Use of *Moringa* spp. seeds for coagulation: a review of a sustainable option

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Abstract Regrettably, it is still common to find places without access to safe drinking water due to a lack of resources or appropriate technologies to support adequate solutions. Remedial efforts will need to focus on appropriate solutions for such locations. Coagulation with *Moringa* spp. seeds has been proposed as a sustainable option for water treatment for low-income locations due to the many other uses of the *Moringa* tree. Yet, its application is not limited to particle separation. A survey of the databases of WOK (Web of Knowledge) and CSA (Cambridge Scientific Abstracts) identified studies utilising *Moringa* spp. seeds as a coagulant. Although the majority of the studies were of laboratory or household applications, there were also reported trials in pilot- and full-scale treatment trains. *Moringa* spp. seed extracts were assessed as primary coagulants, co-coagulants (with aluminium sulfate) or secondary coagulant aids (flocculants). Turbidity reduction efficiencies vary according to the source water characteristics, coagulant preparation technique, and seed type. Treatment benefits of coagulation with *Moringa* spp. seeds are objectively assessed and have been contrasted with practical considerations in view of its sustainable application.

Keywords Coagulation; flocculation; *Moringa* spp; Moringaceae; natural coagulants; water treatment

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Introduction

Earliest historical accounts of the use of plants or their derivatives for water treatment by ancient civilisations have been registered in Sanskrit writings (400 A.D.), the Old Testament, and Roman records (*c*. 77 A.D.), as reported by Baker (1948). Several "plant flocculants" are still traditionally used to treat turbid surface waters in parts of Africa, Asia, and the Americas (Jahn, 1988). These natural coagulants are used at household level, mainly in rural areas, in locations without access to improved water sources. Such applications are usually in developing countries where limited resources may not be sufficient to purchase more commonly used clarification chemicals such as aluminium sulfate. The coagulation capacity of some *Moringa* spp. seeds is of particular interest considering the other uses these plants have for these low-income settings.

The Moringaceae family has only one genus, *Moringa*, with 14 known species (Jahn, 1988). Half of these species are relatively common, but the *Moringa oleifera* is the most planted throughout the tropics due to its many uses (vegetable, oil tree, honey tree, fodder, fuel crop, ornamental, and medicinal). *M. oleifera*, horseradish or drumstick tree, usually reaches 5–10 m high, at most 15 m (Morton, 1991). This robust crop can grow in a wide range of soils and its plantation is not limited to lowlands. Moreover, it is capable of surviving different climatic conditions such as light frost, extreme droughts, and prolonged rainy seasons (Jahn, 1988; Morton, 1991). It may yield the first harvest within a year (Jahn, 1986) and in some locations there may be up to two crops of fruits (seeds) per year (Morton, 1991).

Considering this plant's versatility in its uses and culture, it has the potential to benefit marginalised rural communities, which may not gain access to a safe piped water supply in the near future. Such decentralised (domestic) approaches to water treatment are part

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of the current efforts to meet the Millennium Development Goals with regards to safe water supplies (Mintz *et al.*, 2001; Sobsey, 2002). This paper reviews the use of *Moringa* spp. seeds for coagulation mainly in water treatment. A survey of the databases of WOK (Web of Knowledge) and CSA (Cambridge Scientific Abstracts) identified most studies utilising *Moringa* spp. seeds as a coagulant.

Coagulation with *Moringa* spp. seeds

Of the known *Moringa* species, seven of the more common varieties were identified as having coagulation capacity (Jahn, 1984a; Jahn, 1986; Jahn and Britto, n.d.): *Moringa oleifera*; *M. peregrina*; *M. stenopetala*; *M. longituba*; *M. drouhardii*; *M. ovalifolia*; and *M. concanensis*. *M. oleifera* has been the most characterised species. Coagulation studies using *Moringa* spp. seeds vary considerably in the seed preparation methods, species evaluated, and the turbidity ranges tested.

