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Full Length Research Paper

Performance of *Solanum incunum* Linnaeus as natural coagulant and disinfectant for drinking water

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The paper reports the performance of *Solanum incunum* Linnaeus as coagulant and disinfectant for water purification. The coagulation-flocculation experiment was carried out using a Phipps and Bird PB-700™ Jar Tester. Results show that coagulation depends on Fe(II) content and disinfectant on bioactive natural product compounds from the plant. Turbidity removals were 96, 97 and 75% for raw water with turbidity of 450, 300 and 105 NTU, respectively. Fecal coliform removal increased with coagulant concentration, displayed a maximum removal of 99% at 2.2×10^{-4} g/ml. LD_{50} ranged from 0.62-2.6 × 10^{-5} g/ml, which were within the range of optimum coagulation concentration of 2.2×10^{-5} g/ml. Turbidity and SO_4^{2-} concentrations for the treated water conforms to the Tanzanian Standards and WHO guidelines for drinking water, while fecal coliform counts exceeded the recommended values. The results suggest that *S. incunum* is promising as coagulant and disinfectant product for water purification.

Key words: Coagulant, disinfection, fecal coliform, *Solanum*, turbidity, water.

INTRODUCTION

Water is very important to human life and the entire ecosystem. It is essential part of all living systems, a medium from which life exists and the basic requirement for the development. Water is used for everything from drinking and household uses to watering livestock and the irrigation of crops. Fisheries, industry, food production, agricultural purpose, bathing, recreation, and other services use water to a large extent. When water becomes unusable for any of these purposes, it is polluted to a greater or lesser degree depending on the extent of the damage it can cause. In this case the treatment processes are necessary to make it palatable (Sawyer et al., 2003). The treatment of water may either be purification for domestic use, treatment for specialized industrial applications or treatment of wastewater to make it acceptable for release or reuse. The type and degree of treatment are strongly dependent upon the source and intended use of the water. Water for domestic use must be thoroughly disinfected to eliminate disease-causing microorganisms. One of the key achievements of coagulation-flocculation processes in enhancing drinking water quality is turbidity removal. Although not known to have direct health effects, turbidity is connected with water quality due to the fact that it can interfere with disinfection and provide a medium for microbial growth and as such, it is deemed as an indicator for the presence of microbes in water. Results from a study by Lechevallier et al. (1981) points out that disinfection efficiency was negatively correlated with turbidity. According to this study, since turbidity was associated with total organic carbon content in water, it was shown to interfere with maintenance of a free chlorine residual by creating a chlorine demand. The suspended solids potentially provide attachment sites for viruses or bacteria, interfering with disinfection using chlorine, since these solids have a shielding effect to the microbes.

In developed world water related diseases are rare, essentially due to the presence of efficient water supply and wastewater disposal systems (AWWA, 1990). However, in developing world perhaps as many as 2000 million people are without safe water supply and adequate sanitation. As a result, the toll of water-related disease in these areas are frightening (WHO and UNICEF, 2000; Pokherel, 2004).

In Tanzania, like many developing countries water is mostly abstracted from the surface sources which rarely meet quality standards for human consumption, warranting the need for treatment (Ministry of Water, 2005). Many of these water sources happen to be

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polluted by human excreta, animal excretion and industrial effluents (Ministry of Water, 2008). This has often resulted into water borne epidemics in many parts of the country. The disinfection is mostly done by chlorination process that is followed after coagulation-flocculation process done by using alum (Hydrated aluminium sulphate - $Al_2(SO_4)_3.14H_2O$) normally imported from abroad. Despite the potential human health effects of alum, developing countries like Tanzania cannot afford to procure alternative adequate water treatment chemicals due to high cost associated with them (Mayibi and Evison, 1995; Forkard and Sutherland, 2003). However, purification of potable water from turbid surface sources by coagulation-flocculation and sedimentation for removal of suspended and colloidal materials by easily available plant extract such as Bambarranut (*Voandzeia subterranean*), Moringa (*Moringa oleifora*) and field bean (*Vicia faba*) (Testsaji et al., 2001; Marobhe et al., 2007) is common at household scale in many rural areas of Tanzania where piped water supply is scarce.

