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Evaluating coagulant activity of locally available S*yzygium cumini, Artocarpus heterophyllus* and *Moringa oleifera* for treatment of community drinking water, Uganda

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ABSTRACT

Most rural communities in Africa are without access to treated water and therefore use the readily available unsafe water sources exposing them to water borne diseases. This calls for the need for action to search for affordable and simple solutions. This research therefore examined the effectiveness of readily available natural coagulants *Syzygium cumini* (Javaplum), *Artocarpus heterophyllus* (Jackfruit) *and Moringa oleifera* (Moringa) using 'Jar Test'. Water turbidity and coliforms removal from community drinking water by seeds extracts of natural coagulants was examined. Turbidity removal increased with coagulants concentration in (solvents extracts water and NaCl). Optimal turbidity removal occurred at 40 mg/l coagulant concentration with low and medium turbidity raw water for both solvents extracts and at 60 mg/l for Na Cl extract with high turbidity water. Compared to alum [KAl $(SO_4)_2.12(H_2O)$], the turbidity removal effectiveness was: alum>*Moringa oleifera*>*Artocarpus heterophyllus*>*Syzygium cumini*, except for 1MNaCl extract where it was: *alum*>*Artocarpus heterophyllus*>*Moringa oleifera* >*Syzygium cumini*.Optimal turbidity removal was: *Moringa oleifera* 97.7%, *Artocarpus heterophyllus* 95.8% and *Syzygium cumini* 94.1%. The seed extracts were also effective as water disinfectants (Moringa>Jackfruit>Java plum). The use of Jackfruit and Java plum and Moringa, for water treatment is recommended.

Keywords: Coagulant activity, *Artocarpus heterophyllus, Moringa oleifera, Syzygium cumini,* community drinking water treatment, turbidity removal.

INTRODUCTION

Water is the most essential resource for mankind survival, since it has a direct input on human wellbeing that includes health and dignified life. Providing clean and safe water to people in rural areas of developing countries is a great challenge. This is complicated by the fact that the larger proportion of the world population (approximately, 1.4 billion) live in rural and peri-urban areas, in extreme poverty (Chen and Ravallion, 2008), with no access to clean

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water. Uganda falls in this category of nations where 88% of the population are rural and are in most cases depending on unsafe water sources (UNICEF/WHO, 2011).

The Ugandan rural communities obtain water from protected springs, boreholes and gravity flow schemes (Okot-Okumu and Otim, 2015). Most of the water sources in the rural and in periurban areas that serve low-income communities are contaminated with pathogenic micro organisms (Haruna et al., 2005; Howard et al., 2003; Nsubuga et al., 2004; Okot-Okumu and Otim, 2015). The contaminated water is used for domestic purposes including drinking and hence exposing a large sector of rural communities to health risks especially diarrhoeal diseases (UNICEF/WHO, 2011).

Rural communities usually lack the means of treating the contaminated water before use. The removal of turbidity and contaminants from raw water is essential before human consumption. The available methods such as the use of artificial coagulants to treat raw water before use are unaffordable to poor rural communities. The artificial coagulants like aluminium sulphate can only be used in urban or concentrated community settings because of economic reasons. Alum is also reported to be associated with some diseases (Flaten, 2001) and reduce of water pH (Okuda et al., 2001a). Sludge produced with chemical coagulants is often voluminous and not easily degraded biologically, leading to disposal problems and increased treatment costs (Owen, 2000).

Traditionally, rural Ugandan communities keep water in pots and the quiescent period allowed give time for suspended matter to settle out at the bottom of the pot as the water is used. However, as the volume of the water in the pot reduces through use, the settled dregs are re-suspended into the water that is consumed increasing the risk of contamination. With the increasing environmental pollution, traditional methods used by the community for water handling are becoming more and more inadequate in preventing disease outbreak.

Therefore, alternative water clarification methods such as the use of natural coagulants from plants are now being tested extensively as alternatives to treat water especially for the rural poor, who are not served by conventionally treated water (Marobhe, 2008; Ali et al., 2010).The naturally occurring coagulants are being recognized as safe for human health and termed “green” meaning environmentally friendly (Marobhe 2007; Marobhe, 2008). Ground seed powder of *Moringa oleifera* has traditionally been used for the clarification of turbid drinking water in rural areas in Sudan (Jahn, 1979), Nirmali tree in India (Al-Samawi and Shokralla, 1996) and Cactus in Chile (Diaz et al., 1999). Most of these trees with coagulant properties are widely grown in tropical climate by the population and can therefore be exploited to provide low-cost household solution to the critical need for potable water in rural communities. However, there is need to test new plants species potentials in addition to Moring to generate scientific information that will contribute to the efforts of helping low-income communities to treat drinking water.

Moringa was used in this study because of its history as coagulant so that it can be compared with lesser tested Java plum (*Syzygium cumini)* and Jackfruit (*Artocarpus heterophyllus*) seeds that are known to have phytochemicals like tannins and proteins that have coagulant and disinfection (bactericidal) properties (Ndyomugyenyi et al., 2008). This study therefore was done to evaluate the effectiveness commonly occurring natural coagulants Java plum (*Syzygium cumini)* and Jackfruit (*Artocarpus heterophyllus*) compared with the widely tested Moringa (*Moringa oleifera),* for treatment of poor quality water used by a rural community in Uganda.

MATERIALS AND METHODS

Moringa seeds were obtained from a homestead in Nabweru, Wakiso District, while Java plum and Jackfruit seeds were obtained from Kasubi in Kampala, all in Uganda. Mature seeds (Figure 1) of Moringa, Jackfruit and Java plum were dried in an oven at 50^0C under vacuum for 24 hours and afterwards milled to fine powder using a laboratory mill (Foss Cyclotec TM 1093).The seed powder in each case was sieved (0.5 mm mesh) and stored at room temperature (25 °C) in airtight bottles following Antov et al. (2007).

Fat was removed from Moringa seeds powder by mixing with 95% ethanol (8% w/v) for 30 minutes followed by centrifugation (5 minutes; 270 x g) and drying for 24 hours at room temperature (25 °C). Dry Moringa cake was milled, sieved (0.5 mm mesh) and used to prepare (5% w/v) extract. Aluminium sulphate ($KAl(SO_4)_2.12(H_2O)$) commonly known as alum was obtained from National Water and Sewage Corporation (NWSC) Kampala Uganda. A stock solution of 10 mg/ml of alum was prepared in distilled water and stored at 4 °C for three days before use in the coagulation tests.

