ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT

AZOJETE, March, 2019. Vol. 15(1):109-123

Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.

Print ISSN: 1596-2490, Electronic ISSN: 2545-5818

www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

VEGETABLE PLANTS WITH WATER TREATMENT POTENTIAL: A REVIEW

Alfred N. Jones

(Department of Civil and Water Resources Engineering, Faculty of Engineering, University of Maiduguri, P.M.B 1069, Maiduguri, Nigeria

**Corresponding Author: alfred_ndahi@yahoo.com*

ARTICLE INFORMATION

Submitted 28 March, 2018

Revised 15 December, 2018

Accepted 19 December, 2018

Keywords:
Natural extracts
water treatment
Coagulation
Seed
protein

ABSTRACT

Chemical coagulants and flocculants have been used for decades in water treatment. However, because of cost issues associated with the entailment of importation importing of these chemicals, developing countries were left with no other option than to rely on contaminated water for their domestic consumptions. In view of this, some communities used their ingenuity and successfully employed natural plant and animal products to purify their water supply. In many instances, these products were found to achieve comparable water quality results to that of the conventional chemicals. The aim of this study was to evaluate some of the different plant genera that have been tested in water treatment. Their advantages and setbacks are highlighted. Most notably, some of these natural extracts performed double functions as a coagulant and as disinfectant. Conversely, several research works have pointed out that the main drawback of using natural extract in water treatment is the addition of organic compounds in the treated water which makes it unfit for human consumption due to change in taste, color, and odor. This drawback was, however, overcome in some studies where the materials were purified to obtain only the coagulant compounds. Therefore, the use of natural extracts in drinking water treatment would bring relief to many inhabitants in developing countries in terms of access to clean drinking water. Additionally, the study recommends further investigation into disinfecting the treated water with chlorine to assess their disinfectant by-products (DBPs) formation.

1.0 Introduction

The growing concern about clean water supply in developing countries has triggered innovative research to find potential alternatives to chemicals used in conventional water treatment (Jahn, 1986; Diaz et al. 1999; Zhang et al. 2006). Water treatment in any part of the world seeks to provide the population with clean and safe drinking water, devoid of pathogens (Hyung and Kim, 2009). Access to safe drinking water improves productivity, health and wealth (UN, 2016). However, this life sustaining commodity is inaccessible in many communities across the globe. To tackle this challenge, the World Health Organisation (WHO) formulated a programme to alleviate drinking water supply problems worldwide through the millennium development goals (MDGs), which stipulated the halving of the population without access to clean drinking water by the year 2015 (WHO, 2000). To date, over 663 million inhabitants in developing countries, most of who live in rural areas still lack access to safe and improved drinking water (JMP, 2013, WHO, 2015). Furthermore, the major problems associated with poor access to clean water are exacerbated by economic deprivation and social incapacitation of many of the affected countries, rendering them unable to afford conventional methods of water treatment. In the year 2015, 91% of the world population, approximately 6.6 billion used improved drinking water compared with 82% in 2000 (UN, 2016). However, despite the progress made in water supply in all region of the world, coverage was low in Sub-Saharan Africa and Oceania (UN, 2016). Moreover, not all improved drinking water were properly managed and treated to make it clean because at least 1.8 billion people were exposed to drinking water contaminated with faecal bacteria (UN, 2016). In order to sustain the current effort on water supply, the United Nation came up with 17 goals, tagged Sustainable Development Goals (SDG) to sustain and build upon the progress made by the MDGs by the year 2030. One of the key aspects of the SDG is the implementation of the Integrated Water Resource Management (IWRM) following the MDG goal 6 to half the population without clean drinking water by 2015 (UN, 2016). The 2030 SDG agenda (for goal 6) recognizes the importance of clean drinking water in bringing development in other areas such as health, education and poverty reduction (UN, 2016). Additionally, the SDG is to address the water management cycle holistically with more countries facing the challenge of being below the 25% threshold, which is the first stages of water stress (UN, 2016). To effectively manage the water crises, there is a need for innovative point-of-use (POU) water treatment in developing countries (Ghebremichael, et al. 2006). POU is the most cost-effective and straightforward water treatment technology adopted in ancient civilization by employing natural extracts (Bodlund et al. 2014). The use of natural extracts of plant origin in water treatment dates back to over 4000 years (Kansal and Kumari, 2014) and as far back as to Sanskrit writings where certain natural derivatives were used in water treatment. It is also on record in the Old Testament and Roman archives that the use of natural extracts dates back to 77 AD (Dorea, 2006). Naturally-occurring materials consist of both animal and plant-based resources. For instance, roasted seed powders of maize (Zea-mays) and Nirmali were used to treat water by Peruvian soldiers as well as in some Indian communities (Kansal and Kumari, 2014). In Sudan, rural women used Moringa oleifera (MO) seed extract to treat their drinking water supply (Jahn and Dirar, 1979, Jahn, 1986). Therefore, the aim of this paper was to review some of the natural plant extracts that have been investigated for their viability in addressing the problem of access to clean water supply in developing countries. This review is based on the application of natural plant-based materials in water treatment. The main reason for excluding animal-based materials is, however, based on their applicability, since they are unlikely to be used for mass production due to limited availability.

2. Coagulation and flocculation mechanisms

Coagulation and flocculation are considered to be the principle behind the treatment of both water and wastewater in most conventional plants (Gregory, 2005). Coagulation is simply the process of destabilizing the particles by introducing metal salts to chemically change the colloidal particles, such that the charge maintaining their stability in the water is overcome by charge neutralization where the aggregate are smaller and becomes bigger by agglomeration and are denser (Gregory, 2005). Coagulation mechanism is measured by the rate of destabilization of the colloidal particles in water. The coagulation process is the first step in a conventional water treatment which is achieved through destabilization and precipitation mechanisms, such as surface charge modification, double-layer compression, absorption and particle bridging (Duan and Gregory, 2003, Gregory, 2009). Flocculation, on the other hand, is a slow mixing process (i.e. orthokinetic aggregation) used after the particles are coagulated. Flocculation process brings together (bridging) the destabilized smaller, micro-flocs resulting from coagulation into contact with one another to form larger macro-flocs (Klimpel and Hogg, 1986). Flocculation step is crucial and is measured by the rate of collision efficiency between particles which do not settle and are thus difficult to remove by sedimentation. Floc formation depends on the collision efficiency (α) between the particles (Gregory, 2005) where the intensity of mixing is reduced to achieve optimum performance. The five (5) natural extracts reviewed in this study used in water treatment are as follows:

