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Article

Moringa oleifera Plant as potent alternate to Chemical Coagulant in Water Purification

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Quality of groundwater is threatened due to pollution by industrial, domestic and agricultural waste. A large number of populations are residing in rural areas which are unable to afford high cost water purifiers due to their low income as well as limited awareness. However, limited availability of fresh water has become a critical issue in developing countries. Around 1.2 billion population is deprived of affordable and safe water for their domestic need. Additionally, chemical coagulants which are nowadays being used for water purification pose severe and numerous health hazards to human. Thus utilization of easily accessible natural coagulant for water purification might offer a sustainable, practical and cost effective solution to the current alarming situation in developing countries. Several experimental findings have shown strong efficiency of *Moringa oleifera* plant extracts obtained from different solvents in the improvement of water quality parameters including physicochemical (such as pH, hardness, turbidity, metallic impurities, total dissolved solid) and biological (E.coli count) parameter. We have also highlighted the limitations and advantages of chemical coagulation in water purification. Altogether, this review summarizes one such miracle tree which has shown significant potential as a natural coagulant and its associated underlying mechanism in water purification process.

Keywords: *Moringa Oleifera*. Natural Coagulant. Chemical coagulant. Water treatment. Health Hazard.

INTRODUCTION

Increasing population has led to severe environment degradation thereby posing crucial challenges for developing nations globally (Duguma *et al.*, 2019). There is an exponential increase in water, soil and air pollution which is increasing at a very high rate than their infrastructural development (Qadri, Faiq, 2020; Evans *et al.*, 2019). Demand for fresh drinking water in these developing countries is very high (Boretti, Rosa, 2019). Watersheds are rapidly being utilized for farmlands and residential facilities thereby resulting in reduction of water resource (Wu, Liu, Ma, 2018). In recent years, *Moringa oleifera* has drawn a wider attention towards its utilization as a potential natural coagulant for water purification methods (Mohd-Salleh, Mohd-Zin, Othman, 2019; Polepalli, Rao, 2018). Natural coagulants have several advantages over chemical coagulant such as cost effective and minimal side effects (Freitas *et al.*, 2018; Gitis, Hankins, 2018). Numerous parts of *Moringa oleifera* plants (Nouhi *et al.,* 2019) have been widely utilized for water treatment processes (Okuda, Ali, 2019) due to the presence of water soluble proteins (low molecular weight) (Baptista *et al.*, 2017). Several coagulants have been widely reported in conventional water purification processes. These coagulants are further classified into various categories including synthetic coagulant, inorganic coagulant and natural coagulant. Natural coagulants pose several benefits to mankind which can overcome the side effects of chemical coagulants such as aluminum salts which are associated with several human diseases including Alzheimer's disease (Krupińska, 2020; García-Fayos, Arnal Arnal, Sancho, 2018). Natural coagulants

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have been obtained from various sources such as animals, microorganisms and plants. Additionally, natural coagulants can be differentiated into two categories on the basis of the presence of compounds having coagulation efficacy such as proteins and polysaccharides. Coagulation potential of these compounds relies on the presence of amino and hydroxyl functional groups on them. This short review has illustrated the potential of *Moringa oleifera* plant in water purification process.

CHEMICAL COAGULANT OVER NATURAL COAGULANTS

Several synthetic coagulants have been utilized for water purification (such as ALUM, Aluminium sulfate) but have numerous harmful effects whereas natural coagulants (extracted from plant material) depicted several beneficiary aspects including their non-toxic and biodegradable nature. Natural (or plant-based) coagulants have proven better coagulation potential in eliminating suspended particles and colloidal matters from water resources. Their easy availability and better compatibility with several technologies used for water purification have made it a strong alternative to the chemical coagulants.

EFFICACY OF MORINGA EXTRACT IN TEXTILE WASTEWATER TREATMENT PROCESS

Textile production involves usage of several additives, organic dyes and salts, which results in wastewater generation with high COD (Chemical oxygen demand), turbidity, temperature and suspended solids. Any discharge of this textile wastewater pose severe harmful effects such as aesthetic consequence on water supplies, reduction in light penetration thereby negatively altering dynamics of aquatic ecosystem. Chemical coagulants including aluminium salts and iron have been extensively used in textile wastewater treatment. However, application of inorganic or chemical coagulants in textile treatment process generates large amount of toxic sludge which degrades quality of treated water by altering its pH. Thus natural coagulants have gained major attention in textile wastewater treatment due to their low toxicity biodegradability, wide variety and availability.