Therefore, there is a need of developing cheap and easily available coagulant from plant origin to be used in water treatment. This study aimed at investigation of the effectiveness of plant species *Solunum incunum* as potential low cost material with multiple activities as a natural coagulant and disinfectant in treatment of drinking water at rural household level in Tanzania.

MATERIALS AND METHODS

Plant materials

The leaves of *S. incunum* Linnaeus were collected from Changuku village, Usangi, Kilimanjaro Region (altitude of 1217 m asl). The plant was identified for this study because it is used by the local community as a coagulant for drinking water purification, with no knowledge on how it works. The plant materials were authenticated at the Herbarium, Department of Botany of the University of Dar es Salaam, Tanzania where voucher specimens are preserved.

Raw water

Raw water samples were collected from Ruvu River, Bagamoyo District in Coast Region, which is the largest source of water supply for Dar es Salaam City. A total of 20 grab water samples were collected and kept in clean 20 L plastic buckets. Prior to sampling the buckets were thoroughly cleaned using tap water, followed by rinsing using river water before sampling. Samples were collected from the same point at different intervals**.** The collected samples were transported and analyzed at the School of Environmental Science and Technology (SEST), Ardhi University.

Chemicals and reagents

All the reagents used were of analytical grade, these include sulfa ver-4-sulphate, phos ver-3-phosphate, nitra ver-5–nitrate and ferro ver iron reagent powder pillows, man ver 2 hardness buffer solution, phenol and bromol cresol green methyl red indicator, potassium chromate ($KCrO_4$) indicator and silver nitrate ($AgNO_3$); all purchased from HACH Permachem Reagents Germany.

Concentrated Sulphuric acid (H_2SO_4) and Sodium Hydroxide (NaOH) were purchased from Indo Gulf Trading Co. India.

Preparation of coagulant extracts

The leaves of *S. incunum* were air dried, grinded in a mortar and pestle into powder-form and sieved to remove large particles. 1 g of powder was mixed with 99 ml distilled water to form 100 ml of suspension (approximately 0.01 g/ml concentration). The suspension was then thoroughly mixed using a clean magnetic stirrer for 5 min to extract the active component, followed by filtration of the solution through a piece of clean white cloth so as to remove solid materials. The filtrate was then centrifuged at 30 rpm for 5 min, followed by filtration using Whatman® filter paper. The obtained stock solutions from each of these methods were preserved at -4°C until analyzed.

Experimental setup

The coagulation-flocculation experiment was carried out using Phipps and Bird PB- 700™ Jar Tester (USA) which consists of six beakers mixing paddle and a gauge for revolution per minutes (rpm). Three experiments were performed using three water samples of different turbidities 105, 300 and 450 NTU. For each water sample, six beakers were filled up to 900 ml, placed in the jar tester, agitated at 30 rpm for 5 min. Various concentrations (0.000006, 0.00001, 0.00002, 0.00004, 0.00009, 0.0001, 0.00016, 0.0002 and 0.0003 g/ml) made by adding 0.5, 1.0, 2.0, 4.0, 8.0, 10, 15, 20 and 25 ml stock solution (0.01 g/ml) were added to each of the beakers and then agitated further for 5 min at 150 rpm to achieve uniform mixtures. The mixing speed was then reduced to 30 rpm and maintained at slow mixing for 30 min, followed by sedimentation for 30 min, after which 5 ml of sample was collected at approximately 5 cm from the top of water surface for residue turbidity measurement and coliform assays analyses.

Enumeration of faecal coliforms (*Escherichia coli*)

A membrane medium was prepared by dissolving 37 g of Difco™ m-FC broth base medium into 1000 ml of distilled water, boiled then followed by adding 1 ml of a 1% solution of Rozolic acid in 0.2 N NaOH. A sterilized absorbent pad was placed into a sterilized Petri dish by using sterilized forceps. 2 ml of the prepared sterilized media was added into the Petri dish using a pipette until the pad was saturated. The sterile filter was placed in the filtration unit and 100 ml of water sample was poured and filtered with the aid of vacuum pump. After filtration the sterile filter was removed from the filtration unit and placed into the Petri dish that was saturated with a membrane medium. The Petri dish was incubated at 44°C for 24 h, and membrane filters with between 20 to 80 colonies were counted. The results were expressed as number of bacteria count per 100 ml of sample.

Measurement of turbidity

The turbidity was measured by Naphelometric method using turbidimeter Model 2100 as described in Laboratory Turbidimeter Instruction Manual (HACH, 2000).

