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Valuation of oil extraction residue from *Moringa oleifera* seeds for water purification in Burkina Faso

B. Amante[a,*], V. López-Grimau[a], T. Smith[b]

[a]*UPC Barcelona-TECH, ETSEIAT, Colom, 11, 08222 Terrassa, Spain, Tel. +34 937398686; emails: beatriz.amante@upc.edu (B. Amante), victor.lopez-grimau@upc.edu (V. López-Grimau)*
[b]*Koom Consulting, Topete, 15, 08221 Terrassa, Spain, email: info@koomconsulting.org*

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ABSTRACT

This study is on the reuse of the residue generated by a *Moringa oleifera* oil extraction plant. The residual oil cake produced during the process of oil extraction retains the positively charged protein of the *M. oleifera* seed, which is the active component in the process of attracting and capturing suspended particles in waters. Such coagulant–flocculant properties give rise to the elimination of turbidity in the process of water purification. In the cases studied, it has been demonstrated that the same amount (100 mg/L) of aluminum sulfate coagulant and *M. oleifera* coagulant is required to reduce water turbidity to levels within the International guidelines (<5 NTU). A life cycle analysis (LCA) is also presented in which the coagulant obtained from *M. oleifera* is compared with conventional chemical coagulants. The energy consumption per kg of aluminum sulfate ($Al_2(SO_4)_3$) produced is almost 40% greater than *M. oleifera*-based coagulant. Furthermore, carbon dioxide (CO_2) emissions associated with alum are 80% higher than those of the *M. oleifera*-based coagulant. In addition to turbidity removal, with lower energy consumption and reduced CO_2 emissions, the coagulant derived from the residual oil cake does not provoke any alterations to water pH or conductivity and, therefore, does not require any additional readjustment of these parameters.

Keywords: Moringa oleifera; Natural coagulant; Turbidity removal; LCA

1. Introduction

The semi-arid climate of Burkina Faso (Western Africa) is prone to extreme seasonal variations, chaining long periods of drought with heavy rainfalls primarily between the months of May and October. Deficiencies in both water supply and quality, especially in rural areas, constitute the main cause of illness derived from intestinal parasites, with particularly high incidences in the infantile population.

In recent years, the local development entity BERACIL in Burkina Faso, in collaboration with the development council of Yako, has been leading an agro-economic development program in the municipality of Yako by way of the cultivation of the tropical tree, *Moringa oleifera* (known locally as Arzaan Tiiga or "Tree from Heaven" in the autochthonous language,

*Corresponding author.

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Mooré). The fibrous powder generated by grinding the seeds of *M. oleifera* can be used, among others applications, as a natural coagulant–flocculant in the phase of suspended solid elimination of conventional water purification processes [1–5]. This application is particularly relevant for surface waters such as freshwater reservoirs, which typically have turbidity levels significantly higher than groundwater extracted via perforated wells.

Currently, several pilot scale water treatment plants are already in operation in different locations in Africa, in which the extract of *M. oleifera* seeds is used as a coagulant. In 2010, a pilot plant with a treatment capacity of 10,000 l/d was started up in Zaria (Nigeria) to supply the Ahmadu Bello University [6]. Previously, in 2006, coagulation–flocculation tests were carried out using *M. oleifera* in the drinking water treatment plant of Ggaba II in Kampala (Uganda) [7]. Our previous studies were centered on the design of a plant designed to purify 10,000 l/d of reservoir water using *M. oleifera*, guaranteeing potable water access to 1,000 people in the location of Yako, Burkina Faso [8].

The study presented in this article represents an additional step forward in the scope of our research. This initiative was founded primarily on a greater understanding, the socioeconomic context of Burkina Faso, as well as an increased knowledge of the nutritional uses of *M. oleifera* seed powder (e.g. the use of its oil [9]). The residual oil cake produced during the process of *M. oleifera* oil extraction retains the positively charged protein of the seed which facilitates the process of capturing suspended particles in the water. Such coagulant–flocculant properties give rise to the removal of turbidity in the process of water purification. This study addresses, on the one hand, valuates the waste generated by *M. oleifera* oil extraction (“residual oil cake”) and, on the other hand, it assesses the use of the *M. oleifera* oil as a product.