MORINGA SEEDS AS A NATURAL COAGULANT AND FLOCCULANT

Moringa oleifera seeds have presented a strong evidence for their use as an effective natural coagulant in water treatment process for the improvement of chemical and physical characteristics of ground water such as pH, TDS (total dissolved solids), hardness, turbidity, alkalinity, suspended solids and conductivity (Novita *et al.,* 2019; Taiwo, Adenike, Aderonke, 2020). Also, they have depicted considerable decrease in biological impurities in water such as *E.coli* content (Camacho *et al*., 2017). Overall *Moringa oleifera* seeds pave a strong path towards focusing on its utilization as a strong alternative to chemical coagulant for water purification (Choudhary, Negi, 2017). Natural Coagulants can be extracted via several processes such as soxhlet extraction process using different organic solvents including hexane, methanol, ethanol and water (Sánchez-Martín, Beltrán-Heredia, Peres, 2012). Generally, extraction and purification of all natural coagulants are based upon three stages as depicted in Figure 1. First stage comprises of the pre preparatory phase where the raw plant material is processed and converted into fine powder form suitable for extraction stage such as cleaning and drying. Second stage comprises of extraction where the processed raw material is combined with organic or aqueous solvent to obtain the extract. Lastly, obtained extract is further purified using several processes such as lyophilization and precipitation. Seed extract of *Moringa oleifera* plant has been recognized as one of the highly potent flocculating agent in the treatment of surface water. Moringa seeds have depicted better coagulation activity in the treatment of highly turbidity water. Several pilot scale studies utilized the seed extract of *Moringa oleifera* as primary coagulant in treatment of turbid surface water (Barbosa *et al*., 2018). Several researches have also stated its utility in the treatment of paint waste water which could be further reused for plants (Angelakis *et al*., 1999). Interestingly, water treated with Moringa seed extract has better quality than the water treated with inorganic solvent (aluminium sulphate) (Figure 2). Additionally, combining the coagulation process with electrolysis improved the supernatant quality thereby making it safer for being discharged into water bodies (Du *et al.*, 2019). These data strongly supported the fact that natural coagulants could be a strong alternate to chemical coagulants (Table I).

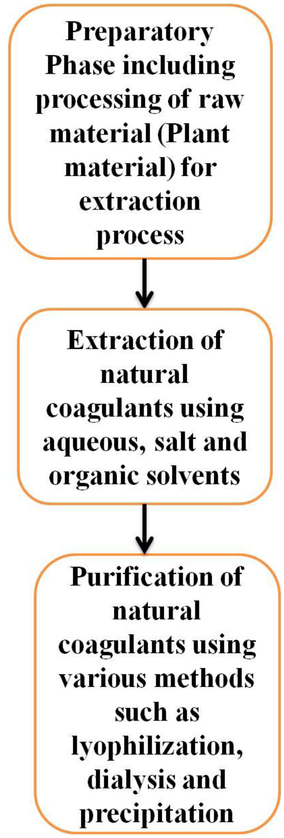

FIGURE 1 - Stages involved in extraction and purification of natural coagulants.

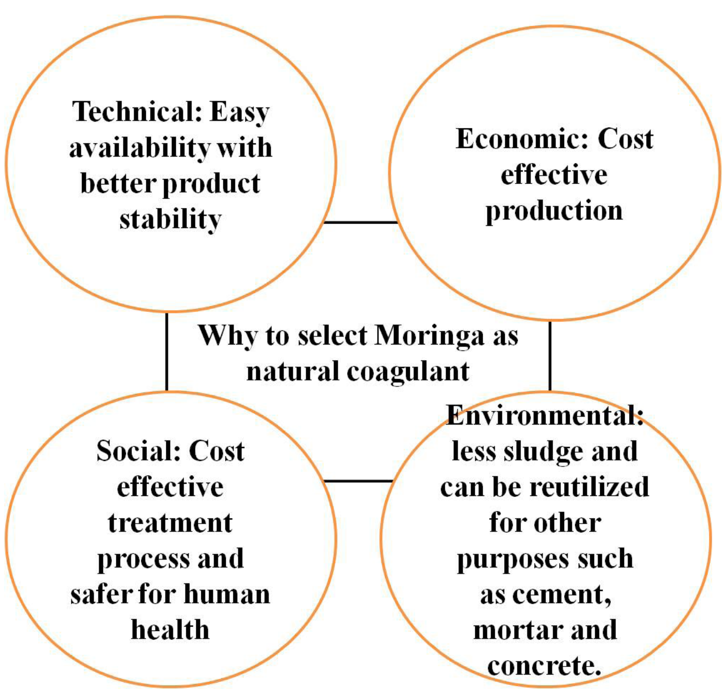

FIGURE 2 - Moringa versus chemical/synthetic coagulants.