Coagulant solutions

Active component. The coagulating compounds in *M. oleifera* seeds have been identified as being of proteinic (Gassenschmidt *et al.*, 1995; Ndabigengesere *et al.*, 1995; Okuda *et al.*, 1999) and non-proteinic (Okuda *et al.*, 2001a) origin. The latter consists of organic polyelectrolytes with molecular weight of *ca.* 3 kDa (Okuda *et al.*, 2001a). The active components of protein origin are positively charged dimeric water-soluble polymers with reported molecular weights varying between 6.5 and 13 kDa and isoelectric pH of 10–13 (Gassenschmidt *et al.*, 1995; Ndabigengesere *et al.*, 1995; Okuda *et al.*, 1999). Most of the coagulating substances are present in the (shelled) seed kernels (Ndabigengesere *et al.*, 1995). The press cake, solid by-product obtained following extraction of seed oil, still contains the active coagulants (Jahn and Dirar, 1979; Folkard and Sutherland, 2002).

Preparation techniques. Typically, *Moringa* spp. seed extract solutions are used for coagulation. The extraction methods vary in complexity. Traditionally, finely crushed seeds or their press cakes are mixed with clean water to form a paste, filtered, and diluted to the desired concentration (Jahn, 1988; Folkard *et al.*, 1999; Muyibi *et al.*, 2002). The use of a cloth bag filled with powdered seeds swirled in water has also been reported (Jahn, 1984b). Extracts have been obtained using (distilled, deionised or tap) water (*e.g.* Muyibi and Evison, 1996; Ndabigengesere and Narasiah, 1998), salt solutions (Okuda *et al.*, 1999) or phosphate buffer (Gassenschmidt *et al.*, 1995). Extract purification steps, *e.g.* dialysis, delipidation, centrifugation, ion exchange, and lyophilisation, are also reported (Ndabigengesere *et al.*, 1995; Okuda *et al.*, 2001a).

Water treatment with *Moringa* spp. seeds

Clarification. The majority of studies evaluating the performance of *Moringa* spp. extracts as primary coagulants have been done on lab-scale experiments utilising jar-tests. However, between the studies different jar-test procedures, extract preparation techniques, and turbidity ranges were tested. Table 1 makes differences in jar-testing conditions plain and summarises the results of particle separation efficiencies from the studies utilising *M. oleifera* seed extracts.

Typically, *M. oleifera* studies on turbid waters (>100 Nephelometric Turbidity Units – NTU) show turbidity reduction efficiencies greater than 80%. Turbidity reduction efficiencies increase at higher initial turbidities (Muyibi and Evison, 1995). In general, low turbidities (<50 NTU) were reported to be inefficiently reduced, sometimes increased, when utilising water-only extract solutions (Jahn, 1988; Sutherland *et al.*, 1990;

Table 1 Optimal particulate reductions in selected studies using *M. oleifera* seeds

Particle concentration	Reduction (%)	Extraction method	Study	Observation
6,480–8,640 mg/L	89–96	None	Jahn and Dirar (1979)	Fine seed powder dosed
150–1,800 NTU	93–99	Not specified	Sutherland *et al.* (1990)	"Whole seed additions" used; limited effectiveness for low turbidities
23–90 NTU	27–83	DW-S	Muyibi and Okuofu (1995)	Pre-selected 50 mg/L dose evaluated
50–750 NTU	92–99	DW-S	Muyibi and Evison (1995)	Red. efficiency increase w/ increasing initial turbidities
105–350 NTU	96–99	DW-S	Muyibi and Evison (1996)	
105 NTU	90	TW-S and TW-NS	Ndabigengesere *et al.* (1995)	Shelled (S) and non-shelled (NS) seeds from two sources, shelled seeds more efficient
35 NTU	66[a] and 95[b]	DW-S[a] and SW-S[b]	Okuda *et al.* (1999)	
0.5[c]–50[d] mg/L	90[c]–99[d]	PSW-S	Okuda *et al.* (2001a)	SW-S also tested, with residual turbidities < 5 NTU

DW-S(-NS) = extraction of powdered shelled (S) or non-shelled (NS) seeds using distilled or deionised water; TW = extraction of powdered seeds using tap water; SW = extraction of powdered seeds using aqueous salt solution; PSW = purified extract from aqueous salt solution

Muyibi and Okuofu, 1995; Okuda *et al.*, 1999; Narasiah *et al.*, 2002). An efficient reduction for low turbidities was possible when aqueous forms of salt extracts were used (Okuda *et al.*, 1999; Okuda *et al.*, 2001a). Flocculation using purified active components or of the recombinant protein from cloned polypeptides has also been observed (Gassenschmidt *et al.*, 1995; Ndabigengesere and Narasiah, 1998; Broin *et al.*, 2002; Suarez *et al.*, 2003).