Alkalinity and hardness concentrations

Alkalinity was measured by using the titration method (digital titrator method), whereby 100 ml of water sample was placed in 250 ml

Table 1. Residue turbidity, percentage removal and pH (n=3).

Dosage ($\times 10^{-4}$ g/ml)	450 NTU			300 NTU			105 NTU			Alum at 300 NTU	
	Residue turbidity	pH	% Removal	Residue turbidity	pH	% Removal	Residue turbidity	pH	% Removal	Residue turbidity	% Removal
0	356.33±16.9	7.3±0.06	20.81±3.76	254±18	7.23±0.09	15.33±6	87.33±2.6	7.23±0.09	16.82±2.48	252	16
0.06	20.67±2.03	7.17±0.67	95.4±0.45	10.67±1.2	7.2±0.06	96.44±0.4	8.67±2.19	7.23±0.09	91.75±2.08	27	91
0.1	10.67±2.6	7.13±0.12	97.63±0.58	5±1.15	7.4±0.1	98.33±0.38	4.67±0.67	7.13±0.18	95.56±0.63	6	98
0.2	1±0.58	7.07±0.88	99.78±0.13	2.67±0.67	7.4±0.17	99.11±0.22	3±0.58	7.1±0.23	97.14±0.55	4	98.7
0.4	2.33±0.33	7.5±0.12	99.48±0.07	3.67±0.33	7.47±0.18	98.78±0.11	5.33±0.33	7.07±0.29	94.92±0.32	4	98.7
0.9	3.33±0.33	7.57±0.2	99.26±0.07	5.33±0.67	7.37±0.18	98.22±0.22	6.67±0.88	7±0.1	93.65±0.84	1	99.1
1	6.67±0.88	7.7±0.21	98.52±0.19	7±1.15	7.3±0.12	97.67±0.38	8.67±1.76	6.87±0.12	91.75±1.68	nd	nd
2	8.33±1.45	7.7±0.32	98.14±0.32	9.67±0.88	7.27±0.67	96.78±0.29	13.33±1.45	7.17±0.07	87.3±1.38	nd	nd

nd – not detected.

Erlenmeyer flask. Six drops of bromocresol green methyl red indicator solution were added and the solution was swirled to mix. The solution was titrated with 1.6 N sulfuric acid by using a digital titrator until the solution changed to light greenish blue-grey. The concentration of total alkalinity in mg/L was read from the digital titrator count (Clesceri et al., 1989).

Hardness was measured by using the titration method (digital titrator method), whereby 100 ml of water sample was placed in 250 ml Erlenmeyer flask. 2 ml of buffer solution (hardness 1) was added to the flask and swirled to mix. Contents of one ManVer 2 hardness indicator powder pillow were added to the mixture in the Erlenmeyer flask and swirled to mix. The mixture was titrated with 0.8 M EDTA until the colour changed from red to blue. The concentration of the total hardness (as mg/L $CaCO_3$) was recorded from the digital counter window (Clesceri et al., 1989).

Chloride and nitrate concentrations

Measurement of chloride was conducted by Argentometric method (Clesceri et al., 1989). 50 g $KCrO_4$ was dissolved in a little of distilled water. $AgNO_3$ solution was added until a definite red precipitation formed. The mixture was left to stand for 12 h, then filtered and diluted to 1 L with distilled water. The filtrate was then titrated with 0.014 M $AgNO_3$, and the Cl^- concentration was calculated as described by Clesceri et al. (1989). Nitrate content in water samples was measured by adding NitraVer®5 Reagent for Nitrate in 25 ml of water sample, followed by vigorous shaking to obtain a uniform mixture which was allowed to settle for 5 min for reaction to take place. A spectrophotometer was set and run at a wavelength of 890 nm and blanks were used for calibration and quality check (HACH, 2002).

RESULTS AND DISCUSSION

The results pertaining to turbidity removal and fecal coliform activity of the extracts from *S. incunum* are shown in Tables 1 and 2. The extract displayed an optimal dose of 2 ml (2 × 10^{-5} g/ml) for treating turbid water samples of initial turbidities of 450, 300 and 105 NTU. The corresponding average percentage removals were 99.78, 99.11 and 97.14 at residue turbidities of 1, 2.67 and 3 NTU, respectively. The coagulation activity envisaged to be influenced by iron content in plants when it is oxidized from Fe^{2+} to Fe^{3+}in which it attracts the colloids by Van der Waal attraction force and settle together by gravity (Pontius, 1990).

