (2004). Also, the use of such substances for water cleanness has developed a strong pressure on the economy of some developing and under-developing nations as the products are imported. This makes the process of wastewater treatment costly in those nations [32]. Alternatively, the use of natural plant materials as coagulant become interestingly significant than the traditional ferric salts commonly used nowadays [33].

Water treatment using natural coagulant from *M. oleifera* seeds is safe, because it contains a natural organic polymer and biodegradable materials [29]. High contaminations are removed and non-hazardous sludge is generated [34]. The sludge volume generated by coagulation activity from the seeds extract is lower as compared with that of alum or other ferric salts. It softens the hard water due to seed proteins that are essential for water purification [32, 35, 36] and also contains antioxidant compounds that may be essential towards waste treatment [14]. Its effectively acts as an absorber of cadmium and disinfect the water from microorganisms. Therefore, the entire disinfection may be accomplished with the traditional approach by boiling and local filtration of the water [33, 37]. After the coagulation processes, the seed residue can be used as fertilizer or animal fodder [6]. Likewise, the dried pods and husks (Fig. 4) can be pyrolysed for activated carbon using one-step steam pyrolysis [32]. Also, improvements in water treatment could be achieved by adding NaCl [6] and KCl in little quantity [36].

Beside conventional treatment method, wastewater treatment also involves the use of microorganism as bio-flocculant [38] via facultative, anaerobic or aerobic digestion. These treatments need to be thoroughly monitored as the aerobic and anaerobic procedures solely depend on microorganisms to degrade the pollutants. Microorganisms are sensitive to environmental changes and great concern needs to be taken to provide a favourable environment for their proliferation. It necessitates skilful attention, responsibility and a long period of retaining or preservation. In addition, treated water cannot be recycled due to corrosive and odorous gasses released by the microorganism [4]. Therefore, a cheap and easy method in combined set with coagulation treatment is required to develop better water treatment system for future retrieval, hence, use of a natural product such as Moringa seeds is the solution.



Fig. 4. *M. oleifera* fruit pods, seeds kernel and husk; pods and husk are pyrolysed for activated carbon production [6].

Additionally, the seeds are among the most useful and nutritious botanical product with high economic values [14]. It is also recognized as medicinal and herbal remedies used in both industrial

and agricultural field because of its possession of chemical compounds as tabulated in Table 1. Equally, useful oil can also be extracted from the seeds [28, 31, 33]. According to National Charity for Organic Growing, *M. oleifera* seeds have the capacity to treat many diseases such as rheumatism, urinary tract infections, sexually transmitted diseases (STD), epilepsy and gout. The medicinal properties of these seeds are well documented and supported by the experience of the traditional Ayurvedic practitioners [32].

Table 1
The different chemical compounds found in *Moringa oleifera* seed

Chemical	
2,4-Methylene-Cholesterol	4-(Alpha-L-Rhamnosyloxy)- Benzylglucosinolate
Beta-Carotene	28-Isoavenasterol
Campestanol	Alpha-Tocopherol
Ash	4-(Alpha-L-Rhamnosyloxy)- Benzylisothiocyanate
Brassicasterol	Behenic-Acid
Carbohydrates	Beta-Sitosterol
Fat	Cholesterol
Glucosinolates	Fiber
Palmitic-Acid	Oleic-Acid
Stearic-Acid	Protein
Arachidic-Acid	

Adapted from Abdulkarim, Long, Lai, Muhammad and Ghazali [39] and Mishra, Singh, Verma, Kumar, Srivastav, Jha and Khosa [20]

4. Extraction and mechanism of *M. Oleifera* seed coagulant (principles and process)

Actually, the initial step for developing a new strategic plan for water treatment involves the characterization of coagulant itself and identifying its active compound. This is mainly to determine the characteristics and nature of coagulation process. Previous findings described proteins as the main water-dissolving constituent in the plant which is responsible for water purification [6, 9].

The coagulant extraction at laboratory scale begins by removing the seeds husk, air dried and grinding the seeds kernel using the clean grinder. Pyrolysis activity is mostly observed for activated carbon as shown in Fig. 5. Subsequent to grinding, oil is removed (depend on research aim) and mostly the seed gives high coagulation effect once oil is removed. The next is the resuspension of the seeds powdered in water at different concentration for optimization purpose (1g/100mL to 5g/100mL or stock of 2.5g/50mL). The stock seeds are blended or agitate at high speed for 2-5 minutes to extract the coagulant agent, then the muslin cloth is normally used to filter the paste and used as a coagulant. The paste concentration may also be varying in order to determine the best concentration for the treatment.