Use of water-only or salt solution *M. oleifera* extracts caused the residual concentration of organics (*i.e.* chemical oxygen demand, ultraviolet absorption, and total and dissolved organic carbon) to increase (Ndabigengesere and Narasiah, 1998; Okuda *et al.*, 2001a; Narasiah *et al.*, 2002). Such an increase in organics could generate disinfection by-products in addition to colour, taste, and odour problems due to microbial decomposition (Ndabigengesere and Narasiah, 1998), possibly also causing an increase in the chlorine demand and the potential for bacterial regrowth (Folkard and Sutherland, 2002). Jahn and Dirar (1979) observed a 300-fold increase of total bacterial counts in treated waters stored for 24 hours. Yet, residual organics did not increase after coagulation with purified *M. oleifera* salt solution extracts (Okuda *et al.*, 2001a).

Jahn (1988) compared the performance of five *Moringa* spp. seeds and attributed variations in efficiencies to: different weight proportions between active agents and other contents (*e.g.* oils) of the seeds; different chemical nature of the flocculants; and facilitating or inhibitory interactions between active components and particulates. *M. longituba* and *M. stenopetala* seeds were found to surpass *M. oleifera* seeds. An optimum dose equivalent and higher to that of *M. oleifera* seeds was required with *M. Drouhardii* and *M. peregrine*, respectively. Although not tested, *M. concanensis* seeds are thought to have a similar performance to *M. oleifera* seeds. Variations in efficiencies also occur between seeds of different origins within the same species (Narasiah *et al.*, 2002).

Two studies have proposed coagulation mechanisms for the *M. oleifera* extract solutions. Ndabigengesere *et al.* (1995) concluded that the dominant coagulation mechanism appeared to be that of adsorption and charge neutralisation; since the optimal dosage of water-extracted coagulant corresponded to a zero zeta potential. Okuda *et al.* (2001b) studied the coagulation activity of a purified salt solution-extracted (non-proteinic) organic polyelectrolyte at pH 9 (optimal). They ruled out other coagulation mechanisms and hypothesised that the active component removed particles by enmeshment in a net-like structure, *i.e.* sweep coagulation.

Comparison and use with aluminium sulfate. *Moringa* spp. seed extracts have been proposed as substitutes for aluminium sulfate in developing countries. The main justification is based on the costs associated with alum, which may proscribe its use in poor locations. Hence studies have compared the performance of *Moringa* spp. extracts with that of aluminium sulfate.

Several comparisons between *Moringa* spp. extracts with alum have been attempted. That is, a comparison of the mass of the seed dosed with that of the metallic salt. However, the fundamental problem is that the seeds may vary in active component concentration and so does the degree of hydration of aluminium sulfate. An objective comparison could be done on a molar concentration basis if the active coagulating substances in the seed extracts were quantified. Therefore, results of these studies should only take into consideration the turbidity reductions achieved independently of the coagulant quantities consumed.

For turbidities higher than 100 NTU, similar turbidity reductions were achieved with *M. oleifera* seed extracts and alum (Jahn and Dirar, 1979; Sutherland *et al.*, 1990; Ndabigengesere *et al.*, 1995). Yet, at low turbidities (<50 NTU), *M. oleifera* seed extracts achieved at most 60% turbidity reductions (Muyibi and Okuofu, 1995). In the same study and conditions (< 50 NTU), the minimum reduction achieved with aluminium sulfate was of 75% (40 mg as alum/L dose). At low turbidities, alum is likely to perform better than non-purified aqueous extracts of *M. oleifera* seeds.