2.1 Moringa oleifera (MO) seeds

MO is a tropical plant species which belongs to the family known as Moringaceae. MO is referred to as a multipurpose or multifunctional plant because most of its parts have been found to be very useful, for instance, it is used in folk medicine and as a primary source of food (Fuglie, 2001). The leaves, stem, roots, shell, seed oil and protein are used in a variety of applications such as a vegetable in soup, cure of diabetes and lowering of blood pressure in patients, cooking oil and in the preparation of morning coffee. As such, it is often referred to as being a 'miracle tree' (Fuglie, 2001). MO contains high mineral and protein content and is recommended to be used to fight malnutrition in developing countries (Ghebremichael, 2004). It is resistant to drought and is found in abundance in most regions of Africa and Asia. It is thought of being native to Asian countries and Africa and grows within one year of planting. Many people have used MO leaves as a source of vegetable in Asia and Africa because of its nutritional values (Morton, 1991). MO seed oil has been used as machine lubricant and in the cosmetic industry (Ghebremichael, 2004). Figure 1 shows some seed of MO

Figure 1 shows some seeds, leaves and stem of Moringa oleifera

The plant is the most studied natural material in water treatment to date (Jahn, 1986). Jahn and Dirar (1979) conducted the first study using MO water extract in Sudan as was being prepared by the people for the removal of turbidity from the Nile River. Significant turbidity removal was reported compared to that obtain with ash which was also used in many villages in Sudan. In addition, having seen the potential of MO as a coagulant in water treatment, Jahn (1986) further studied the quality of water produced using MO water extract. The study observed a change in taste and colour of the water treated using the extract and also noted an odour is emanating from the water after 48-hour post treatment. To address the issue of deterioration in water quality, Jahn (1986) recommended that water treated using MO extract to be consumed within 24 hour treatment. Following these studies, Ndabigengesere et al. (1995) characterized the active coagulant compound in MO seed using different techniques such as lyophilisation, dialysis, ultrafiltration, chemical precipitation and electrophoresis. Interestingly, it was observed that the active agents in MO extract are proteins with a molecular weight of 13kDa and isoelectric point (IEP) of 10 and 11 (Ghebremichael et al. 2005).

Furthermore, the result of zeta potential measurement of MO extract suspension showed that it is a cationic polyelectrolyte with surface charge of (+6 mV) and its coagulation mechanism was

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

reported to be by adsorption and charge neutralization (Ndabigengesere et al. 1995). In contrast, Okuda et al. (1999), Okuda et al. (2001a) and Okuda et al. (2001b) improved the extraction process using NaCl concentration and purified the seeds by dialysis, de-lipidation and ion exchange. Overall, the studies showed improved coagulation performance of MO using the salt extract to water extract (in terms of turbidity removal), and the coagulation mechanism was said to be neither by double-layer compression, interparticle bridging nor by charge neutralization but by enmeshment of particles (Okuda et al. 2001a). Okuda et al. (2001b) also argued that protein analysis by Lowry and Bio-Rad methods after dialysis showed negative results and the polysaccharide concentration analysis also showed zero concentration. Similarly, it was clear that there was no more lipid after the extraction step. Thus, it is arguable that MO salt extract is neither a protein, polysaccharide nor lipid, but a polyelectrolyte having single molecular weight (MW) band as small as three kilo Dalton (3kDa). Conversely, Gassenschmidt et al. (1995) identified the MW of the purified MO protein in ion exchange column (IEC) as also consisting of dimeric MW bands of 6.5 and 14 kDa with isoelectric point (IEP) of 11 whereas Ghebremichael et al. (2005) found the MW of the purified MO protein on a cationic exchanger to be less than 6.5 kDa with IEP greater than 9.6. The slight variation in the protein band with MW around 6.5 kDa and IEP of (10 and 11, and >9.6) may be due to the different processing methods adopted to obtain MO protein. Interestingly, Ali et al. (2010) used a high-performance liquid chromatography method to identify the bioactive MW of the coagulant protein in MO seed. The result showed that MO protein has MW between 1 and 6.5kDa. Although, many studies (Jahn 1986; Ndabigengesere et al 1995; Ghebremichael et al. 2006) have accepted that the active agent in MO is a natural cationic protein showing charge neutralization as the main coagulation mechanism, except that of Okuda et al. (2001b) who revealed that the coagulating compound is not a cationic protein but a polyelectrolyte. Thus, the results reported by Okuda et al. (2001b) should be considered because there might be a coagulating agent in MO with such property.

An assessment of the quality of treated water by Ndabigengesere and Narasiah (1998a) using both dry shelled and non-shelled MO in a jar test experiment showed that the concentration of organic load in treated water increased significantly at higher dosage with no change in water pH, alkalinity and conductivity in treated water with small sludge volume production. These results were considered to be an advantage compared with the application of aluminium sulphate (AS) in water treatment. It is noteworthy that all the purified protein reported showed high coagulation performance in a jar test experiments compared with the crude samples under different laboratory conditions due to increased adsorption (Okuda et al., 2001b, Ghebremichael et al., 2005, Ghebremichael et al., 2006, Sanchez-Martin et al., 2010, Ali et al., 2010). The studies also indicated that the issue of organic nutrients addition in treated water was eliminated and showing dissolved organic carbon (DOC) removal in water and the pH remained unaffected. Similarly, both Muyibi et al. (2002) and Pritchard et al. (2009) used MO seed obtain from Nigeria and Malawi in treating turbidity in pond water in Kano-Nigeria and in a shallow well in Malawi which achieved between 92 – 99% turbidity removals. The findings from these studies showed no significant variation in MO extracts performance in respective to region.