Proximate analysis on the seeds was done (AOAC, 1990). Moisture content (vacuum Oven), total ash (furnace), crude protein (Micro-Kjeldahl), crude fibre (Labconco fibre machine) and fat (SoxtecTM2050) analyses were done (AOAC, 1990). Total carbohydrates were determined by difference. The amount of protein in solvent extracts was determined using micro-Kjeldahl method to evaluate the efficiency of extraction of bioactive compounds with different solvents. All proximate analyses were done in triplicate and were done in the Animal Science Laboratory, College of Agricultural and Environmental Science, Makerere University.

Distilled water, 0.5 M Sodium chloride and 1 M Sodium chloride were the solvents used in the preparation of the seeds coagulant extracts. The procedure for the preparation of seed extracts is summarised in Figure 2. Five (5) gof Moringa seed cake, and powder of Java plum and Jackfruit seeds were mixed with 200 ml of the solvents in a 500 ml beaker using a magnetic stirrer for 30 minutes and filtered through What man filter paper No. 3 . The filtrates were topped with solvents to 500ml to get 10mg/ml crude seed extracts. The concentration of seed extracts was in mg/l on the assumption that all the seed powder dissolved in the solvents used. The seed powder extracts were used fresh for the coagulation assessments.

Water samples for the assays were obtained from community drinking water sources (Nabweru Village, Nabweru Sub-County, and Wakiso District). The water samples were classified as low turbidity (<50NTU), medium turbidity (50-100NTU) and high turbidity (100-200NTU) turbidity (Katayon et al., 2004) and water samples in the same category were pooled together for the coagulation assays. The raw water were analysed for physico-chemical and microbial parameters (APHA 1998).Watercolour (Lovibond Tintometer Model E AF 900), turbidity (Turbidimeter, Hach DR/2100Q), TSS (Filtration –gravimetric method), TDS and conductivity (Hach 44600 conductivity meter), Nitrate-nitrogen (cadmium reduction, spectrophotometric), TN (Kjeldahl method), phosphorus (ascorbic acid, spectrophotometric), $Ca^{++}$and K^+ (flame photometer- Jenway - PFP7), total coliform, and faecal coliform (APHA, 1998). All equipment were calibrated before use according to supplier instructions. All physicochemical analyses were done in the water laboratory of the Department of Environmental Management, Makerere University. Microbiological analysis was carried out at Microbiology and Parasitology laboratory, College of Veterinary Medicine of Makerere University. The 'Jar Test' (Ŝćciban et al., 2005) was used to assess coagulant activity on low, medium and high turbidity

with varying coagulant doses: (0, 20, 40, 60, 80 and 100 mg/l). 500 ml raw water samples (low, medium and high turbidity) in beakers were rapidly mixed (2000 rpm) for 2 minutes to ensure evenly mixed water before adding the seeds extracts. Alum (1% W/V) was also used at concentrations of 0, 20, 40, 60, 80 and 100 mg/l. The water mixing speed was reduced to 80 rpm as the seed extracts and alum were added and maintained for 30 minutes, after which the water samples were allowed 60 minutes quiescent sedimentation. Each treatment condition was in triplicate.

The optimal pH for the coagulant activity was obtained by running the assays at different pH values (3.0-10.0). The determined optimal coagulant activity pH was then used to carry out all other turbidity removal and disinfectant assays. After sedimentation, an aliquot of 100 ml of clarified water was pipetted from mid-depth of the beakers into clean and dry bottles for water quality analysis. The residual turbidity of treated water was determined and turbidity removal (%) of extracts was calculated (Equation 1).

Equation 1: Turbidity Removal (%)

$$Turbidity\ removal(\%) = \frac{(Tu - Ts)}{Tu} * 100$$

……. (1)

Where: T_u - Turbidity of the untreated water

T_s - Residual turbidity of the clarified water.

Microbial analysis of raw and treated water was done for coliform bacteria. Treated water samples were taken aseptically using sterile bottles (Oven, 120 °C for 2 hours) and analysed for total coliform and faecal coliforms (APHA, 1998).The percentage bacterial removal from raw water was calculated using Equation 2.

Equation 2: Coliform bacteria removal (%)

$$Coliformbacterial\ removal(\%) = \frac{(Cblk - Cs)}{Cblk} * 100$$

…… (2)

Where: C_{blk} is the total coliform bacteria of untreated water sample;

C_s is the total coliform bacteria in the treated sample.

Test for antibacterial activity of the plant seed extracts were performed using agar-well diffusion method (NCCLS, 2002). Nutrient agar was prepared and poured onto petri dishes. The agar plates in the petri dishes were inoculated with 100 µl of suspension containing $1.5x10^6$ cfu/ml of bacteria (*Salmonella typhi, Salmonella dysenteriae, Pseudomonas aerogenosa, Staphylococcus aureus, Escherichia coli, Staphylococcus faecalis)* and wells loaded with 0, 20, 40, 60, 80 and 100 mg/l concentrations of seed extracts. The plates were then incubated at 37 °C for 24 hours; zones of inhibition (mm) around on each well were measured and recorded at the end of the incubation time. The inhibitory ability of seed extracts were expressed as minimum inhibitory concentration (Andrews, 2001).

Analysis of Variance (two- way ANOVA) was used to test whether any significant difference (<0.05) existed between the various treatments (GenStat 12.2, 2010). Multiple mean comparisons using least significant difference (LSD) was carried out to establish the significance of means at 0.05 probability value. The Fisher's LSD test computes the pooled SD from all the groups assayed.

RESULTS

Proximate analysis results on the seeds used in the coagulant activity assays are summarized in Table 1. Moringa seeds contained highest level of protein and fat and Java plum seed had the lowest chemicals amounts. Protein extraction assays exhibited significant difference ($p<0.05$) of recovery in increasing order: Java plum<Jackfruit<Moringa for all solvents, with water being the most efficient extracting solvent (Table 2).

The physicochemical and bacteriological characteristics of raw water

used in the coagulant activity assays are summarised in Table 3.The optimal pH for water extract coagulant activity was between 8.0 and 10.0. Turbidity removal increased with increasing concentration of the coagulants (Figure 3). Figure 4 shows turbidity removal in low, medium and high turbidity water by Moringa seed extracts. Coagulation activity among solvents was significantly different ($P<0.05$) from control with the highest activity obtained in water extract, followed by 0.5 M NaCl and 1 M NaCl. In medium turbidity, Moringa extracts exhibited optimal dose at 40 mg/l and turbidity removal of 90%, 89% and 84%, for water, 1 M NaCl and 0.5 M NaCl solvents respectively. For high turbidity water, the 0.5 M NaCl extracts optimal coagulant activity (97.8% turbidity removal) was attained at 60mg/l. For high turbidity water turbidity removal increased with dose of coagulant (Figure 4 and was significantly different ($P<0.05$) among solvents.