This article presents the results of a study on the reuse of a *M. oleifera* oil extraction plant by-product as a coagulant. Additionally, and with the aim of demonstrating that the revaluation of waste is environmentally sustainable, in this article, a life cycle analysis (LCA) is also presented.

Assessment by analysis is a tool used to assess the potential environmental impacts and resources used throughout a product’s life cycle, i.e. from raw material acquisition, via production and use phases, to waste management [10]. Since its origin in the late 1960s [11], LCA has been widely used in many fields; environmental management, industrial manufacturing, military systems, and tourism, and by a wide array of entities; industries, governmental agencies, and other organizations, as a robust tool for assessing environmental impacts and resource depletion attributable to a specific product (goods or services). Over the past decades, LCA methodologies have been developed over time and are now encouraged by governments all over the world [12].

The LCA presented in this paper compares the natural coagulant obtained through the reuse of a natural oil cake from *M. oleifera* with a conventional chemical coagulant.

In developing countries, such conventional chemical coagulants are usually imported, entailing a high economic cost and dependence on third parties. Moreover, the sludge produced in wastewater treatment processes involving chemical coagulants must be treated, thus leading to an even greater overall financial and environmental cost. The use of local natural or organic coagulants minimizes costs and emissions, and consequently provides a higher quality product together with greater self-sufficiency, a factor of especially high importance for a developing country. The LCA results presented serve to measure and compare the differences in levels of consumption and emissions of kg CO_2 e. in these two scenarios.

The carbon dioxide (CO_2) is a potent greenhouse gas and plays a vital role in regulating the earth’s surface temperature through radiative forcing and the greenhouse effect. Greenhouse gas emissions, expressed as kg of CO_2 equivalent (kg CO_2 e.), are the most common environmental indicator [13]. Equivalent carbon dioxide (CO_2 e.) is describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of CO_2 as the reference.

2. Methods

For the development of the LCAs, a series of experiments were performed, primarily for the elimination of water turbidity. Suspended solids elimination tests were carried out with both the natural and chemical coagulants and measured using a turbidity meter. By way of such tests, the dosage of coagulant required to eliminate turbidity in the different samples was determined.

The dosage of coagulant applied was initially based on the studies carried out by [13–16], and comprised 25, 50, and 100 mg/L for turbidities between 30 and 150 NTU. Considering the 95% turbidity removal demonstrated in these studies, a concentration of 100 mg/L was initially selected as the most appropriate for carrying out the initial tests. As will be highlighted further on this study, analyses were also carried out using lower dosages, in order to determine the effect of adding sodium chloride (NaCl) to *M. oleifera* coagulant.

For the purposes of the LCA study, the 100 mg/L dosage was applied, given that, the lower concentrations of alum and *M. oleifera* (without NaCl added) did not comply with the international parameters. Moreover, the pH and conductivity of the samples were measured so as to be able to assess the variation of such parameters based on the coagulant used.

2.1. M. oleifera *oil extraction*

Dry *M. oleifera* seeds were supplied by the *Centre National de Semences Forestières* of Burkina Faso. Shells were removed manually and kernels were reduced to powder using a domestic grinder.

One gram of crushed *M. oleifera* seeds was fed into a Soxhlet extractor fitted with a 250-mL round-bottom flask and a condenser. The extraction was run for 2 h in triplicate ($n = 3$) with 100 mL of two different solvents: hexane and ethanol. After the extraction, the solvent was distilled off under vacuum in a rotary evaporator. The extracted oil yield is expressed as the percentage in weight (mean ± standard deviation). Oil yield extraction was higher for ethanol (36.1 ± 1.83%) than for hexane (24.6 ± 2.19%). The ethanol extraction yield is in accordance with results of other authors [17], whereas hexane only achieves a partial oil extraction. For this reason, in this study, ethanol was selected as the solvent for oil extraction.