Muyibi and Evison (1995a) and Muyibi and Evison (1995b) optimized physical parameters in kaolin water and also investigated the softening potential of hardness in waters using MO extracted with de-ionise (DI) in synthetic water spiked with calcium chloride, naturally hard surface water and groundwater in Newcastle Upon Tyne. The results observed higher coagulant dose demand in high turbidity water with increased rapid and slow mix velocity gradient and time compared with optimization of low turbidity water. Similarly, in the case of hard water, it was observed that calcium hardness softened faster with an increased in MO dosage while pH showed no effect on hardness removal. In addition, a reduction of over 27% in alkalinity of the groundwater was observed, thus presenting another advantage in using MO over AS as a coagulant. In synthetic wastewater treatment, Ndabigengesere and Narasiah (1998b) showed excellent removal of lead from contaminated synthetic water using shelled and unshelled MO extracts due to the formation of natural organic matter (NOM) complexes with lead. The performance of the stored MO extracts and raw seed in low medium and high turbidity water (50, 100-200 and 200-300 NTU) were assessed by Katayon et al. (2004) who stored MO extract suspension at room temperature of 3 and 28 °C for 1, 3, 5 and 7 days and Katayon et al. (2006) who again stored the raw seeds at 3 and 28 °C for between 3 and 5 months respectively. Maximum turbidity removal of 92.3% was observed in 300 NTU compared with between 73-86% in the (50-100 NTU) water using sample which had been stored for one day while maximum performance of 14 and 3% was recorded with crude extract stored for 5 and 7 days respectively. In addition, performance decreased with storage where seeds which had been stored for 1 month out performed those stored for up to 5 months in high turbidity water. Interestingly, the efficiency of MO seed was found to be independent of temperature condition.

Aside its turbidity removal potential, Madsen et al. (1987) investigated the traditional method of water purification in Sudanese village at 30 °C using MO extract to remove turbidity, faecal coliform and other enteric bacteria. A turbidity reduction of between 80-99% was observed with a 1-4 Log removal of bacteria. After 24-h post treatment, a regrowth of secondary bacteria such as Salmonella typhimurium, Shigellasonnei and E-coli were witnessed whereas Vibrio cholerae, Streptococcus faecalis and Clostridium perfringens remain totally inhibited. Later, Ndabigengesere and Narasiah (1998b) investigated the efficacy of shelled and non-shelled MO seed, and AS in treating two samples each from municipal and industrial waste water from Magog Canada. Both shelled, non-shelled and AS application resulted in considerable reduction in total coliform count from 35000 to 3000 for total coliform and 21000 to 1800 for faecal coliform per 100 ml. However, after resuspension of the sludge, a regrowth of both total and faecal coliform was witnessed, suggesting that the microorganisms were not inactivated but lived in the sludge. Hence, the claim that MO extract could inactivate pathogen in water by some authors is not in agreement with this study. Conversely, Ghebremichael et al. (2005) reported an antimicrobial activity of 1.1-4 Log removal of E-coli (D31 and K12) and B. thuringiensis (Bt7, Bt75) and P. aeruginosawhen purified MO protein was obtain on an IEC. Furthermore, some studies have shown that the coagulation compound in MO extract is a water-soluble protein capable of removing total coliform and E-coli in natural pond water (Anwar et al., 2007, Pritchard et al., 2010). Recently, da Conceicao et al. (2015) used MO DI water extract to obtain a result that was compliant with Brazilian drinking water standards in fluoride-polluted groundwater. The importance of MO was further demonstrated by Petersen et al. (2016) who showed the potential of MO extract to successfully eliminate Cryptosporidium parvum oocysts in waste water intended for irrigation farming.

As reported in the preceding sections, the main setback of using MO extracts is the continuous increase organic compounds into the treated water (Okuda et al., 2001b, Ghebremichael et al., 2006, Marobhe et al., 2007) leading to a change in colour, taste and odour. Following this setback, purification of crude MO seed to address this change yielded positive results where only the coagulant MO protein was obtained (Ghebremichael et al., 2006, Ali et al., 2010, Sanchez-

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

Martin et al., 2010). Interestingly, the two-step purification of MO proteins using 0.3 and 0.6 M NaCl concentrations significantly reduced residual DOC in treated water (Sanchez-Martin et al., 2010). This is advantageous because any issue related to disinfection by-product (DBP) formation would have been taken care of if the final water is recommended to be disinfected using chlorine. In contrast, there are limited studies on the application of MO extract in waste water treatment and sludge dewatering ability. Assessment of possible DBP formation should be done to understand if MO could release natural organic compounds that could exacerbate this challenge.

2.2 Cactus Mucilage

Cactus is an indigenous plant grown in many arid and semiarid regions of the world (Sáenz et al., 2004) and is a member of Cactaceae family as shown in Figure 2 with many species in Central America (Shilpaa et al., 2012). The Opuntia species is well-known as a primary source of mucilage substances similar to that of Okra (OK) (Sáenz et al., 2004, Miller et al., 2008). The mucilage contains compounds such as L-rhamnose, D-galactose, L-arabinose, D-galactose and some other compounds such as galacturonic acid (Sáenz et al., 2004, Yin, 2010). Cactus is also medicinal and has been used in the treatment of several ailments by native herbalists (Yin, 2010).

Figure 2 A Cactus pad prickly pear type used as coagulant. (Source: Alamy stock photo site)

Because of the presence of water-soluble mucilage in Cactus latifaria pad, Diaz et al. (1999) prepared 5% w/v suspension in water which was initially extracted with methanol to remove the polar substances in the cactus pad. The jar test results conducted on 20 – 200 NTU synthetic water show that in all the turbid water tested, between 10–20 mg/l dose was the optimum to achieve residual turbidity of less than 10 NTU. Furthermore, Diaz et al. (1999) compared and observed the performance of Cactus latifaria in water treatment with that of AS and MO to be similar although the required dose of AS was higher, yet turbidity removal efficiency was the same. In addition, the methanol-treated solid from Cactus latifaria was tested for coagulation which did not show any difference with the non-treated solids, thus indicating the use of solvent to remove polar substances could only incur additional cost and offer no advantage in terms of performance. Cactus latifaria contain about 11.6% protein (Diaz et al., 1999). Furthermore, Zhang et al. (2006) used water extract of Cactus Opuntia species in a jar test experiment to test for turbidity, alkalinity and effect of change in pH of the water on its performance. Turbidity removal was 94% in 200 NTU water using an optimum dose of 50 mg/l higher than that reported by (Diaz et al., 1999). However, at optimum pH (pH at which maximum turbidity removal was achieved) of 10, Zhang et al. (2006) demonstrated low performance of Cactus Opuntia in 10°C than in 35°C water although the difference was not much. The effect of turbidity removal on alkalinity in water treated with Cactus Opuntia also showed increase in turbidity removal resulted in increased final water alkalinity and Zhang et al. (2006) suggested that the presence of some ions in the sample affected the coagulation process. However, this study indicated that the performance of Cactus Opuntia species was similar to that of AS and MO extract in water treatment (Zhang et al., 2006) but the impact of ions in the sample need a serious evaluation.