Turbidity removal was the highest in water with 450 NTU (Table 1 and Figure 1), and decreased with decrease of turbidity, similar to the findings reported by Marhobhe (2007). The disinfectant had opposite trend which are in accordance with findings reported by Norbert (2001), it works better after the removal of turbidity. The bioactivity properties of *S. incunum* as a disinfectant can be due to bioactive natural product compounds with medicinal values such as steroids and diosgenone, which are known to occur in the genus *Solanum* (Pabon, 2009; Jin et al., 2009; Ahmed et al., 2009). Traditionally, the plant materials of *S. incunum* are used for cure of abdominal pain, dyspepsia, fever, stomach-ache, snake bite, chest pains, ringworms and syphilis (Kokwaro, 1992). These activities are conceived to be responsible for the disinfectant properties since both activities works on similar mode of action (Suarez et al., 2003). Comparison of *S.*

Table 2. Residue FC and percentage removal (n=3).

Initial dosage ($\times 10^{-4}$ g/ml)	450 NTU		300 NTU		105 NTU	
	FC	% Removal	FC	%removal	FC	% removal
0	47.67±2.91	24.34±4.6	43.67±3.33	23±4.1	26±1	28.28±8.93
0.06	41.33±2.4	34.39±3.82	23±1.15	46.27±5.54	18.5±2.5	47.52±5.27
0.1	33.33±1.2	47.09±1.9	16.33±1.2	61.8±5.54	12±1	66.24±8.18
0.2	29±1.15	53.97±1.83	10.33±1.76	75.9±4.64	10±3	73.59±3.83
0.4	20.67±0.88	67.19±1.4	5.33±1.45	87.69±3.13	5.5±3.5	86.31±7.24
0.9	11.67±0.67	81.48±1.06	2.33±0.88	94.84±1.74	3±2	92.31±4.2
1	3.67±0.88	94.18±1.4	0.67±0.33	98.39±0.82	1±0	97.22±0.45
2	0.67±0.33	98.94±0.53	1±0.58	97.87±1.23	1.5±0.5	96.06±0.71
LD_{50}	2.402 (1.252-4.082) ml 2.7 (1.4-4.5) $\times 10^{-5}$ g/ml		0.561 (0.249-0.894) ml 6.2 (2.8-9.9) $\times 10^{-6}$ g/ml		1.115 (0.507-1.802) ml 1.2 (0.5-2) $\times 10^{-5}$ g/ml	

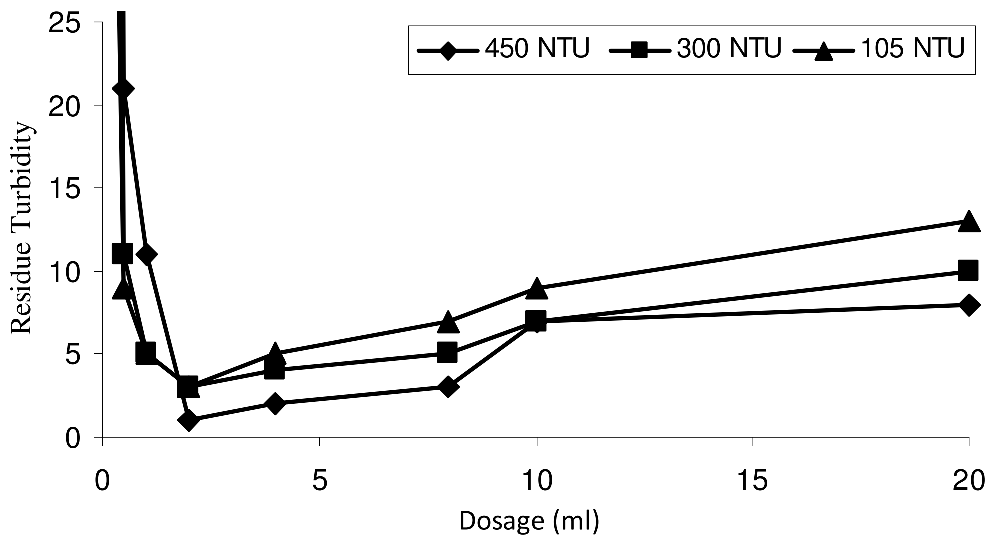

Figure 1. Performance of *S. incunum* extract.

incunum with a commercial coagulant Alum® (Figure 2) indicate that at coagulant doses less than 4 ml, *S. incunum* performed equally well in turbidity removal. For coagulant doses less than 2 ml (2 × 10^{-5} g/ml), *S. incunum* outperformed Alum in turbidity removal.