Protein content of the *M. oleifera* seeds before and after oil extraction was determined by way of Kjeldahl nitrogen analysis (protein = $N(\%) \times 6.25$). The protein content of seeds before extraction was 25.0 ± 1.45% (mean ± standard deviation, $n = 3$). The protein content of the defatted residue after extraction with ethanol was 34.38 ± 2.03%. Such an increase in protein content has been demonstrated to favor the coagulant effect of *M. oleifera* solutions.

2.2. *Preparation of coagulant from* M. oleifera

The residue obtained after the extraction of oil from the seeds, also called *M. oleifera* meal, was dried at 60˚C for 24 h, and then stored at room temperature. Suspensions of oilseed residue at 5% (w/v) were prepared with distilled water by stirring at room temperature (for 2 h). Finally, the coagulant solution was obtained by filtration of the suspended solids using a 0.45-μm glass fiber filter.

2.3. *Turbidity removal tests*

Water samples were collected from the Kanazoé reservoir, the only reservoir of the Yako district which retains extractable water throughout the year. Tests of turbidity removal were carried on 500 mL water samples by adding 100 mg/L of coagulant. The efficiency of *M. oleifera* was compared with at the same concentration. Trials in triplicate with *M. oleifera* and with alum were performed using a jar-test which is designed for the small-scale replication of industrial coagulation–flocculation treatments.

Water samples were first submitted to rapid stirring at 150 rpm for 10 min, and subsequently, they were stirred slowly at 20 rpm for 30 min. Finally, the treated samples were allowed to stand for 1 h to facilitate natural sedimentation.

2.4. *Assessment by analysis*

As a case study, the Kanazoé dam in Yako, a rural settlement in Burkina Faso, was selected. At this location, the construction of a water purification plant incorporating the above-mentioned coagulants was proposed. The water purification plant is designed to produce 10,000 l/d of water. One kilogram of coagulant was selected as the functional unit of the LCA, since 100 mg/L solutions of both *M. oleifera* and attained turbidity levels below International guidelines.

3. Results and discussion

As outlined previously, all laboratory tests were carried out using synthetic high turbidity water. As can be observed in Fig. 1, the initial characteristics of this water consisted of a pH of 7.1 and a turbidity of 50 NTU (by way of the addition of kaolin). Tests were also carried out with alum and *M. oleifera* at both 25 and 100 mg/L. It can be observed that turbidity levels remain between 40 and 37–38 NTU and with a dosage of 100 mg/L, the

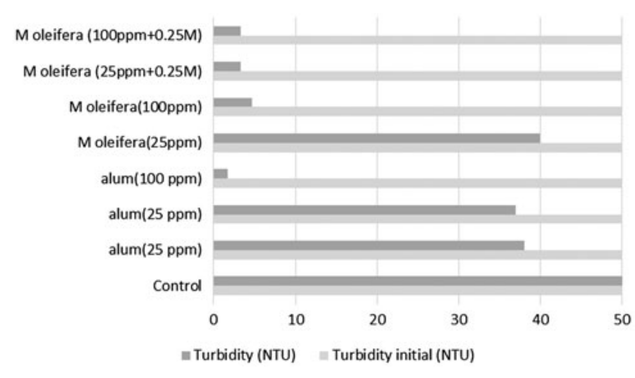

Fig. 1. Results of synthetic high turbidity water with *M. oleifera* and alum using 25–100 mg/L concentrations.

turbidity levels dropped to between 4.7 and 1.7 NTU. Such results corroborated the bibliographic information consulted [13–15], thus establishing the benchmark coagulant concentration as 100 mg/L.

Once the dosage was established for the synthetic high turbidity water, tests were then performed with samples of agricultural runoff water.

3.1. Turbidity removal tests

The main water treatment results with *M. oleifera* and with alum are presented in Table 1. These results were compared with International guidelines (2011) [18] for drinking water as established by the World Health Organization. In this Table 1, it can be observed how the Kanazoé water reservoir presents turbidity levels which exceed WHO limits [18]. On the other hand, nitrate pollution resulting from the use of fertilizer and/or other sources appears to be minimal. The presence of ions in the form of salinity (expressed as conductivity) was also moderate.