Further study was conducted by Miller et al. (2008) using Cactus Opuntia species in kaolin suspension at pH of 10. Turbidity removal was reported to be 98% in 162－200 NTU water ranges (Miller et al., 2008). Although Opuntia spp.is ananionic compound with iso-electric point (IEP) of 2, the coagulation mechanism is mainly by adsorption and bridging as observed from the microscopic image of flocs formed and zeta potential measurement (Miller et al., 2008). Furthermore, these studies indicated that the mucilaginous substance obtained from Cactus (Opuntia and latifaria) is a strong water treatment candidate (Diaz et al., 1999, Miller et al., 2008, Yin, 2010, Zhang et al., 2006). The presence of galacturonic acid and protein in the cactus pad was found to be responsible for the coagulation process which achieved significant turbidity removal in water (Diaz et al., 1999, Miller et al., 2008). In the tropics, Cactus plant could be a useful alternative to the traditional coagulant currently in use. Shilpaa et al. (2012) also evaluated the potential of powder Opuntia ficus indica in a jar test experiment using synthetic water. At 20 mg/l, Cactus Opuntia mucilage reduced the turbidity from 500 to 1.3 NTU, approximately 99.8% reduction. In waste water treatment, Nharingo et al. (2015) revealed that Cactus fiscus indica water extract contains a bio-flocculent capable which removed 100 % of Pb and 85.74 % of zinc (Zn) in a waste water sample. In addition, Cactus extract achieved 84.16 % removal of Cd and 93.02 % of copper (Cu) in Zimbabwean River (Nharingo et al., 2015).

Overall, all the studies indicated the water treatment potential of Cactus plant species at smaller coagulant dosage compared with AS and other natural coagulants. Investigation of its toxic effect has not been conducted as it is not a primary source of food. Thus its application in drinking water needs to be carefully evaluated. Also, there has not been any detailed study regarding the effect of natural organic matter (NOM) addition and the application of its purified form in water treatment processes, this also needs further evaluation.

2.3 Nirmali extract

The plant Nirmali (Strychnos potatorum), Linn, is a plant belonging to the Loganiaceae family as shown in Figure 3 (Jayaram et al., 2009). Nirmali seed extract is used extensively in folk medicine in many parts of India and Sri Lanka (Jayaram et al., 2009). Literature has shown that the first ground seed powder was investigated as water treatment coagulant by Sen and Bulusu (1962) who attributed the removal of turbidity due to the presence of an anionic polyelectrolytes and protein.

Figure 3 some seeds of Nirmali used in water treatment (Source: Alamy stock photo site)

Similarly, Tripathi et al. (1976) observed that the coagulation potential of Nirmali seed extract was due to the presence of carbohydrates and alkaloids having a －COOH－ group with free OH－ which significantly improved its turbidity removal performance. Adinolfi et al. (1994) also investigated the combination of polysaccharide and galactan extracts from the ground powder of Nirmali seed to achieve a turbidity removal of 80% in synthetic kaolin water. In addition, Raghuwanshi et al. (2002) conducted some analysis on 20 agro-based coagulants and observed that with 3 mg/l dose of Nirmali seed extract as a coagulant aid in combination with AS, the dosage of AS was reduced from 45 mg/l to 25 mg/L, achieving residual turbidity of less than 0.2

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

NTU. The volume of sludge produced after the experiment was found to be 40% lower compared with the volume of sludge produced using AS as a primary coagulant. Similarly, Sowmeyan et al. (2011) had shown that 80% of the turbidity in 32 NTU water was removed using Nirmali seed extract. It is clear from these results that Nirmali seed possesses some water treatment potential even though the number of studies conducted so far is limited to turbidity removal and sludge volume production.

However, further study was conducted by Jayaram et al. (2009) who evaluated the use of the Nirmali seed powder for the removal of heavy metal waste water using a batch mode adsorption experiments at varying pH and contact time. The study observed that the removal of Pb was highly affected by pH, contact time, biomass dose and metal concentration and its adsorption ability was 16.4 mg/g. The Fourier transform infrared (FTIR) spectroscopy analysis showed the adsorption process of the extract was due to the presence of many functional groups (Jayaram et al., 2009). It is noteworthy that at present there is little information with regard to NOM addition and the effect of OH groups along galactomannan and that of galactan chains which were said to ultimately lead to abundant adsorption sites for interparticle bridging (Yin, 2010) using Nirmali extract.

2.4 Common bean seed

Common bean belongs to the genus and species of *(Phaseolus vulgaris)* Figure 4. It is a good source of protein and carbohydrate and highly consumed in Latin American and African countries (de Almeida Costa et al., 2006). The protein contents in raw and freeze-dried cooked Common bean sample was reported to be between 20.9 and 22.1% whereas the carbohydrate component is 54.3 and 59.9% respectively (de Almeida Costa et al., 2006).