TABLE I - Coagulant studies using different parts of *Moringa oleifera* plant

S. No.	Type of Water Sample	Dosage	Part of Plant	References
1	Synthetic Water	80 mg/L	Aqueous seed extract	Jadhav, Mahajan, 2014
2	Synthetic Water	200 mg/L	Aqueous seed extract	Arantes *et al.*, 2015
3	Synthetic Water	70 mg/L	Saline solution seed extract	Mohamed *et al.*, 2015
4	Surface Water	13.78 mg/L	Saline solution seed extract (Ultrafiltered)	Baptista *et al.*, 2015
5	Surface Water	50-100 mg/L	Saline solution seed extract	Gamez, Luna-delRisco, Cano, 2015
6	Surface Water	1250 mg/L	Aqueous seed extract	Salazar Gámez, Luna-delRisco, Salazar Cano, 2016
7	Synthetic Water	75 mg/L	Aqueous seed extract	Garcia-Fayos *et al.*, 2016a
8	Synthetic Water	8.328 mg/L	Saline solution seed extract	Garcia-Fayos *et al.*, 2016b
9	Surface Water	200, 400, 800 mg/L	Saline solution seed extract	Santos *et al.*, 2016
10	Surface Water	30 mg/L	Saline solution seed extract	dos Santos *et al.*, 2016
11	Surface Water	50 mg/L	Seed oil extraction	Camacho *et al.*, 2017
12	Surface Water	13 mg/L	Seed Protein	Baptista *et al.*, 2017
13	Synthetic Water	100 mg/L	Seed Protein	Choudhary, Neogi, 2017
14	Surface Water	40 mg/L	Seed Protein	Hoa, Hue, 2018
15	Surface Water	50 mg/L	Seed Powder waste	Landazuri *et al.*, 2018
16	Surface Water	50 mg/L	Seed Extract (Aqueous, Saline and powder)	Valverde *et al.*, 2018
17	Surface Water	200, 400, 800 mg/L	Saline solution seed extract	dos Santos *et al.*, 2018
18	Surface Water	100, 200, 400 mg/L	Saline solution seed extract	Mateus *et al.*, 2018
19	Surface Water	0.75 mg/L	Seed Powder	Zaid *et al.*, 2019
20	Ground Water	50, 100, 150 mg/L	Leaves extract	Pandey *et al.*, 2020
21	Ground Water	25, 50, 100 mg/L	Seed+Leaves extract	Alam *et al.*, 2020

MORINGA LEAVES AS A NATURAL COAGULANT

Recently our team has elucidated the beneficial potential of *Moringa oleifera* leaves in water purification (Pandey *et al.*, 2020a). Leaves have overcome the limitations of limited availability and durability of seed powder since they are present throughout the year. Extracts of *Moringa oleifera* leaves in different organic solvents have shown significant potential in reducing the biological, chemical and physiological impurities in ground water thereby adding strongly to the beneficial role of *Moringa oleifera* plant in water purification process. Our team has also explained the increased efficacy of plant leaves used in combination for water purification process than used alone (Pandey *et al.*, 2020b). This article has revealed that combined extract obtained from two different plants including Moringa and Neem have better efficacy than extracts obtained from both plants individually. Additionally, we have also investigated the efficacy of Moringa leaves in combination with seed extract and observed better coagulating potential of combined treatment in comparison to individual extract (Alam *et al.*, 2020). Few studies have also reported that turbidity removal is enhanced in Moringa treated water treated with Moringa (Freitas *et al.*, 2016). Several researchers have also postulated that water treated with both Moringa and alum would have lesser amount of aluminium in it due to the interaction of Moringa with aluminium ions thereby providing more safe drinking water. Interestingly, water treatment with Moringa along with alum would not interfere with the coagulation potential of alum and further enhance the floc size which can get easily removed (Boulaadjoul *et al*., 2018). These results further demonstrated the better efficacy of natural flocculants in comparison to chemical coagulants (Table I).