Figure 5 shows turbidity removal by Java plum seed extracts. Water, 0.5 M NaCl and 1 M NaCl extracts had turbidity removal of 69%, 65% and 59% in low turbidity water; 85%, 82% and 85% at 40 mg/l dose in medium turbidity water and ; 94%, 90% and 94% at 60 mg/l dose in high turbidity water respectively. Turbidity removal for high turbidity water was significantly higher ($p<0.05$) than for medium and low turbidity water. In all cases there was significant difference ($p<0.05$) in turbidity removal between the solvent extracts and the control.

Figure 6 shows turbidity removal in low, medium and high turbidity water by Jack fruit seed extracts. Water, 0.5 M NaCl and 1 M NaCl extracts had turbidity reduction of 74%, 70%, and 63.5% at 40 mg/l dose in low turbidity water; 92%, 80%, and 89% at 40 mg/l dose in medium turbidity water and 95%, 86.5% and 93% at 60 mg/l dose in high turbidity water respectively. In all cases there was significant difference ($p<0.05$) in turbidity removal between the solvent extracts and the control and turbidity removal for high turbidity water more significantly ($p<0.05$) t higher than for medium and low turbidity water.

Figure 7 shows turbidity removal by water seed extracts from low, medium and high turbid water compared with the activity of aluminium sulphate (Alum). Coagulant effectiveness was in the order: Alum >Moringa>Jackfruit>Java plumat all extract doses. Moringa and alum activity were significantly different ($P<0.05$) with those of jackfruit and java plum at low water turbidity and not at medium and high turgidities ($P>0.05$).

Figure 8 shows turbidity removal by 0.5 M NaCl seed extracts from low, medium and high turbidity water compared with alum. Coagulant effectiveness was in the order: Alum >Jackfruit>Moringa>Java plum at all extract doses. Figure 9 shows turbidity removal by 1 M NaCl seed extracts in low, medium and high turbidity water compared with alum. Coagulant effectiveness was in the order: Alum >Jackfruit>Moringa>Java plum at all extract doses.

Table 4 shows total coliform removal from turbid water by seed extracts. Total coliform (TC) removal from the turbid increased with increasing dose of the extract coagulants. The overall efficacies for Moringa, Jackfruit and Java plum at 100 mg/l were 77(62-94)%, 75(70-89)% and 64(60-69)%TC removal respectively. LD_{50} was attained at 30 mg/l, 30 mg/l and 20 mg/l for Moringa, Java plum and Jackfruit water extracts respectively. Table 5 shows removal of faecal coliform from turbid water by seed extracts. The efficacy ranged between 64(51-87)% Moringa, 62(54-69)% Java plum and 81(66-95)% Jack fruit extracts. LD_{50} was

achieved at 20 mg/l, 30 mg/l and 20 mg/l with Moringa Java plum and Jackfruit water extracts respectively. At 100 mg/l, *Moringa oleifera* and *Artocarpus heterophyllus* seed extracts showed good antibacterial activity. All bacteria were effectively inhibited at seed extract concentrations of 80-100 mg/l (Table 6). The inhibitory ability of seed extracts expressed as minimum inhibitory concentration are displayed in Table 7 and were 63 µg/ml, 125 µg/ml and 250 µg/ml for Moringa, Jackfruit and Java plum respectively. *Staphylococcus aureus* was the most susceptible of all microbes tested.

Table 1: Proximate analysis results (% dry weight) of Moringa, Java plum and Jackfruit seeds used in coagulant activity and bioactivity assays.

Seed or Cake	Dry matter	Total Ash	Protein[a]	Fat	Crude Fibre	Total Carbohydrates[b]
Moringa	96.31±0.41	3.86±0.02	38.10±0.35	37.95±1.17	4.24±0.67	15.85±1.06
Moringa Cake	92.70±0.54	4.35±0.04	46.41±1.01	22.30±1.54	7.25±0.25	19.64±2.54
Java plum	87.00±1.90	2.00±0.14	5.60±0.58	0.77±0.08	4.62±0.10	87.01±0.61
Jackfruit	93.69±1.30	3.23±0.42	14.62±0.17	1.56±0.64	3.80±0.02	76.82±0.95

[a] Crude Protein = Nitrogen (%)x 6.25, b Carbohydrates obtained by difference, Values are means ± SD

Table 2: Protein recovery (mg/l) from Moringa cake, Java plum and Jackfruit seed powder (5 g/l) by different solvents*****.

Plants	Distilled water	0.5MNaCl	1MNaCl	P<0.05
Moringa cake	1920.62±2.98[h]	1540.91±1.83[g]	1467.66±6.28[f]	S
Java plum	381.50±2.89[b]	301.90±2.86[a]	390.20±3.84[b]	S
Jackfruit	684.20±5.00[e]	627.87± 6.13[d]	551.90±3.86[c]	S

*Same letters indicate no significant difference ($p<0.05$). Seed ($LSD_{0.05}$=4.18); Solvent ($LSD_{0.05}$=4.18); Seed; Solvent ($LSD_{0.05}$=7.24)

Table 3: Quality characteristics of raw water used for the coagulation activity assays+.

Raw water	Turbidity	TSS	TDS	TN	PO_4^{3-}	NO_3^- N	CND	Ca^{++}	K^+	TC	FC
Low turbid	26.5	31.01	28.30	2.35	0.04	0.80	44.20	0.24	0.12	4167	57.32
Med. turbid	56.2	70.93	56.50	2.78	0.06	0.90	82.3	0.28	0.11	6008	71.47
High turbid	125.7	123.59	152.67	2.88	0.08	1.04	222.6	0.31	0.13	8078	63.25

[+] All values in mg/l except conductivity (µS/cm), turbidity (NTU), Total coliform (TC) and Faecal Coliform (FC)-(Cfu/100ml)

Table 4: Removal of total Coliform from pond water with Moringa, Java plum and Jackfruit seed extracts) within 1 - 2 hours of water treatment.