The coagulation process occurs in successive phases intended to overcome the forces stabilizing the suspended particles in wastewater, allowing collision of particles and growth of floc. In a situation where the first step is incomplete, the subsequent step will be also unsuccessful. The initial coagulation stage; destabilizes the particle's charges. Means it is the coagulants with opposite

charges to the suspended solids are added to the water to neutralize the negative charges on dispersed non-settleable solids such as clay and colour-producing organic substances in the wastewater. As soon as the charge is neutralized, the smaller particles are capable of sticking together, while the larger particles formed through the process called micro-flocs (un-visible process). Now, the water surrounding the newly formed micro-flocs should be clear. If it is not clear to the reasonable percentage, means all the particles' charges have not been fully neutralized and coagulation has not been carried out completely. Hence, increase in the concentration of coagulant may be needed to achieve a maximum effluent reduction. Finally, a high-energy rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve maximum coagulation effect and reduction of effluent. Extra-mixing of the water does not affect the bioactive agent, but insufficient mixing may leave the step incomplete. The Moringa seed coagulants should be added where sufficient mixing is occurring and provide proper contact time in the rapid-mix chamber (2-5 minutes) for appropriate coagulation act.

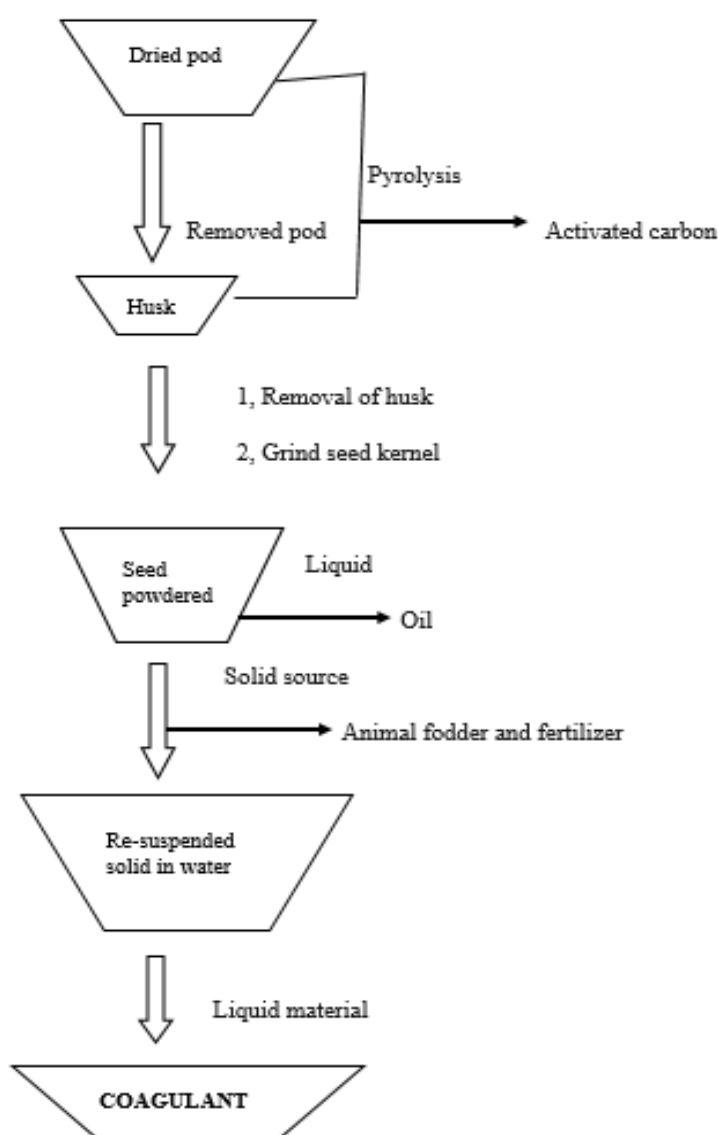


Fig. 5. Coagulant extraction process (Note: Oil can also be remove based on the nature of the research)

The coagulant particles mixture and settling-out occur through the following basic processes:

- a) Two flat compression
- b) Sweep flocculation
- c) Accumulation and charged neutralization
- d) Accumulation and inter-particle climbing / stemming

Particles aggregate and are settled out in solution through the above mentioned basic mechanisms via; double-layer compression, sweep flocculation, adsorption and charge neutralization and adsorption and interparticle bridging. The presence of salt compounds normally causes compression of the double layer, resulting in destabilization of particles in the wastewater whereby repulsive electrostatic interactions are overwhelmed by attractive van der Waals forces. Sweep flocculation or enmeshment in the precipitate occurs when the precipitating coagulant traps suspended particles within a colloidal floc as it forms or settles. Destabilization of particles through charge neutralization occurs when suspended particles in solution are attracted to opposite charged ions. Bridging takes place when the coagulant forms a polymer chain that can attach multiple particles so that particles are bound to the coagulant [52]. The coagulant can be extracted as described in Fig. 5.