Figure 4 Some seeds of Common bean used as coagulant in water treatment. (Source: Alamy stock photo site)

Similarly, Sciban et al. (2006) had shown that the protein content in Common bean seed is between 20 and 30% while Gunaratna et al. (2007) and Marobhe et al. (2007) identified the protein compounds to be cationic after purification on a cationic IEC, which is capable of removing turbidity in water. Common bean extract have low sugar contents, phenolic and phytic acid and the IEP was obtained by measuring the zeta potential at varying pH and the point with zero zeta potential (i.e. pH 3.61) regarded as its IEP (Kukić et al., 2011). An important analysis by SDS-PAGE was conducted by Montoya et al. (2008) on the coagulant protein from Common bean to identify its MW. The MW was then identified as being a dimeric protein with MW of approximately 20 and 50 kDa. In contrast, Morales - de León et al. (2007) observed in a separate SDS-PAGE analysis that the IEP is 4.5 and two MW proteins present in Common bean are 26 and 49 kDa. It is notable, however, that both the IEP and MW of Common bean seed are different from that of MO seed and may likely present some unique activities. However, similar assessment was made on the concentration of protein in Common bean seed by Antov et al. (2010) who observed an equivalent concentration of 0.51 mg/ml in the seed, and this support the fact that Common bean is a popular food amongst the Brazilian population for a long time (de Almeida Costa et al., 2006). The presence of high protein contents in Common bean has resulted in innovative researches into the coagulation potential of its extract because several studies using natural extracts indicated protein as a coagulant compound (Ndabigengesere et al., 1995, Ghebremichael et al., 2006, Bodlund et al., 2014).

Common been has been investigated for its suitability in water treatment by Sciban et al. (2005) who reported higher turbidity removal of the extract at pH above 10 and in low turbidity water of 18 NTU. However, this result is not in agreement with previous studies who observed poor performance of natural extracts in low turbidity water (Ndabigengesere et al., 1995; Katayon et al., 2006). This is a useful property that gives it a unique advantage over other extracts. However, considering the impact of NOM in treated water, Sciban et al. (2006) and Antov et al. (2010) performed partial purification of the protein using ammonium sulphate, desalting, dialysis and ion exchange (IEX) and elution with sodium chloride (NaCl) solution. The results showed a good turbidity removal efficiency of 72.3% in 35 NTU water which was 22 times higher than the performance of the crude DI water extract at a dose of 0.73 mg/l. Similarly, the purified sample produced organic matter concentration of 0.35 compared with 5.9 mg of crude extract treated water from 2.3 mg/l. This finding agrees with the results obtained by some authors who using MO extracts (Gassenschmidt et al., 1995, Ghebremichael et al., 2005, Sanchez-Martin et al., 2012) who observed greater adsorption ability and reduced NOM in treated water. Additionally, the purification of Common bean did not require lipid extraction because it does not have lipid which is advantageous. The challenge of possible floc formation being inhibited through surface coating as indicated with other extracts is also eliminated in Common bean (Ali et al., 2010). Sciban et al. (2006) further observed that, precipitation and desalting by dialysis of the samples eluted with 0.5, 1.0, 1.5 and 2.0 M NaCl solutions presented different coagulation mechanisms. Such observation suggests that there may be different protein in the various fractions with varying coagulation potential. Identification and characterisation of these proteins would give a clearer understanding of fraction with higher activity. With an average of 50 grams of the extract, 20 L of turbid water was treated, achieving 90% turbidity removal. However, coagulant protein from common bean obtained by ultrafiltration of the crudes extract produced lower turbidity removal of 49% compared with 51% achieved with the crude sample (Antov et al., 2012). In terms of extraction time, Kukić et al. (2011) reported that 10 min is sufficient to extract coagulant protein from Common bean compared with 3hrs using a magnetic stirrer which would save time used in processing the extract.

Beside the coagulation ability of the Common bean species, the antimicrobial compounds in the seed has been reported elsewhere (Amarowicz et al., 2008). Tannin extracted from Common bean was compared with a conventional drug, streptomycin in bacterial inhibition. The minimum inhibitory concentration (MIC) of bacteria with tannin were 125 μg/ml for Listeria monocytogenes, Salmonella Typhimurium and Lactobacillus plantarum while streptomycin achieved only 31.3 and 7.8 μg/ml MIC for Salmonella Typhimurium and Lactobacillus plantarum respectively (Amarowicz et al., 2008).

2.5 Luffa cylindrica extract

Luffa cylindrica is a member of (Cucurbitaceouse) family which is in abundance in many tropical countries Figure 5, such as Asia, Africa and the United State (Partap et al., 2012). It is spongy and commonly called sponge gourd, mainly used by local people in washing their body and cleaning of cooking utensils. Luffa cylindrical has a cellulose structure which is negatively charged when in

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

contact with water (Shahidi et al., 2015a). The immature fruit is eaten raw as it contains compounds such as lavonoids and ribosome-inactivation protein (RIP) used in traditional medicine (Anbukarasi and Kalaiselvam, 2015).

Figure 5 A bunch of Luffa cylindrica used in water treatment. (Source: Alamy stock photo site)

Similarly, Bhattarai (1989) has reported that one of the most used natural extract among Nepal population is the seed of luffa cylindrical. In addition, the importance of luffa cylindrical has been reported in a study by Ruiz-Marín et al. (2009) who investigated the removal of nutrients and organic matter in a bioreactor supported with Luffa cylindrical fibre. The results showed that Luffa cylindrical improved biofilm development as a support material. It recorded a significant removal of biochemical oxygen demand of 92.5% compared with 80% obtained with PVC as a support material (Ruiz-Marín et al., 2009). The study further observed that, in the final effluent the mean ammonia nitrogen concentration was 17 mg/l for Luffa cylindrical and 19 mg/l for PVC support respectively (Ruiz-Marín et al., 2009). Though, the study of luffa cylindrical is new, one of the first known optimization study using a jar test apparatus was conducted by Sowmeyan et al. (2011) on different natural extracts including luffa cylindrical and AS as primary coagulants. While several authors followed through aqueous extracting processes by washing using tap water, Sowmeyan et al. (2011) used formaldehyde for the washing of the seeds. The reason for using this chemical instead of water is because it is efficient in the washing and cleaning of dust and debris on any substance. Interestingly, Luffa cylindrical achieved maximum turbidity and hardness removal of approximately 86 and 40% respectively. However, a reaction between the extract and chloride in water causes a reduction of up to 7.6% in chloride concentration at optimum dose of 8g/l of the extract (Sowmeyan et al., 2011). Thus, the application of luffa cylindrica in water treatment may pose some challenges if chlorine is used as disinfectant because it will consume the available residual chlorine in the treated water. Additionally, as with the other natural coagulants, Luffa cylindrical also achieved 60% removal of total dissolved solid (TDS) in water treatment (Sowmeyan et al., 2011).