Solvent	Turbidity	Extract (mg/l)	0	20	40	60	80	100	Efficacy(%) at 100mg/l
Distilled water	Low	*Moringa*	4.24±0.40	2.58±0.035	1.72±0.09	1.64±0.12	1.43±0.11	0.40±0.07	91
		Java plum	4.40±0.14	2.85±0.50	1.75±0.35	1.06±0.27	1.23±0.04	1.23±0.39	72
		Jackfruit	4.00±0.71	1.68±0.25	0.88±0.14	0.82±0.05	0.50±0.07	0.200±0.07	95
	Medium	*Moringa*	6.00±0.71	4.00±0.71	2.18±0.46	1.38±0.25	1.35±0.14	1.49±0.73	75
		Java plum	6.08±0.61	3.50±1.41	2.18±0.46	2.18±0.46	2.24±0.37	1.87±0.26	69
		Jackfruit	5.08±0.81	2.30±0.35	2.18±0.46	1.43±0.64	1.40±0.21	1.25±0.48	75
	High	*Moringa*	8.10±0.96	5.40±0.95	2.94±0.62	1.86±0.33	1.82±0.19	2.02±0.98	75
		Java plum	8.21±0.82	4.73±1.91	2.94±0.62	2.94±0.62	3.02±0.50	2.51±0.35	69
		Jackfruit	6.85±1.09	3.11±0.48	2.94±0.63	1.93±0.86	1.89±0.29	1.30±0.35	81
0.5 M NaCl	Low	*Moringa*	3.93±0.601	1.90±0.21	1.78±1.03	1.22±0.33	0.84±0.078	0.400±0.35	90
		Java plum	4.00±0.71	2.68±0.25	2.26±0.34	1.83±0.04	1.78±0.32	1.25±0.04	69
		Jackfruit	3.00±0.71	3.00±0.71	2.00±0.71	1.28±0.11	0.87±0.12	0.70±0.07	83
	Medium	*Moringa*	5.78±0.39	4.18±0.46	2.80±1.06	3.23±0.39	2.78±0.32	1.76±0.37	70
		Java plum	6.00±0.78	4.20±1.70	2.61±0.55	2.61±0.55	2.69±0.44	2.24±0.31	63
		Jackfruit	5.04±0.69	2.76±0.42	2.61±0.56	1.72±0.77	1.68±0.26	1.25±0.57	75
	High	*Moringa*	7.80±0.53	5.64±0.62	3.78±1.43	4.35±0.53	3.75±0.43	2.26±0.50	71
		Java plum	8.10±1.06	5.67±2.29	3.52±0.75	3.52±0.75	3.63±0.60	3.02±0.42	63
		Jackfruit	6.80±0.92	3.73±0.57	3.53±0.75	2.32±1.04	2.27±0.35	1.02±0.28	85
1 M NaCl	Low	*Moringa*	4.00±0.71	2.18±0.24	2.00±0.71	2.01±0.69	1.73±0.39	1.38±0.04	66
		Java plum	3.73±0.32	1.42±0.62	2.13±0.11	0.86±0.01	2.00±0.71	1.48±0.35	60
		Jackfruit	3.97±0.54	2.01±0.27	1.24±0.37	2.18±0.46	1.60±0.071	1.17±0.03	71
	Medium	*Moringa*	6.18±0.95	4.76±0.37	3.00±0.71	1.20±0.47	2.97±0.74	2.28±0.32	63
		Java plum	5.07±0.69	3.78±1.53	2.35±0.50	2.35±0.50	2.42±0.40	2.03±0.25	60
		Jackfruit	5.50±1.41	2.48±0.38	2.35±0.50	1.55±691.1	1.51±0.23	1.35±0.52	76
	High	*Moringa*	7.33±0.13	6.43±0.50	4.05±0.95	1.65±0.63	4.02±1.00	2.42±0.29	67
		Java plum	6.84±0.93	5.10±2.06	3.17±0.68	3.17±0.67	3.26±0.54	2.74±0.35	60
		Jackfruit	7.43±1.91	3.35±0.52	3.18±0.68	2.09±0.94	2.04±0.31	1.82±0.70	76

Means are multiplied by 10^3, seed, turbidity, solvent, dose ($LSD_{0.05}$= 1.34)

Table 5: Removal of Faecal Coliforms from pond water with Moringa, Java plum and Jackfruit seed extracts at varying concentrations within 1-2 hours of water treatment.

Solvent	Turbidity	Seed extract (mg/l)	0 (control)	20	40	60	80	100	Efficacy (%) at 100mg/l
Distilled water	Low	*Moringa*	50.93±4.85	30.96±0.43	20.62±1.11	19.66±1.45	17.14±1.28	16.84±0.85	67
		Java plum	52.91±1.70	34.27±5.95	21.04±4.25	12.75±3.23	14.73±0.43	14.73±4.68	72
		Jackfruit	48.10±8.50	20.14±2.98	10.61±1.60	9.8±0.60	6.01±0.85	2.41±0.85	95
	Medium	*Moringa*	72.15±8.50	48.10±8.50	26.15±5.53	16.53±2.98	16.23±1.70	17.95±8.72	75
		Java plum	73.08±7.27	42.09±17.01	26.15±5.53	26.15±5.53	26.94±4.42	22.43±3.15	69
		Jackfruit	51.75±1.06	16.59±2.55	15.71±3.34	10.34±4.62	10.11±1.54	7.28±1.02	86
	High	*Moringa*	59.75±1.06	48.75±1.77	35.31±7.46	22.32±4.02	21.92±2.30	24.24±1.78	59
		Java plum	98.67±9.81	56.82±22.96	35.31±7.46	35.31±7.46	36.36±5.97	30.23±4.18	69
		Jackfruit	59.22±1.10	29.87±4.63	28.28±6.01	18.61±8.31	18.13±2.79	16.19±6.22	73
0.5 M NaCl	Low	*Moringa*	47.20±7.23	22.85±2.55	21.34±12.33	14.61±4.00	10.04±0.94	4.81± 4.25	90
		Java plum	48.10±8.50	32.17±2.98	27.18±4.08	21.95±0.43	21.34±3.83	21.95±0.43	56
		Jackfruit	36.08±8.50	36.08±8.50	24.05±8.50	15.33±1.28	9.69±0.44	8.42±0.85	77
	Medium	*Moringa*	69.44±4.68	50.20±5.53	33.67±12.75	38.78±4.68	33.37±3.83	33.19±4.42	52
		Java plum	72.15±9.35	50.51±20.41	31.39±6.63	31.39±6.63	32.32±5.31	26.91±3.78	63
		Jackfruit	60.58±8.29	33.19±5.10	31.42±6.68	20.67±9.23	20.22±3.08	17.99±6.91	70