Despite similar treatment performance, *M. oleifera* seed extracts have some advantages over alum. The non-purified aqueous extracts are effective over a wide range of pH (Folkard and Sutherland, 2002). Yet, Okuda *et al.* (2001a) found that the optimum coagulation pH for the purified salt solution extract was 8 or higher. Unlike alum, *Moringa* spp. derived coagulants do not affect the final pH (Jahn, 1988; Ndabigengesere *et al.*, 1995). Sludge volumes produced using *M. oleifera* extracts are up to five times less than that generated with aluminium sulfate (Ndabigengesere *et al.*, 1995). An explanation could be that the three waters of hydration are needed to satisfy the covalent bonding of Al in commercial alum (Cornwell, 1999); this chemically bound water increases the sludge volume. Apart from their inorganic content, sludges from both types of treatment are biodegradable to some extent; this is of limited significance from a domestic water treatment perspective. It is plausible that the *Moringa* spp. extract sludges could have an advantage from a nutritional value when considering land application. Land application of alum sludge may be undesirable because it may absorb inorganic phosphorus from the soil, inhibiting P uptake from plants (Cornwell, 1999). Moreover, alum sludges can also present Al phytotoxicity depending on its pH-dependent solubility.

Thus far, *Moringa* spp. extracts have only been considered as a primary coagulant. It is contended that its use with alum could bring savings in the quantities of aluminium sulfate required for coagulation (Sutherland *et al*., 1990). An economy of alum would demand that performance with a reduced amount used with a coagulant aid (or co-coagulant) is comparable to its use on its own. Results from Muyibi and Okuofu (1995) do not suggest such economy when using *M. oleifera* extracts as secondary coagulants, *i.e.* coagulant aids. Sutherland *et al*. (1990) observed that *M. oleifera* seeds did "not appear to lend themselves to traditional theories concerning coagulant-aid systems." The use of *M. oleifera* seeds or their extracts mixed together with aluminium sulfate has been termed co-coagulation. In this mode, Sutherland *et al*. (1990) report reductions in alum usage in the range 50–80%. Moreover, for a justifiable reduction in alum usage, data from two other studies suggest alum savings of 40% (Muyibi and Okuofu, 1995; Muyibi and Evison, 1996).

Filtration. The use of *Moringa* spp. extracts with alum or as a substitute has been evaluated for use with rapid sand filtration. Some bench- and pilot-scale studies report filtered effluent turbidities of less than 5 NTU (Folkard *et al.*, 1993; Liew *et al.*, 2003); others achieved turbidity reductions to less than 1 NTU (McConnachie *et al.*, 1999; Raghuwanshi *et al.*, 2002; Mandloi *et al.*, 2004). At full-scale (source turbidity: 270–380 NTU), trials with *M. oleifera*-derived coagulants yielded final turbidities below 2 NTU at times and consistently less than 4 NTU (Folkard *et al.*, 1995; Folkard and Sutherland, 2002). These studies indicate that the use of *M. oleifera* extracts could achieve effluents meeting the recommended aesthetic maximum limit of 5 NTU (WHO, 1993) with considerable savings in alum requirements. Yet, it is questionable if rapid sand filtration is the most appropriate filtration technology for developing countries, in view of its level of technical expertise and energy requirements.

Other uses in water treatment. Although the majority of water treatment studies evaluated the use of *Moringa* spp. seed extracts on particulate removal, other applications of the seeds or their extracts are reported. Significant bacterial and pathogenic organism removals can be achieved (Madsen *et al.*, 1987; Olsen, 1987; Jahn, 1998). Reductions in (micro)organism levels are achieved by coagulation and by the antibiotic properties of the seed extracts (Eilert *et al.*, 1981; Olsen, 1987; Suarez *et al.*, 2003). *Moringa* spp. seed extracts have also been proposed to remove freshwater algae (Shehata *et al*., 2002) and have demonstrated a capacity to soften hard waters (Muyibi and Evison, 1996). Moreover, *M. oleifera* seed husks yielded a low-cost activated carbon (Pollard *et al.*, 1995).