Furthermore, the anionic nature of Luffa cylindrical made it an active extract for the removal of cationic metals in waste water (Anbukarasi and Kalaiselvam, 2015) in the form of Luffa fibre. Anbukarasi and Kalaiselvam (2015) investigated the water adsorption potential of composite particle fibre and showed a significant performance than the non-treated sample which can be used in damp site. In a very important test in water purification, Shahidi et al. (2015b) performed some batch adsorption tests using Luffa cylindrica fibre as a natural adsorbent for the removal of Cadmium (Cd) (II). The results indicated that a high possibility of using Luffa for the removal of Cd (II) in water with adsorption capacity of 6.7 mg/g. However, cadmium removal was observed to be highly dependent on solution pH, dosage and Cd (II) concentration.

Because of the presence of antioxidants such as saponin, RIP, phenolic compounds etc. direct application of Luffa cylindrical extracts against E-coli and many other bacteria is reported elsewhere (Oyetayo et al., 2007). Shaheed et al. (2009) evaluated the potential of luffa cylindrica fruit and seed between 40 and 333g/l as a disinfectant against total and faecal coliform in water treatment using a contact time from 15-180 min. The results showed that the inhibition of the two indicator organisms was variable and dose dependent with a maximum performance of 86% at 180 min for faecal bacteria. Although the overall results revealed some disinfection ability in luffa plant, the performance did not achieve the WHO standard for drinking water quality. Similarly, the limited results conducted using the extract as a coagulant is not sufficient to judge its potential in water treatment which requires more studies.

3. Conclusion

Coagulation and flocculation are the first step in conventional water treatment. It is a major unit operation which is straightforward with regard to potable water production. Several natural extracts as reviewed contain coagulating compounds that could compete effectively with the inorganic ones. They have potential to be used as either primary coagulants or as coagulant aids in water treatment. In most cases, destabilisation of the colloidal particles in water was achieved or induced through charge neutralisation and bridging action resulting in low sludge volume. Interestingly, while many studies have been conducted to assess their turbidity and bacterial removal efficiency, production/processing of such products in commercial quantity are yet to commence. However, it is noteworthy that apart from MO, most of those plants presented have limited information although they have been tested in water treatment in one form or the other. Some of the few natural plant-based extracts that have been used in water treatment are at this moment presented: However, it is noteworthy that most research work used a batch test in a series of jar tester to evaluates their coagulation and flocculation performance.

Additionally, there is still the need to conduct some studies especially with regards to disinfection by-product (DBP) formation precursor. Possibility of its industrial application should also be encouraged further in order to provide local communities in developing countries with cheaper access to potable water supply. It is also important to characterise natural extract to properly understand the main agents responsible for coagulation by different naturally-occurring extracts.

References

Adinolfi, M., Corsaro, MM., Lanzetta, R., Parrilli, M., Folkard, G., Grant, W. and Sutherland, J. 1994. Composition of the coagulant polysaccharide fraction from Strychnos potatorum seeds. Carbohydrate Research, 263: 103-110.

Ali, EN., Muyibi, SA., Salleh, HM., Alam, MZ. and Salleh, MRM. 2010. Production of Natural Coagulant from Moringa Oleifera Seed for Application in Treatment of Low Turbidity Water. Journal of Water Resource and Protection, 2: 259-266.

Amarowicz, R., Dykes, GA. and Pegg, RB. 2008. Antibacterial activity of tannin from Phaseolus vulgaris, Fagoypyrum esculentum, Corylus avellana and Juglans 79: 217-219.

Anbukarasi, K. and Kalaiselvam, S. 2015. Study of effect of fibre volume and dimension on mechanical, thermal, and water absorption behaviour of luffa reinforced epoxy composites. Materials and Design (1980-2015), 66, Part A: 321-330.

Antov, MG., Ciban, MB. and Petrovic, NJ. 2010. Proteins from common bean (Phaseolus vulgaris) seed as a natural coagulant for potential application in water turbidity removal. Bioresource Technology, 101: 2167-2172.

Antov, MG., Ciban, MB. and Prodanovic, JM. 2012. Evaluation of the efficiency of natural coagulant obtained by ultrafiltration of common bean seed extract in water turbidity removal. Ecological Engineering, 49: 48-52.

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

Anwar, F., Latif, S., Ashraf, M. and Gilani, AH. 2007. Moringa oleifera: a food plant with multiple medicinal uses. Phytotherapy research, 21: 17-25.

Bhattarai, K. 1989. Tapping water in ancient times. Water Nepal, 3: 1-10.

Bodlund, I., Pavankumar, AR., Chelliah, R., Kasi, S., Sankaran, K. and Rajarao, GK. 2014. Coagulant proteins identified in Mustard: A potential water treatment agent. International Journal of Environmental Science and Technology, 11: 873-880.

Da Conceicao, VM., Ambrosio UGRI, MCB., Silveira, C., Nishi, L., Vieira, MF., De Jesus Bassetti, F., Vieira, AMS. and Bergamasco, R. 2015. Removal of excess fluoride from groundwater using natural coagulant Moringa oleifera Lam and microfiltration. Canadian Journal of Chemical Engineering, 93: 37-45.

De almeida Costa, GE., Da silva Queiroz-Monici, K., Pissini Machado Reis, SM. and De oliveira, AC. 2006. Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea, common bean, chickpea and lentil legumes. Food Chemistry, 94: 327-330.

Diaz, A., Rincon, N., Escorihuela, A., Fernandez, N., Chacin, E. and Forster, CF. 1999. A preliminary evaluation of turbidity removal by natural coagulants indigenous to Venezuela. Process Biochemistry, 35: 391-395.

Dorea, C. 2006. Use of Moringa spp. seeds for coagulation: a review of a sustainable option. Water Science and Technology: Water Supply, 6: 219-227.

Duan, J. and Gregory, J. 2003. Coagulation by hydrolysing metal salts. Advances in colloid and interface science, 100: 475-502.

Fuglie, L. J. 2001. The miracle tree: The multiple attributes of moringa, Church World Service, West Africa Regional Office, Dakar. 68 pp. Senegal.