Solvent	Turbidity	Seed extract (mg/l)	0 (control)	20	40	60	80	100	Efficacy (%) at 100mg/l
		Moringa	93.75±6.32	67.78±7.46	45.46±17.22	52.36±6.31	45.03±5.19	44.81±5.97	52
	High	*Java plum*	89.19±1.14	68.18±27.55	42.37±8.95	42.37±8.95	43.64±7.16	36.33±5.09	59
		Jackfruit	73.18±0.97	44.81±6.89	42.42±9.02	27.90±12.47	27.29±4.16	24.28±9.33	67
		Moringa	48.10±8.50	26.18±2.93	24.05±8.50	24.17±8.33	20.74±4.68	16.53±0.43	66
	Low	*Java plum*	44.79±3.83	17.02±7.40	25.55±1.28	10.34±0.17	24.05±8.50	17.74±0.43	60
		Jackfruit	47.74±6.46	24.17±3.23	14.91±4.42	26.15±5.53	19.24±0.85	14.01±3.15	71
		Moringa	74.25±11.48	57.24±4.42	36.08±8.50	14.67±5.61	35.77±8.93	39.38±3.83	45
1 M NaCl	Medium	*Java plum*	60.91±8.25	45.45±18.37	28.25±5.97	28.25±5.97	29.04±4.85	24.41±3.06	60
		Jackfruit	66.14±17.01	29.87±4.59	28.28±6.02	18.6±8.31	18.19±2.77	16.19±6.22	76
		Moringa	88.17±1.57	77.27±5.98	48.7±11.48	19.81± 7.57	48.30±12.05	53.17±5.16	49
	High	*Java plum*	82.23±11.14	61.36±24.80	38.09±8.12	38.13±8.06	39.22±6.52	32.89±4.17	60
		Jackfruit	65.00±1.41	40.33±6.20	38.18±8.13	25.08±11.26	24.57±3.75	21.86±8.39	66

Seed, Turbidity, Solvent, dose ($LSD_{0.05}$=14.91)

Table 6: Antimicrobial activity of Moringa, Jack fruit and Java plum water extracts on selected microbial species[a].

	Diameter[b] of inhibition zone (mm) by *Moringa oleifera* seed extracts (mg/l)					
	0 (control)	**20**	**40**	**60**	**80**	**100**
Microbes						
E.coli	R	R	8	11	12	13
P.aeruginosa	R	R	9	12	13	14
S.typhi	R	R	R	R	11	13
S.dysenteria	R	R	R	11	12	12
S.aureus	R	7	8	10	12	14
S.faecalis	R	R	R	9	12	13
	Diameter[b] of inhibition zone (mm) by *Syzygium cumini* seed extracts (mg/l)					
Microbes						
E.coli	R	R	R	9	11	11
P.aeruginosa	R	R	R	9	11	12
S.typhi	R	R	R	R	9	10
S.dysenteria	R	R	R	8	10	11
S.aureus	R	R	R	8	10	9
S.faecalis	R	R	R	R	10	11
	Diameter[b] of inhibition zone (mm) by *Artocarpus heterophyllus* seed extracts (mg/l)					
Microbes						
E.coli	R	R	7	10	10	12
P.aeruginosa	R	R	8	11	12	13
S.typhi	R	R	R	8	10	11
S.dysenteria	R	R	7	10	11	12
S.aureus	R	R	8	10	13	14
S.faecalis	R	R	R	8	11	13

R: Resistant, [a]: inoculum dose=1.5 x 10^6 cfu/ml; [b] : Diameter taken after 24 hours incubation at 37 °C

Table 7: Growth inhibition and Minimum Inhibitory Concentration (MIC) of Moringa, Java plum and Jackfruit water extracts on selected bacteria.

	Growth[b] at varying *Moringa oleifera* extract concentrations[c] (µg/l)						
	0 (control)	**31**	**63**	**125**	**250**	**500**	**MIC (µg/ml)**
Bacteria species[a]							
E.coli	+++	++	+	-	-	-	125
P.aeruginosa	++	++	+	-	-	-	125
S.typhi	++	++	+	+	-	-	250
S.dysenteriae	++	++	+	-	-	-	125
S.aureus	+++	+	-	-	-	-	63
S.faecalis	+++	++	+	-	-	-	125
	Growth[b] at varying *Syzygium cumini* extract concentrations (µg/l)						
Bacteria isolates							

E.coli	+++	++	+	+	-	-	250
P.aeruginosa	+++	+	+	+	-	-	250
S.typhi	++	++	+	+	+	-	500
S.dysenteriae	++	+	+	+	-	-	250
S.aureus	+++	++	++	+	-	-	250
S.faecalis	+++	++	+	+	+	-	500
	Growth[b] at varying *Artocarpus heterophyllus* extract concentrations (µg/l)						
Bacteria species							
E.coli	+++	++	+	-	-	-	125
P.aeruginosa	+++	++	+	+	-	-	250
S.typhi	++	++	+	+	-	-	250
S.dysenteriae	++	+	+	-	-	-	125
S.aureus	+++	++	+	-	-	-	125
S.faecalis	+++	+	+	-	-	-	125

[c]: Seed extracts incorporated into nutrient broth; -: no visible growth, +: poor growth, ++: slight growth, +++: dense growth; [a]: inoculum size: 1.5.0 x 10^6 cfu/ml; [b]: Data taken after 24 hours incubation at 37°C.

Figure 1: Seeds and seed cakes of Moringa, Jackfruit and Java plum plants.