Discussion

From the reviewed studies it is apparent that crude *Moringa* spp. extracts are capable of achieving turbidity reductions comparable to those of aluminium sulfate. Yet, the particle removals did not always meet the WHO aesthetic turbidity guideline of 5 NTU (WHO, 1993). Nonetheless, surface waters treated with this natural coagulant are aesthetically more acceptable and probably microbiologically safer than the raw water. No studies were identified which reported on the effectiveness of household water treatment (clarification) using *Moringa* spp. seeds on the reduction of waterborne disease. However, Olsen (1987) citing Lund and Jahn (1980) states that families using indigenous clarifying materials "seemed to have a lower incidence of gastrointestinal disturbances."

Microbiological safety after treatment and during storage can be guaranteed by disinfection. With the exception of chlorine-resistant protozoan pathogens, free chlorination is effective against the majority of waterborne pathogens. A recent review of household free chlorination studies revealed that the microbiological quality of stored water improved and diarrhoeal disease incidence was reduced significantly (Sobsey, 2002). Thus, it is plausible that household chlorination could be successfully incorporated into an education programme on the use of *Moringa* seeds for point-of-use coagulation. This would signify the self-sufficiency of the beneficiaries in relation to particle separation.

The increase in organics caused by coagulation with crude *Moringa* spp. seed extracts could lead to the increase in chlorine demand and the formation of disinfection by-products. Possible chronic health risks due to disinfection by-products are relatively insignificant in view of the acute risks of diarrhoeal disease due to inadequately disinfected water.

Based on postulated long-term health risks possibly associated with Al in drinking water, *e.g*. Alzheimer's disease (AD), many authors have justified the use of *Moringa* spp. seed extracts in conjunction with or in place of alum (Ndabigengesere *et al.*, 1995; Okuda *et al.*, 1999; Broin *et al.*, 2002; Narasiah *et al.*, 2002; Raghuwanshi *et al.*, 2002; Shehata *et al.*, 2002; Suarez *et al.*, 2003). However, more than 99.9% of the ingested Al is excreted in the stool as an insoluble hydroxide due to the transformations it suffers through the gastrointestinal route (Reiber *et al.*, 1995); besides, epidemiological studies relating drinking water Al exposure to AD had inconclusive and contradictory results. There is no evidence to support a causal role for Al in Alzheimer's disease (WHO, 1996). Therefore, the use of *Moringa* spp. seed extracts are justified on the basis of the savings associated with alum costs. Arguably, other problems (not health-related) due to elevated concentrations of Al in alum-treated waters could be taken into account. These potential problems are listed in Driscoll and Letterman (1988) and Van Benschoten and Edzwald (1990).

Savings in alum are applicable to community water treatment plants. In the case of systems relying on rapid sand filtration, it is questionable if this approach is adequate for developing countries due to the maintenance costs involved. Multi-stage filtration systems are a combination of gravel pre-filters and slow sand filters that could be a more cost-effective alternative for low-income settings.

Benefits of the extract purification methods are unlikely to reach developing countries without substantial costs that could even exceed those associated with alum. Other unsettled issues relative to the commercial viability of *Moringa* spp. extracts were reviewed by Folkard and Sutherland (2002). Rural communities are not likely to benefit from the mass use of *Moringa* spp. seed extracts other than perhaps the cultivation of *Moringa* trees as a cash crop. Coagulation with *Moringa* spp. seeds is so far considered to have a potential as a sustainable solution for water treatment at household level only. Even so, it must be considered that quality of water alone is not sufficient to improve the livelihoods of marginalised poor communities. Access to water sources is of equal importance, since much time can be spent on the collection of water. In this manner, mainly riparian dwellers would benefit the most from the coagulating properties of *Moringa* spp. seeds.

In terms of future research, examination into the performance of *Moringa* spp. seed extracts in coloured waters is warranted. That is, when used as primary coagulants, polyelectrolytes may not be as effective as metallic salts to treat water with significant amounts of colour-causing organics (Letterman *et al.*, 1999). This could further limit the application of *Moringa* spp. seeds.

Conclusions

Coagulation with *Moringa* spp. seed extracts can achieve particle separation efficiencies similar to aluminium sulfate. It could be a sustainable solution for domestic water treatment for turbid sources in developing countries. Coagulation properties of purified extracts are promising, but are still at developmental stage and its benefits will be unlikely to reach low-income countries.

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