MECHANISM BEHIND WATER FLOCCULATION AND COAGULATION

Conventional or traditional wastewater treatment methods comprises of a blend of chemical, physical or biological methods for the removal of several impurities including metals, colloids and organic matter. Various techniques such as conventional methods (including flocculation, coagulation, filteration, biodegradation and adsorption), emerging removal processes (including advanced oxidation, nanofilteration, biosorption and adsorption) and established recovery methods (oxidation, evaporation, ion exchange, membrane separation and solvent extraction). COF (Covalent organic frameworks) have also proven their strong water purification potential as potent adsorbents by capturing numerous pollutants such as radionuclides, heavy metal ions and organic pollutants from water (Liu *et al*., 2021). Table II summarizes these conventional methods that are being used for water treatment with their limitations and advantages (Crini, Lichtfouse, 2019). Several reports have proposed the involvement of cationic proteins in the adsorption and integration of destabilized particles during coagulation process of Moringa oleifera seeds (Kansal, Kumari 2014). Gassenschmidt *et al.* (1995) reported comparative study of Moringa oleifera seed with a cationic polymer (synthetic) 554 K and described the coagulation process via bridge formation. Flocculation of impurities (negatively charged particles) is due to the association positively charged polymer to the surfaces of particles via Coulomb forces. It further results in particle agglomeration due to surface charge neutralization and electrostatic repulsion reduction.

Another mechanism namely ‘‘patch charge’’ was also proposed by Gassenschmidt *et al.* (1995) applying to small basic proteins like cationic proteins of Moringa oleifera plant. In this proposed mechanism, flocs formation occurs due to particle collision. Another investigation by Fahmi *et al.* (2011) reported enhanced coagulation efficacy of Moringa seeds when extracted in sodium chloride solution. The underlying mechanism behind the improved coagulation potential of Moringa seeds could be the possible salting-in phenomenon of seed proteins, which leads to increased solubility (due to protein–protein dissociation). Recent findings reported a more potential method for improving the coagulation potential of Moringa plant in water purification. This study explained the improved coagulation potential of combined seed and leaves extract due to the potent role (flocculation) displayed by bioactive compounds present in them (Figure 3).

TABLE II - Summary of conventional and traditional methods of wastewater treatment

Conventional method	Specifications	Limitations	Advantages
Precipitation method	Pollutants uptake with product separation	Chemical consumption, pH variation, unable to remove metals at low doses	Simple techniques and equipment, Cost effective, combat with wide range of pollutants including fluoride and metals
Evaporation method	Concentration technique, Thermal and separation process	Costlier method for wastewater purification, high investment costs for medium and small industries, corrosion issues	Versatile technique, Efficient process of water production for recycling of distillates, good for phenol separation by steam distillation, organic removal from water
Flocculation or Coagulation method	Pollutants uptake with product separation	Needs adjunction of coagulants and flocculants, pH variation, and Increased sludge generation, Low arsenic removal ability	Simple process, Cost effective, Highly efficient for colloidal particles, Efficient sludge removal and Significant reduction in the COD (chemical oxygen Demand), BOD (biochemical oxygen demand) and total organic carbon

TABLE II - Summary of conventional and traditional methods of wastewater treatment