Gassenschmidt, U., Jany, KD., Bernhard, T. and Niebergall, H. 1995. Isolation and characterization of a flocculating protein from Moringa oleifera Lam. Biochimica et Biophysica Acta (BBA)-General Subjects, 1243: 477-481.

Ghebremichael, KA. 2004. Moringa seed and pumice as alternative natural materials for drinking water treatment, Ph.D Thesis Unpublished, Royal Institute of Technology (KTH), Stockholm, Sweden.

Ghebremichael, KA., Gunaratna, KR. and Dalhammar, G. 2006. Single-step ion exchange purification of the coagulant protein from Moringa oleifera seed. Applied Microbiology and Biotechnology, 70: 526-532.

Ghebremichael, KA., Gunaratna, KR., Henriksson, H., Brumer, H. and Dalhammar, G. 2005. A simple purification and activity assay of the coagulant protein from Moringa oleifera seed. Water Research, 39: 2338-2344.

Gregory, J. 2005. Particles in water: properties and processes, CRC Press, Taylor and Francis Group, IWA Publishing, London. pp. 1-179.

Gregory, J. 2009. Monitoring particle aggregation processes. Adv Colloid Interface Sci, 147-148: 109-23.

Gunaratna, K., Garcia, B., Andersson, S. and Dalhammar, G. 2007. Screening and evaluation of natural coagulants for water treatment. Water science and technology: water supply, 7: 19-25.

Jahn, SAA. 1986. Proper use of African natural coagulants for rural water supplies. Research in the Sudan and a guide for new projects. GTZ, 541 P, Eschborn.

Jahn, SAA. and Dirar, H. 1979. Studies on natural water coagulants in the Sudan, with special reference to Moringa oleifera seeds. Water Sa, 5: 90-97.

Jayaram, K., Murthy, I., Lalhruaitluanga, H. and Prasad, M. 2009. Biosorption of lead from aqueous solution by seed powder of Strychnos potatorum L. Colloids and surfaces B: Biointerfaces, 71: 248-254.

JMP, W. 2013. Progress on drinking water and sanitation: 2013 update. Tech. rep., WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, New York.

Kansal, SK. and Kumari, A. 2014. Potential of M. oleifera for the treatment of water and wastewater. Chem Rev, 114: 4993-5010.

Katayon, S., Megat Mohd Noor, MJ., Asma, M., Thamer, AM., Liew Abdullah, AG., Idris, A., Suleyman, AM., Aminuddin, MB. and Khor, BC. 2004. Effects of storage duration and temperature of Moringa oleifera stock solution on its performance in coagulation. International Journal of Engineering and Technology, 1: 146-151.

Katayon, S., Noor, MJM. M., Asma, M., Ghani, LAA., Thamer, AM., Azni, I., Ahmad, J., Khor, BCA. and Suleyman, AM. 2006. Effects of storage conditions of Moringa oleifera seeds on its performance in coagulation. Bioresource Technology, 97: 1455-1460.

Klimpel, R. and Hogg, R. 1986. Effects of flocculation conditions on agglomerate structure. Journal of colloid and Interface Science, 113: 121-131.

Kukić, DV., Šćiban, MB., Tepić, AN. and ProdanoviĆ, JM. 2011. Influence of the composition of common bean extracts on their coagulation ability. Acta Periodica Technologica (Serbia).

Madsen, M., Schlundt, J. and Omer, E. 1987. Effect of water coagulation by seeds of Moringa oleifera on bacterial concentrations. The Journal of tropical medicine and hygiene, 3: 101-9.

Marobhe, N., Dalhammar, G. and Gunaratna, K. 2007. Simple and rapid methods for purification and characterization of active coagulants from the seeds of Vigna unguiculata and Parkinsonia aculeata. Environmental technology, 28: 671-681.

Miller, SM., Fugate, EJ., Craver, VO., Smith, JA. and Zimmerman, JB. 2008. Toward understanding the efficacy and mechanism of Opuntia spp. as a natural coagulant for potential application in water treatment. Environmental science & technology, 42: 4274-4279.

Montoya, CA., Leterme, P., BEEBE, S., Souffrant, WB., Molle, D. and Lalles, JP. 2008.

Phaseolin type and heat treatment influence the biochemistry of protein digestion in the rat intestine. British journal of nutrition, 99: 531-539.

Morales ‐ De león, JC., Vázquez ‐ mata, N., Torres, N., Gil ‐ zenteno, L. and Bressani, R. 2007.

Preparation and characterization of protein isolate from fresh and hardened beans (Phaseolus vulgaris L.). Journal of food science, 72: C96-C102.

Morton, JF. 1991. The horseradish tree, Moringa pterygosperma (Moringaceae)—a boon to arid lands? Economic Botany, 45, 318-333.

Moturi, WK., Tole, MP. and Davies, TC. 2002. The contribution of drinking water towards dental fluorosis: a case study of Njoro Division, Nakuru District, Kenya. Environmental Geochemistry and Health, 24, 123-130.

Muyibi, SA. and Evison, LM. 1995a. Moringa oleifera seeds for softening hardwater. Water Research, 29: 1099-1104.

Muyibi, SA. and Evison, LM. 1995b. Optimizing physical parameters affecting coagulation of turbid water with Morninga oleifera seeds. Water Research, 29: 2689-2695.

Muyibi, SA., Mohd. Noor, MJM., Leong, TK. and Loon, LH. 2002. Effects of oil extraction from Moringa oleifera seeds on coagulation of turbid water. International journal of environmental studies, 59: 243-254.

Corresponding author's e-mail address: alfred_ndahi@yahoo.com

Ndabigengesere, A. and Narasiah, KS. 1998a. Quality of water treated by coagulation using Moringa oleifera seeds. Water Research, 32: 781-791.

Ndabigengesere, A. andnarasiah, KS. 1998b. Use of Moringa Oleifera Seeds as a Primary Coagulant in Wastewater Treatment. Environmental Technology, 19: 789-800.

Ndabigengesere, A., Narasiah, KS. and Talbot, BG. 1995. Active agents and mechanism of coagulation of turbid waters using Moringa oleifera. Water research, 29: 703-710.