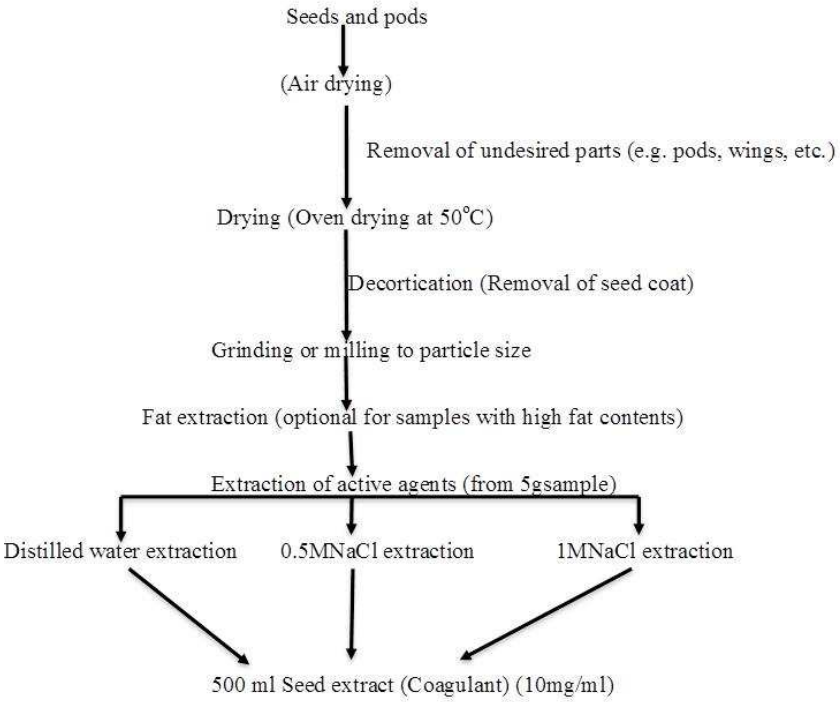

Figure 2: The steps used in the study to prepare seeds extract coagulants.

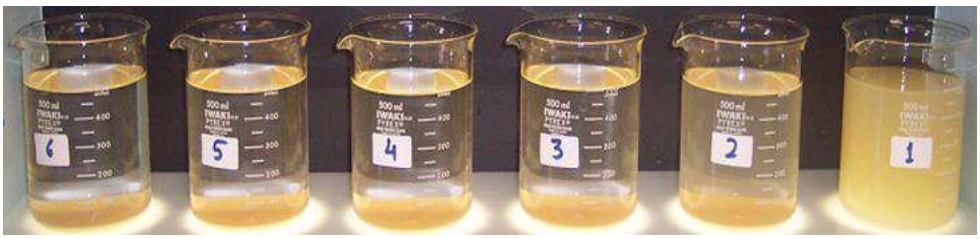

Figure 3: Standard Jar test setup for coagulation of turbid water with seed extracts. Concentration ranges 1 to 6 in the order 0, 20, 40, 60, 80 and 100 mg/l respectively.

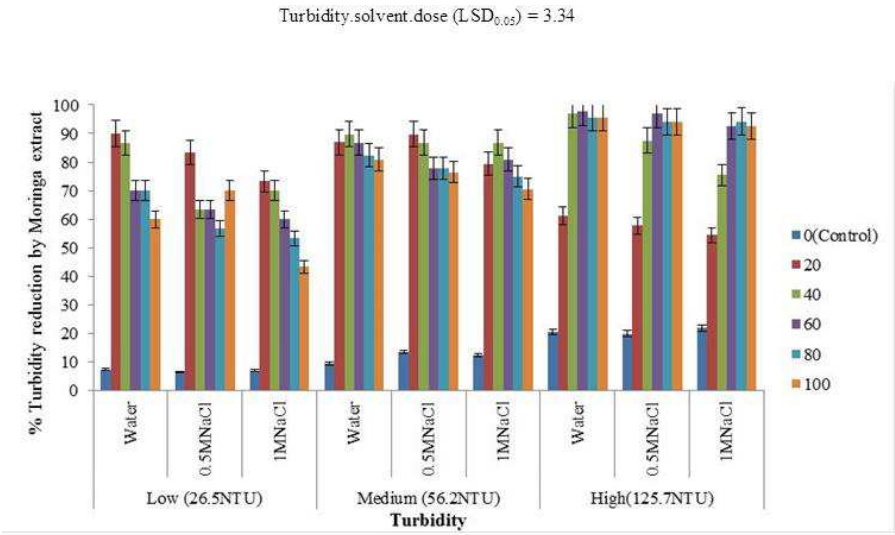

Figure 4: Average turbidity reduction by Moringa extracts in water and NaCl solvents (significant difference between solvent extracts for low turbidity water, and between all solvents and control, $p<0.05$).

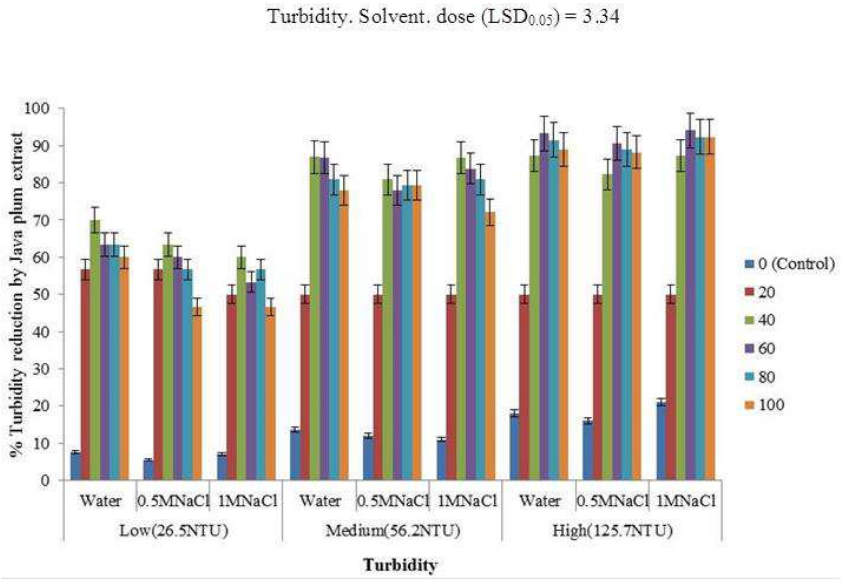

Figure 5: Average turbidity reduction by Java plum extracts in water and NaCl solvents (significant difference between solvent extracts activity for the different raw water turbidity levels, $p<0.05$).