As can be seen in Table 1, the addition of 100 mg/L of the two coagulants leads to a reduction in water turbidity to levels within WHO limits (<5 NTU). While alum was demonstrated to be more effective at turbidity removal than *M. oleifera*, a pre-adjustment of the pH is required (to pH 6 as outlined in methods) in order for it to work effectively, and its addition results in an increase in conductivity.

In order to increase the effectiveness of the natural coagulant l *M. oleifera*, it has been demonstrated that by adding 0.25 M of NaCl, the turbidity removal efficiency is improved significantly, reducing levels 40 to 3.3 NTU. It must also be highlighted that *M. oleifera* does not modify the pH, and the variation of conductivity is minimal and falls within International guidelines. Even following the addition of the concentration of NaCl, the overall conductivity of the water being treated remains virtually unaltered.

In this study, as discussed previously, the removal efficiency of nitrates was not measured due to the fact that the presence of this parameter in the waters used in this study was not considered to be of great significance. In the current phase of this study, very encouraging tests are being carried out to determine the effectiveness of *M. oleifera* in the elimination of *Escherichia coli*, in light of research of [19], WHO, in 1981 identified an active microbial agent in *M. oleifera*.

This active agent is readily soluble in water at 1.3 μmol/L and is nonvolatile. Eilert et al. presented a study of the antimicrobial action of *M. oleifera* seeds and how it was tested on three bacteria species "*Bacillus subtilis* (gram-ve), *Serratia Marcescens* (gram-ve) and *Mycobacterium Pheli*." The result showed that *B. subtilis* was completely inhibited by 56 μmol/L and *M. Pheli* by 40 μmol/L. And only partial inhibition was observed for *S. Marcescens*.

Thilza et al. [20] reported that *M. oleifera* leaf stalk extract had mild actions against *E. coli* and *Enterobacter aerogenes*. Bukar et al. [21] also studied the antimicrobial activities of Moringa seed chloroform extract and Moringa seed ethanol extract. They were both found to have inhibitory effects on the growth of *E. coli* and determined the minimum inhibitory concentration to be >4 mg/mL.

Bichi et al. [22] have shown that its highest level of disinfection was achieved with the use of defatted seed cake and removing the active ingredients by way of aqueous extraction. Bichi et al. [23] also found that the optimal conditions for the extraction of the bioactive compounds were 31 min mixing time, 85 rpm mixing speed, and 3.25 mg/mL *M. oleifera* dosage. In a separate study, Bichi et al. [24] developed a kinetic model for the application of *M. oleifera* seeds extract in water disinfection and determined the coefficient of specific lethality (Λcw) for *E. coli* inactivation to be 3.76 L/mg/min.

Table 1
Results of water purification with *M. oleifera* and with alum 100 mg/L of concentration

	Parameter			
Source	Turbidity (NTU)	Conductivity (μs/cm)	pH	Nitrates (mg/L)
Initial	53	340	7.4	0.0
M. oleifera	4.3	340	7.4	0.0
M. oleifera + 0.25 M NaCl	3.2	420	7.4	0.0
Alum	1.1	370	6.7*	0.0
WHO limits	5	2,000	6.5–8.5	50

*Alum increased water pH to 6.7, thus remaining within experimental guidelines and not requiring further pH readjustment.

Table 2
Comparison between *M. oleifera* and alum in terms of energy consumption and CO_2 emissions

Scenario	Raw material	Production	Transport	Preparation and use	Sludge transport	Total
Energy consumption (functional unit kWh/kg)						
1 kg *M.oleifera* coagulant	20 kg seeds	–	1.471	2.926	7.350	11.747
1 kg alum	$Al(OH)_3$ (456 g) H_2SO_4 (492 ml)	3.150	2.456	0.062	11.025	16.631
CO_2 emissions (functional unit kg CO_2 e./kg)						
1 kg *M.oleifera* coagulant	20 kg seeds	–	0.407	1.126	2.036	3.162
1 kg alum	$Al(OH)_3$ (456 g) H_2SO_4 (492 ml)	1.210	1.445	0.024	3.054	5.709

3.2. Life cycle assessment

As described in paragraph 3.1, for the same amount of alum coagulant and *M. oleifera*-based coagulant, it was able to reduce turbidity to levels within International guidelines (<5 NTU). For both scenarios studied in the LCA, it used 1 kg of *M. oleifera* coagulant and 1 kg of alum. The different phases that were taken into account for the development of the LCA were production, transport, preparation, and use of the coagulant, and finally, sludge transport.