Nharingo, T., Zivurawa, MT. and Guyo, U. 2015. Exploring the use of cactus Opuntia ficus indica in the biocoagulation–flocculation of Pb(II) ions from wastewaters. International Journal of Environmental Science and Technology, 12, 3791-3802.

Okuda, T., Baes, AU., Nishijima, W. and Okada, M. 1999. Improvement of extraction method of coagulation active components from Moringa oleifera seed. Water Research, 33, 3373-3378.

Okuda, T., Baes, AU., Nishijima, W. and Okada, M. 2001a. Coagulation mechanism of salt solution-extracted active component in Moringa oleifera seeds. Water Research, 35: 830-834.

Okuda, T., Baes, A. U., Nishijima, W. and Okada, M. 2001b. Isolation and characterization of coagulant extracted from Moringa oleifera seed by salt solution. Water Research, 35: 405-410.

Oyetayo, F., oyetayo, V. and Ajewole, V. 2007. Phytochemical profile and antibacterial properties of the seed and leaf of the Luffa plant (Luffa cylindrica). J. Pharmacol. Toxicol, 2: 586-89.

Partap, S., Kumar, A., Sharma, NK. and Jha, K. 2012. Luffa Cylindrica: An important medicinal plant. Journal of Natural Product and Plant Resources, 2.

Petersen, HH., Petersen, TB., Enemark, HL., Olsen, A. and Dalsgaard, A. 2016. Removal of Cryptosporidium parvum oocysts in low quality water using Moringa oleifera seed extract as coagulant. Food and Waterborne Parasitology, 3: 1-8.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, AS. and O'Neill, J. G. 2010. A comparison between Moringa oleifera and chemical coagulants in the purification of drinking water - An alternative sustainable solution for developing countries. Physics and Chemistry of the Earth, 35: 798-805.

Pritchard, M., Mkandawire, T., Edmondson, A., O'Neill, J. and Kululanga, G. 2009. Potential of using plant extracts for purification of shallow well water in Malawi. Physics and Chemistry of the Earth, Parts A/B/C, 34: 799-805.

Raghuwanshi, PK., Mandloi, M., Sharma, AJ., Malviya, HS. and Chaudhari, S. 2002. Improving filtrate quality using agrobased materials as coagulant aid. Water quality research journal of Canada, 37: 745-756.

Ruiz-marín, A., Campos-Garcia, S., Zavala-loría, J., Solana, F. and Canedo-lópez, Y. 2009. Assessment of Luffa cylindrica as Support in Biofilms Reactors for the Biological Treatment of Domestic Wastewater. Water, Air, and Soil Pollution, 199: 13-21.

Sáenz, C., Sepúlveda, E. and Matsuhiro, B. 2004. Opuntia spp mucilage's: a functional component with industrial perspectives. Journal of Arid Environments, 57: 275-290.

Sanchez-Martin, J., Ghebremichael, K. and Beltran-Heredia, J. 2010. Comparison of single-step and two-step purified coagulants from Moringa oleifera seed for turbidity and DOC removal. Bioresource Technology, 101: 6259-6261.

Sanchez-Martin, J., Beltran-Heredia, J. and Peres, JA. 2012. Improvement of the flocculation process in water treatment by using Moringa oleifera seeds extract. Brazilian Journal of Chemical Engineering, 29: 495-501.

Sciban, M., Antov, MG. and Klasnja, M. 2006. Extraction and partial purification of coagulation active components from common bean seed. Acta Periodica Technologica (Serbia), 41: 141-147.

Sciban, M., Klasnja, M. and Stojimirovic, JL. 2005. Investigation of coagulation activity of natural coagulants from seeds of different leguminose species. Acta Periodica Technologica (Serbia and Montenegro), 36: 81-87.

Sen, A. and Bulusu, K. 1962. Effectiveness of Nirmali seed as coagulant and coagulant aid. Env. Hlth, 4: 31-40.

Shaheed, A., Templeton, MR., Matthews, RL., Tripathi, SK. and Bhattarai, K. 2009. Disinfection of waterborne coliform bacteria using Luffa cylindrica fruit and seed extracts. Environ Technol, 30: 1435-40.

Shahidi, A., Jalilnejad, N. and Jalilnejad, E. 2015b. A study on adsorption of cadmium(II)ions from aqueous solution using Luffa cylindrica. Desalination and Water Treatment, 53: 3570-3579.

Shilpaa, B., Akankshaa, K. and Girish, P. 2012. Evaluation of cactus and hyacinth bean peels as natural coagulants. Int. J Chem. Environ Eng. 3(3): 187–191

Sowmeyan, R., Santhosh, J. and Latha, R. 2011. Effectiveness of herbs in community water treatment. International Research Journal of Biochemistry and Bioinformatics, 1: 297-303.

Tripathi, P., Chaudhuri, N. and Bokil, S. 1976. Nirmali seed a naturally occurring coagulant. Indian J. Environ. Health, 18 (4): 272-281.

United Nation UN, 2016. The Sustainable Development Goals Report 2016. United Nation, New York. pp. 1-56. http://unstats.un.org/sdgs Accessed 19/12/2016.

WHO, AU. 2000. United Nations Millennium Declaration: Resolution adopted by the General Assembly. 55/2. 18 September 2000. New York: USA.

WHO, U. 2015. Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment. Geneva: World Health Organization.

Yin, CY. 2010. Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochemistry, 45, 1437-1444.

Zhang, J., Zhang, F., Luo, Y. and Yang, H. 2006. A preliminary study on cactus as coagulant in water treatment. Process Biochemistry, 41: 730-733.

Stock photo site (2019). Photo presentation of Agricultural products.

https://shutterstock.com/stock-photo/moringa-oleifera: Accessed on 06/05/2019.

https//www.alamy.com/stock-photo/luffa-cylindrica: Accessed on 06/05/2019

https//www.alamy.com/stock-photo/common-bean: Accessed on 06/05/2019

https//www.alamy.com/stock-photo/cactus-pad: Accessed on 06/05/2019

https//www.alamy.com/stock-photo/nirmali-seed: Accessed on 06/05/2019

Corresponding author's e-mail address: alfred_ndahi@yahoo.com