4.1. Coagulation activity assay

A little quantity of coagulant is normally administered using mechanical stirrers called Jar test operation. At laboratory scale, the water volume for the analysis should be in satisfactory volumes (100mL – 1000mL) with the accurate administration of the coagulant. A small quantity of sample is necessary to facilitate the biochemical studies of coagulation assay [7]. The coagulant extract is added to highly turbid water sample and immediately homogenize.

The solution is mixed with rigorous, followed by gentle swirling to allow the repelled suspended particles to charge to the cationic stock solution. The speedy mixing (for short period of time) occur within second fractions [40], while the slow mixing (it takes longer time) accelerates the electrostatic flocculation to occur and allow larger flocs particles to condense the effluents [41]. The later mixing provides efficient time for proper sedimentation of flocs, aggregation of heavy particles and settling-out to the underside of the container which leads to sludge generation at the bottom and clean supernatant usually obtained.

4.2. Incorporating the Seeds Coagulant in Wastewater Treatment and the Quality of the Treated Water

Wastewater treatment series via coagulation–flocculation to sedimentation–filtration using *M. oleifera* seeds revealed maximum turbidity and suspended materials removal [42, 43]. The powdered seeds generate less sludge volume and promotes Chemical Oxygen Demand (COD) removal [34]. The seeds uphold effective coagulant particles and properties which have been confirmed in laboratory studies. The seeds are neither harmful to humans nor animals. It is quite efficient in reducing microorganisms' presence in raw water. Thus, water treated using such natural coagulant is more recommendable to use compared to one treated with alum [36].

The Moringa seeds coagulant solution is water soluble material as observed from the coagulation activity of the seeds on raw water and can easily overcome the presence of a microorganism in the water. Treating water at different dosage is recommended and yielded a positive outcome. This is one of the merits of Moringa seeds over alum; because alum cannot significantly reduce microorganism from the treated water as reported by Alo, Anyim and Elom [44]. Furthermore, the physicochemical properties of water treated with this coagulant have shown an encouraging result

of effluent reduction such as colour (up to 79.96 % reduction) [45], turbidity of about 60 % [42], COD (> 30 %) [36] and > 47 % suspended solids removal [46, 47]. These may be due to relatively active flocs formed at the comparatively maximum seeds dosage. The extreme flocs being more probable to resist the hydraulic shear forces confronted during filtration process [34]. Also, the seeds did not significantly affect the pH value of the water, but it acts as a pH buffer [48, 49] (Fig. 2). In contrast, the pH value reduced to 4.2 when water being treated using alum. Besides that, the conductivity of the treated water normally changed. Therefore, optimizing the *Moringa oleifera* seeds coagulant in wastewater treatment process is required to enhance its coagulation-flocculation effectiveness toward high effluent removal. Thus, by increasing the seeds dosage which might maximize the coagulant efficiency. Equally, optimization of such natural products to produce effective, safe and environmentally friendly method for wastewater treatment will be an important substitute for using conventional chemicals [4, 50] and equally overcome the existing microbes in the water [51]. Similarly, this has shown that the seeds are more economical and environmentally safe for wastewater treatment than the use of alum or other synthetic chemicals [9, 27].

5. Conclusion and future perspective

Concisely, *M. Oleifera* seeds extract is a potential source for water treatment due to its efficacy. When used for the treatment of wastewater, excellent results were obtained. The seeds are environmentally friendly because they do not further deteriorate the environment. Also, due to its availability and maximum effluent removal from both domestic and synthetic wastewater, the application of the seeds in wastewater treatment is undeniable. Intrinsically, the following suggestions may improve the efficacy of the seeds.

- I. Further research should be carried out to find the elements responsible for the coagulation process.
 - II. Oil should be extracted from the seeds before using as a coagulant for water treatment. This is because if oil is extracted from the seeds, the optimum effluent reduction will be achieved as reported by Bhatia, Othman and Ahmad [4] and Chaudhuri Chaudhuri and Khairuldin [11].
 - III. Optimization using non-synthetic chemicals (in less quantity) is advisable.
- Hence, extensive study of this plant material will provide significant insights on the proteins responsible for the coagulation activity.

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