For the alum scenario, it did not take into account the processing of this waste, given that in Burkina Faso, the lack of compliance with certain environmental regulations is notoriously frequent. Nevertheless, sludge transportation to the designated landfill for alum was taken into account; the nearest landfill was located at an estimated distance of 75 km, which is 50% greater than the distance required for *M. oleifera* sludge transport requirements (50 km). As can be observed in Table 1, alum modifies the pH, which occasionally has to be adjusted with the use of hydrochloric acid or sulfuric acid (to acidify the water) and sodium hydroxide, also known as lye or caustic soda, for basifying. The addition of alum basified the water to be treated and subsequently the pH could be adjusted. However, in this study, and particularly considering the scenario of alum, the impact of the increase of the pH was not taken into account and, as is demonstrated in Table 1, the pH rises to 6.7 following the addition of alum and thus still rises within International guidelines (6.5–8.5).

In the *M. oleifera* scenario, the production phase of the raw material was not taken into account, given that it recycled and revalued the residue derived from the production of *M. oleifera* oil (residual oil cake). Nevertheless, transportation to the water treatment plant was considered. The other phases of this scenario are preparation and use, and the final transport of the sludge generated by the water treatment plant for later fertilization use. These arable lands are calculated to be within a 50-km radius of the water treatment plant.

In Table 2, a comparative analysis can be observed between the coagulant obtained from *M. oleifera* oil cake and the chemical coagulant alum. As can be observed in the Table 2, the energy consumption per kg of alum is almost 40% more than the natural coagulant, and the CO_2 emissions for alum is 80% more than the natural coagulant.

It can be observed that the preparation and use phase for the natural coagulant requires more energy than alum due to the increased time and frequency (once per week) of the manufacturing process.

In the case of alum, it can be observed that the extraction and transportation of the raw materials in the country in question entails 33.7% of energy consumption and 46.5% of CO_2. For this scenario, the transport required for this raw material was calculated taking in to account the fact that the $Al(OH)_3$ would be shipped via air (using the most commonly used flight routes and aircrafts) and the mine selected is in the closest proximity. In the case of H_2SO_4, for the purposes of this study, it is considered a secondary product and can be obtained locally.

We can see clearly that one of the limiting factors, from an environmental and even economic perspective, is the dependence on raw materials supplied from other countries, such is the case of $Al(OH)_3$ for the production of alum. The main drawback of the use of the natural coagulant, however, is its short lifespan and, consequently, the number of times it has to be prepared thus entailing 25% of energy consumption and 36.5% in CO_2 emissions.

4. Conclusion

The use of natural, locally based products entails water treatment practices that are more environmentally friendly, while at the same time reducing the dependence of the affected regions on other nations, or reducing the need for imports from other countries. Such factors are of special importance with an issue as vital as drinking water supply.

It could be seen that with the same quantity of alum coagulant and *M. oleifera*-based coagulant, turbidity levels could be reduced to below International guidelines (<5 NTU). In addition, it has been demonstrated that the required dosage of *M. oleifera* can be reduced by adding NaCl, as can be observed in Fig. 1, while enhancing exponentially the effectiveness of the *M. oleifera*. It has also been demonstrated that, under these conditions, with a dosage of only 25 mg/L, the same results were obtained as with 100 mg/L (3.3 NTU being the post-treatment concentration in both cases).

Through the LCA, it has been demonstrated that natural *M. oleifera* coagulant consumes 40% less energy than alum and produces 80% less in CO_2 emissions.

In addition to turbidity removal, with lower energy consumption and reduced CO_2 emissions, the resultant coagulant from the residual oil cake does not entail any alterations to the water pH or conductivity and, therefore, does not require any additional readjustments of these parameters.

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