Conventional method	Specifications	Limitations	Advantages
Membrane filtration method	Nondestructive separation with semipermeable barrier	High Investment costs, high maintenance, high energy requirements, high operation costs, variations in membrane design, Low throughput, faster membrane clogging	Wider range of availability of commercial membrane, wider module configurations and applications, smaller and simple space requirement, no chemicals requirement, limited solid waste generation
Flotation method	Separation method	High initial capital, Energy and maintenance and operation costs pH dependent	Needs physicochemical process with various types of nonionic or ionic collectors, Efficient for removal of low density particles, Metal selective and Low retention time
Chemical method	Use of oxidants such as Cl2, O3, KMnO4, ClO2, H2O2,	Costlier method, needs high doses of ozone , intermediates formation No BOD, COD reduction, Release of high sludge	Efficient and rapid process, no storage associated dangers, effective pollutants destruction and efficient color reduction, color and odor elimination, efficient for sulfide and cyanide removal, efficient product biodegradability, No sludge generation
Biological methods	Use of pure or mixed biological cultures	Needs favorable environment and proper maintenance of microorganisms and non degradable compounds, Slow process, Low dye biodegradability, Poor BAS decolorization and foaming, biological sludge generation and uncontrolled product degradation, need of detailed enzymatic processes knowledge	Contaminants (Organic) biodegradation with microorganisms, economically effective, wide range of species are used in mixed or pure cultures, high biodegradability, High BOD and BAS removal from water
Filtration or Adsorption method	Non destructive method involving usage of solid material	High investment and material cost, Nondestructive and non selective process, Performance is based on material type, adsorbents type, Rapid saturation and clogging issues, inefficient with dye, Expensive regeneration, Economically non viable	Simple Technology and equipment, Wide variety of commercial products, target contaminants, effective adsorption process, Excellent separation of wide range of Pollutants, COD removal, efficient for suspended solids and turbidity
Ion exchange Method	Nondestructive method	Economic problems such as costlier resin, high maintenance cost, regeneration, time effective, Rapid clogging of reactors, needs physicochemical pretreatment for the removal of contaminants, pH dependent process, limited efficacy for certain pollutants	Simple Technology, Well established techniques, easy maintenance and control, Flexible with filtration and precipitation, High resin regeneration, Efficient and Rapid process, Produces high quality treated effluent, Least expensive and good for metal removal

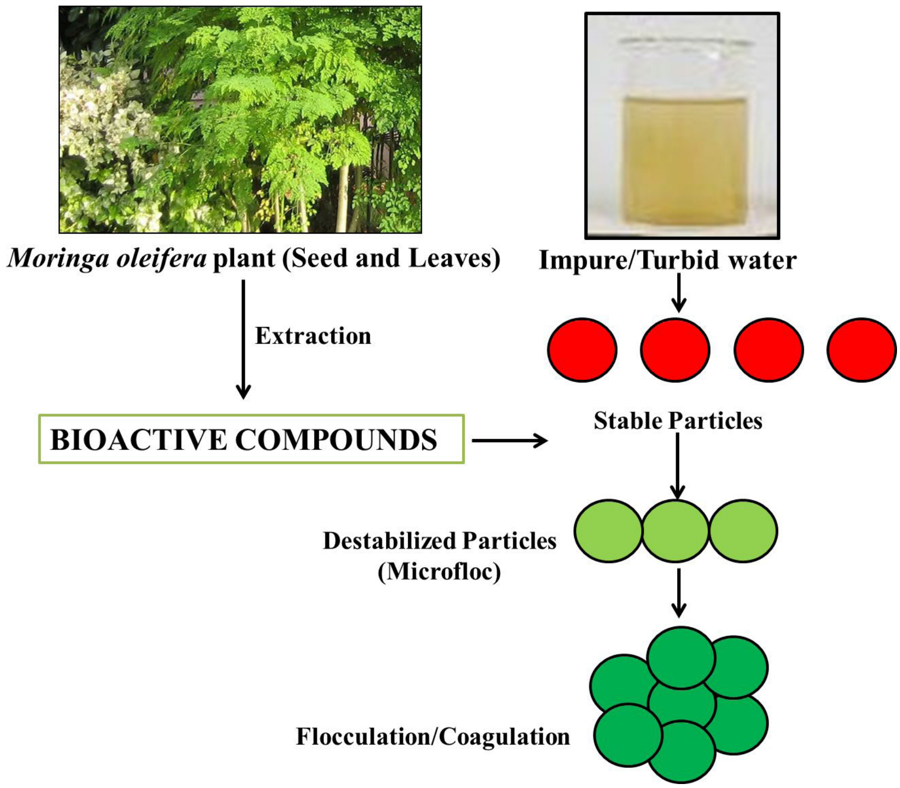

FIGURE 3 - Mechanism behind the flocculation process by *Moringa oleifera* plant.

CONCLUSION

Nature has blessed mankind with various solutions to obtain pure water and to eliminate the pollutants released into the water bodies via anthropogenic behavior. Materials comprising coagulating capabilities could be obtained from several natural sources such as plant and microorganisms. Several studies have proven the efficacy of natural coagulants in water treatment. This review has shown the strong potential of Moringa plant in water purification process with no side effects thereby proving it a strong alternative to chemical coagulants. Further studies are still needed to develop cost effective technologies which can maximally exploit the potential of *Moringa oleifera* leaves in water purification.

CONFLICT OF INTEREST

All the authors associated with this manuscript declare that there is no conflict of interest.

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