Turbidity.solvent.dose ($LSD_{0.05}$) = 3.34

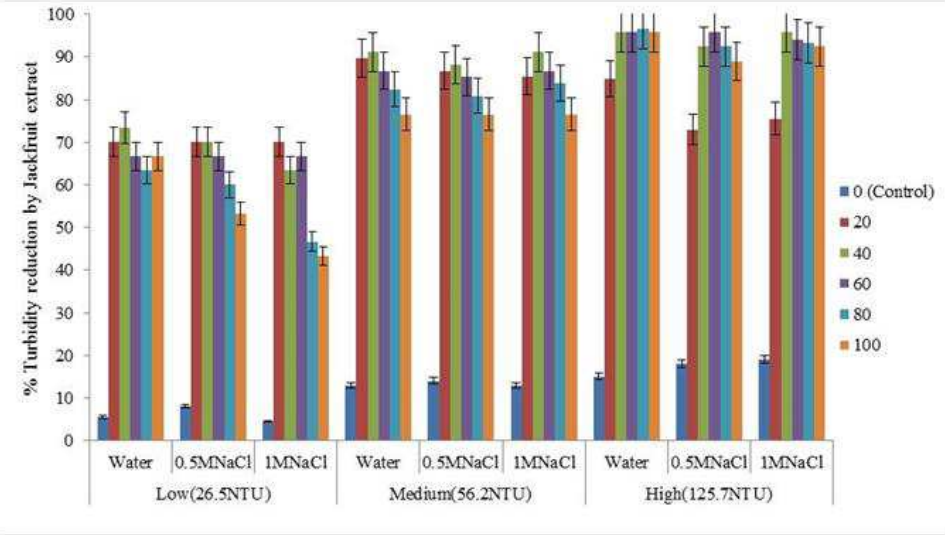

Figure 6: Average turbidity reduction by Jackfruit extracts in water and NaCl solvents (significant difference between solvent extracts for low and medium turbidity water at high doses, $p<0.05$).

Seed.turbidity.dose ($LSD_{0.05}$) = 3.34

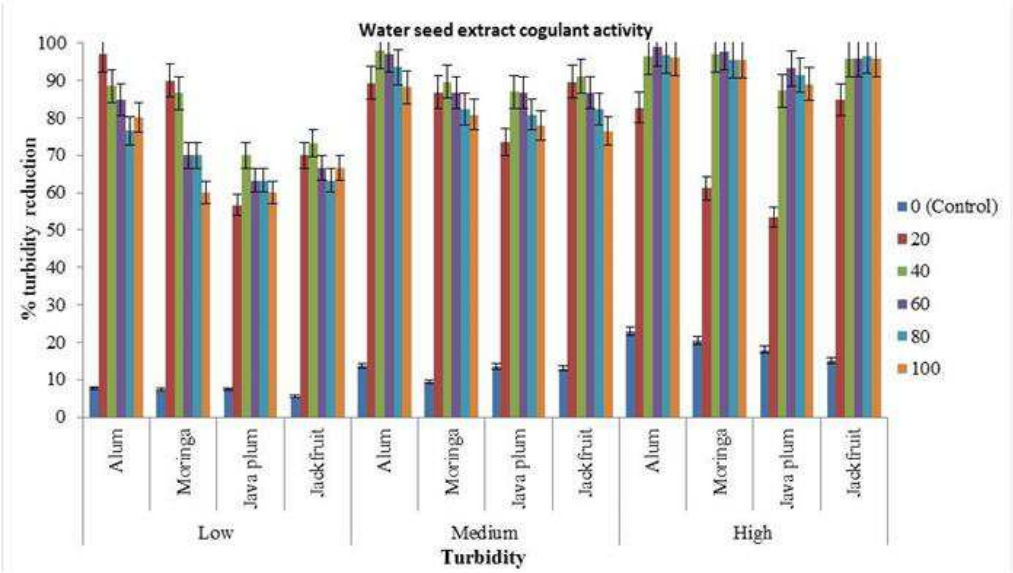

Figure 7: Turbidity reduction by water extract (Moringa, Jackfruit, Java plum) compared with alum (no significant difference between moringa and alum at all water turbidity and with jackfruit for medium and high turbidity water, $p>0.05$, for medium and high coagulant doses).

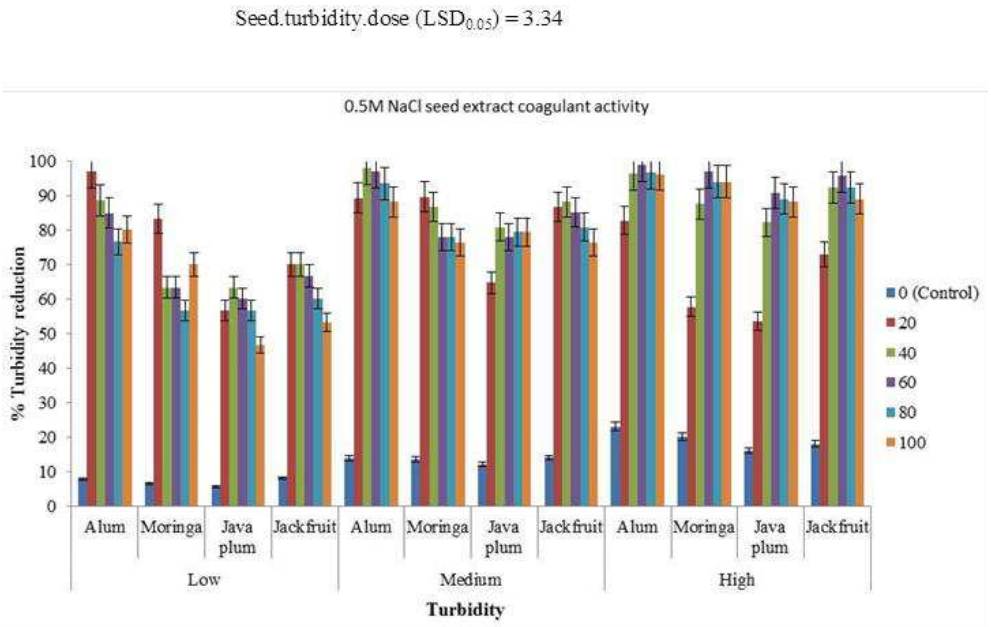

Figure 8: Turbidity reduction by 0.5NaCl extract (Moringa, Jackfruit, Java plum) compared with alum (no significant difference between plant coagulant extracts and alum for high turbidity water, $p>0.05$ for medium and high coagulant doses).