Table 3 shows the physical and chemical parameters of the raw water of different turbidities before treatment. The turbidities, bacterial count and SO_4^{2-} were beyond the acceptable values as per TBS and WHO guidelines. Table 3 also shows the parameters after treatment with natural coagulants, whereby after treatment water with initial turbidity of 300 NTU displayed turbidity and SO_4^{2-} within the acceptable TBS and WHO values. The bacterial count was beyond the acceptable values. Thus, the bacterial count in Table 3 and the LD_{50} values in Table 3 still indicate the potential of *S. incunum* to be used as a disinfectant agent for water purification.

Conclusions

The investigation of the effectiveness of *S. incunum* in turbidity and FC removal for water clarification have shown promising results that could be developed into simple and low cost coagulant/disinfectant for water purification to be used in local communities. The increase in residue turbidity after the optimum point was due to increase of plant chlorophyll concentration in water. Interestingly, it has been coincidentally found out that *S. incunum* also affected the survival of fecal coliform, calling for further research on the plant both as a coagulant and disinfectant. Detailed investigation on the performance of *S. incunum* in both dry and wet season should be done so as to establish proper collection time that will ensure full availability of the active ingredients. Further investigation should also focus on removing

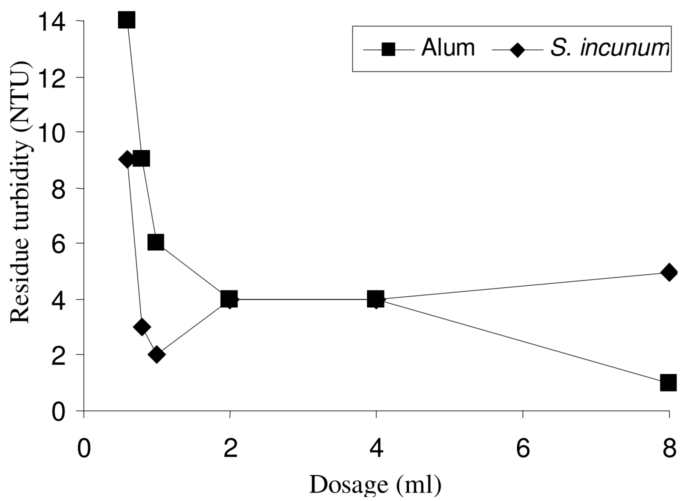

Figure 2. Comparison of *S. incunum* and Alum®.

Table 3. Physical and chemical characteristic of treated water.

Parameter	Raw water			Treated water*	TBS	WHO
Turbidity (NTU)	450	300	105	2	30	25
pH	7.3	7.8	8	7.49	6.5-9.2	6.5-9.2
Conductivity (µS/cm)	121.3	124.9	132.1	121	nm	nm
Salinity (%)	0.1	0.1	0.1	0.1	nm	nm
Total alkalinity (mg/L)	75.5	84	74	58	nm	nm
Fecal coliform (count/100 ml)	47×10^4	43×10^4	26×10^4	10×10^4	0	0
SO_4^{2-} (mg/L)	500	643	725	21	400	600
Fe^{2+} (mg/L)	nd	nd	nd	0.09	1.0	1.0
NH_3-N (mg/L)	3.75	3.71	3.08	0.17	nm	nm
TDS (mg/L)	84.3	103	94	60.5	nm	nm
NO_3^- N (mg/L)	nd	nd	nd	0.4	nm	100
Total hardness (mg/L)	nd	nd	d	63	nm	600
Cl^- (mg/L)	nd	nd	nd	47	600	800

*treated from raw water of 300 NTU, nm - not mentioned, nd – not determined.

chlorophyll pigment in order to curtail the problem of turbidity increase due to chlorophyll increase.

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