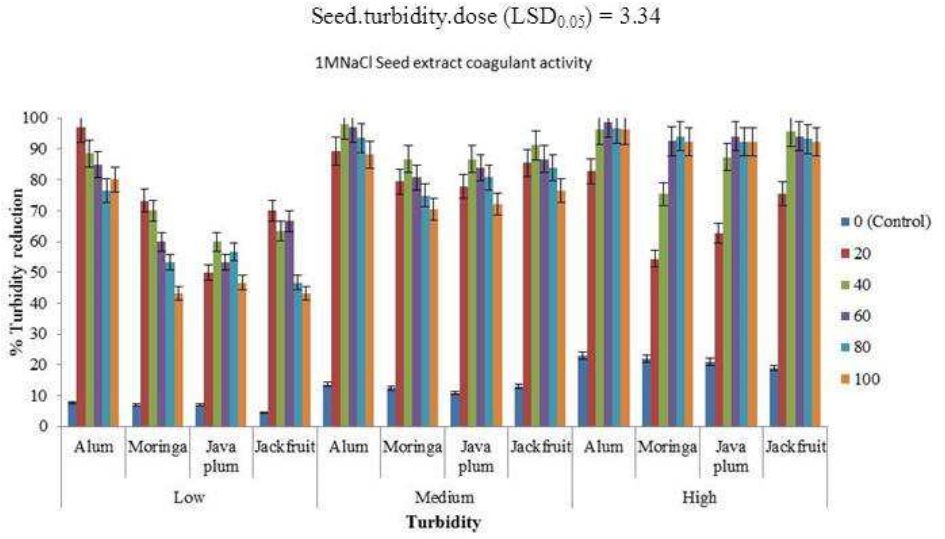

Figure 9: Turbidity reduction by 1NaCl extract (Moringa, Jackfruit, Java plum) compared with alum (no significant difference between plant coagulant extracts and alum for high turbidity water, $p>0.05$.

DISCUSSION

Proximate analysis on the seed residues was done for comparison with other seeds used for water treatment and for use in future studies on the potential application of these seeds for water treatment. Results for protein, ash, dry matter and fibre revealed characteristics similar to those reported by other authors (Akinmutimi, 2006; Kalibbala 2007; Ndyomugyenyi, 2008; Pritchard et al., 2009; Rahman et al., 2009;Sodamade et al., 2013; Olagbemide and Alikwe, 2014). The study of coagulant activity on Moringa (*Moringa oleifera),* Java plum *(Syzygium cumini)* and Jackfruit (*Artocarpus heterophyllus)* revealed promising level of turbidity removal from dirty water that is comparable to previous studies on Moringa and other plant seeds (Kalibbala 2007; Amagloh and Benang, 2009; Preston et al., 2010; Ali et al., 2010; Wilson and Andrews, 2011; Nand et al., 2012; Sanchez-Martin et al., 2012; Kabore et al., 2015). This can be attributed to probable similarity in the turbidity removal agents in the seeds, known to be cationic proteins with pI >9.6 (Ghebremichael et al., 2005).Java plum and Jackfruit seeds demonstrated good protein contents (Table 1) and therefore would be expected to exhibit evident coagulant activity as in *Moringa oleifera* that was confirmed by this study.

Water extracts had optimal coagulant activity at a lower dose than salt extracts although salt extracts performed better at higher turbidity and coagulant activities increased with seeds extract doses as also demonstrated by other studies (Okuda et al., 2001b; Ghebremichael et al., 2005; Kalibbala 2007; Marobhe, 2008). The observations can be explained by the ability of salts to increase extraction efficiency of coagulants but not the coagulation process (Okuda et al., 2001b). The apparent observed increased coagulation activity by NaCl is due to the salting-in mechanism in proteins found in the extracts leading to increased protein solubility as the salt ionic strength is increased.

Compared to untreated water significant ($p<0.001$) microbial inhibition was achieved by the plant extracts with Jack fruit having comparable abilities with Moringa. Bacteria were effectively removed through coagulation since they settle together with their natural supporting structure and elimination from water is achieved. Water seed extracts showed the best bioactivity in the reduction of turbidity and inhibition of microbial agents in the water samples tested. Microbial removal potential of all the plant seeds extracts was very promising similar to study by Doughari et al. (2007) and can deliver water of acceptable quality (WHO, 2011a) for immediate use. It is however known that such treated water contains high organic content that encourages microbial regrowth (Preston et al., 2010; Sanchez-Martin et al., 2012; Kabore, 2015). Water from such treatment therefore must be consumed immediately if possible and in any case, it should not be drunk after 24 hours. This shortcoming could be addressed by simple household chlorination using chlorine tablets commonly used by communities in developing countries and in emergency situations (WHO, 2011b).However, Preston et al. (2010) found that chlorine use for disinfection of water is not successful after treatment with Moringa since the high residual organic content increases chlorine demand. Therefore, even though the use of chlorine tablets is common among communities in Uganda, it will not be effective on water treated with natural coagulants.

Although the use of the natural coagulant treated water may be unsafe from 18 hours after treatment because of possible bacterial regrowth (Preston et al., 2010; Sanchez-Martin et al., 2012; Kabore et al.,

2015), pre-treatment such as solar water disinfection (SODIS) is known to make such water safer (Wilson and Andrews, 2011). In Africa where there is plenty solar radiation the poor communities could put their water in the sun for some hours as a pre-treatment method before the application of coagulants. Since most communities in the rural area do not keep drinking water for more than 24 hours before drinking, the use of SODIS water treated with natural coagulants would be safe as of WHO (2011a) standards. Given the average household size of 5 in Uganda and estimated water consumption of 7.5/l/capita/day (WHO 2003), each household would require to treat 37.5 l/day, which is affordable since the labour for water collection, seeds powder preparation and water treatment will be provided by household members. Incorporation of simple technology like sand filtration to the natural coagulant treatment system should be investigated. For effectiveness and sustainability basic training of household members to carry out water treatment and maintaining hygiene is necessary.

Jackfruit and Java plum have demonstrated that apart from their nutritional use in Africa they can join Moringa as plants of important application in water treatment especially for the poor communities who are usually endangered by the use of turbid and microbiologically unsafe water. In Uganda, the three plants (Moringa, Jack fruit and Java plum) are countrywide in distribution and are therefore readily available for use.

Conclusion

The search for solutions to water consumption problems requires innovations that are affordable and simple for take-up by the rural poor. For decades now, the use of natural coagulants has been tested in many countries in Africa and Asia with varying levels of success. *Moringa oleifera* has been the most investigated natural coagulant in this respect. This study investigated other plants, Java plum (*Syzygium cumini*) and Jackfruit *(Artocarpus heterophyllus*) and found their potency for water treatment comparable to *Moringa oleifera*. The plants extracts have demonstrated effective turbidity removal and disinfection effect comparable to the conventional water treatment coagulant alum, making community water safe for use. Being eco-friendly (Green) and having demonstrated great potentials as water treatment agents Java plum (*Syzygium cumini*) and Jackfruit *(Artocarpus heterophyllus*) should be investigated further individually and in combination with other natural coagulants for community water treatment.

COMPETING INTEREST

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

RN was the field investigator and drafted the manuscript. Aauthor JO-O designed the study and supervised the work. All authors read and approved the final manuscript.

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