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Performance of *Cyperusesculentus*and*Glycine max* Seeds as Natural Coagulant for Domestic Wastewater Treatment

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ABSTRACT
Increased discharges of untreated wastewater to the environment have resulted in degrading water quality, endangering human health and ecosystems, contributing to water scarcity and constraining sustainable economic development. Hence, there is need for adequate wastewater treatment in order to improve water quality and promote a healthy environment. Chemical coagulants are already being used for treatment, but their enormous cost, human and environmental hazard associated with their use has necessitated the need for searching natural coagulants for wastewater treatment. In this study, laboratory scale studies using jar test experiments were carried out on sullage wastewater to analyse the performance of *Cyperusesculentus* (Tigernut) and *Glycine max* (Soybean) seeds as natural coagulant on domestic wastewater treatment. Results indicated that the seed extracts (singularly or in combination with alum) have a noticeable effect on all the parameters considered. Treatment with tigernut and soybean seed extracts (Singularly) gave 96.08% and 87.71% turbidity reduction efficiencies, 76.52% and 77.21% COD reduction efficiencies, 7.72mg/l and 6.37mg/l phosphate, 4.08mg/l and 3.98mg/l Nitrate. These values were comparable to those of alum. The pH of the treated water remains largely unaffected due to the buffering capacity of the seed extracts. Results further revealed that the combination of tigernut seed extract and alum solution gave the overall best results with all the parameters within WHO acceptable limit for both drinking water and effluent discharge except for pH. However, result of pH suggested that few chemicals will be required for pH adjustment. It was deduced from the study that the performance of the seed extracts (singularly or in combination with alum) are satisfactory, thus they have coagulating capabilities and are suitable for domestic wastewater treatment.

Keywords: Natural Coagulant, *Cyperusesculentus*, *Glycine max*, Seed extracts, Alum, Sullage, Coagulation.

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I. INTRODUCTION

Water is considered as a basic need of life**.**Freshwater is essential for healthy lives and environment. Yet this resource is limited in supply, as more than half of the available 0.3% freshwater [1, 2] has already been used [2]. The small fraction available is under serious threat due to factors like over exploitation, poor management and ecological degradation [3, 4]. Population growth and economic development have greatly influenced the increased demand for portable water [5] as well as anthropogenic activities which has increased generation of wastewater and its overall pollution load [6, 7].In most developed and developing countries, the vast majority of wastewater (about 80%) is released directly to the environment without adequate treatment, with detrimental impacts on human health, economic productivity, the quality of ambient freshwater resources, and ecosystems[7, 8].

Wastewater is a critical component of the water management cycle, water after it has been used is all too often seen as a burden to be disposed of or a nuisance to be ignored. The results of this neglect are now obvious. The immediate impacts include the degradation of aquatic ecosystems and waterborne illness from contaminated freshwater supplies [7]. Untreated wastewater directly contributes to increase diarrhoea diseases, such as cholera, typhoid fever and rotavirus [8]. Diseases such as these are responsible for 297,000 deaths per year of children under five years old, or 800 children every day [9]. The highest rates of diarrhoea-attributable child deaths are experienced by the rural communities in developing countries [8]. About95% of the global wastewater is released into the environment without treatment [10]. Raw wastewater or untreatedwastewatercontains solids, endocrine disrupters (chemical that interfere with hormones), inorganic nutrients, heavy metals and pathogens [8]. If an excess of nutrients (such as nitrogen and phosphorous) are released into the environment from untreated wastewater, it can foul natural ecosystems and disrupt aquatic life.Continuous failure to address wastewater as a major social and environmental problem would compromise other efforts towards achieving the 2030 Agenda for Sustainable Development.

Improving clean water and sanitation have a clear global target. The United Nation's sustainable development goal 6 is to, by 2030, achieve adequate and equitable water supply and sanitation for all and to halve the proportion of untreated wastewater. Achieving this target will be difficult, particularly in developing countries where there are limited wastewater management systems. Most developing countries are still faced with the problem of accessing portable water. The availability of water resources is also intrinsically linked to water quality, as the pollution of water sources may prohibit different type of uses. One-third of the world's drinking water is obtained from surface sources like rivers, dams, lakes, and canals [11, 12] and these sources serve as the best choice for the discharge of domestic and industrial wastewater due to their ease of accessibility [13, 14].Anthropogenic activities have been identified as a major source of pollution of water bodies [15], thus water bodies are threatened by wastewater effluents.Increased discharges of untreated wastewater have resulted in the degradation of water quality around the world [7]. If current trends persist, water quality will continue to degrade over the coming decades, endangering human health and ecosystems, contributing to water scarcity and constraining sustainable economic development. Contaminated water and poor sanitation are strongly linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, malaria, typhoid and polio etc. [4,16, 17, 18, 19]. According to WHO [20], about 94% death cases in the world can be reduced by safe water and hygienic environment. Hence,it is crucial to subject water from every source to varying forms of treatment or purification before consumption, or discharge in the case of wastewater.

Conventional drinking water treatment involves a series of processes such as aeration, coagulation, flocculation, sedimentation, filtration and disinfection [21]. Coagulation and flocculation are very crucial processes in water treatment as they determine the success or failure of a water treatment unit [4, 22, 23], thus these processes improve the overall water treatment unit's efficiency [24]. In wastewater treatment, coagulation has been practiced since earliest times and used for removing colloidal particles and other contaminants from the water [25]. Coagulants (either natural or chemical) are used to achieve this aim, due to their ability to agglomerate fine colloidal particles in water into larger ones (flocs) which settle easily and hence facilitate their removal [26]. In convectional water treatment, inorganic coagulants (e.g. aluminium and ferric salts) and synthetic polymers (e.g. polyacrylamide derivatives and polyethylene imine) are widely used because of their effectiveness [27]. However, because of the high cost of importation of these coagulants (in developing countries) coupled with the health and environmental issues associated with their use[28], there have been a growing research interest in natural plant based coagulants as alternatives to inorganic coagulant and synthetic polymers. The use of natural coagulant, mainly polysaccharides and proteins represents a vital development towards sustainable environmental technology [29] as they are cost effective, biodegradable and are presumed to be safe for human health [28, 30].

Fewer studies [4, 31] have attempted the potentials of natural coagulants for domestic wastewater treatment and they have been found effective. Some of these coagulants include *MorigaOleifera*(which is well known within the scientific community), okra and cassava etc. Large amount of domestic wastewater (sullage) is generated from homes and restaurants in most developing countries including Nigeria and their challenge is to provide adequate sanitation facilities, especially for the poor. Coagulation is a simple, cost effective and efficient technique for water and wastewater treatment [32]. Hence, there is need for scientific investigation into other natural coagulants (plant based) in order to achieve the 2030 agenda for sustainabledevelopment. Therefore, this study is aimed at assessing the efficiency of*Cyperusesculentus* (tigernut) and*Glycine max* (soybean) seeds as plant-based coagulants for the treatment of domestic wastewater (sullage). Previous studies have shown that soybean and tigernut seeds contain proteins, carbohydrates (including starch), lipids, tannins and minerals [33, 34, 35, 36]. In addition, they are readily available and can be acquired at a low cost.

II. MATERIALS AND METHODS

The *Cyperusesculentus* (tigernut) and *Glycine max* (soybean) seeds used for this study were sourced from a local market (Oba market) in Benin City, Edo State, Nigeria. They were identified and authenticated by a Botanist in the Department of Plant Biology and Biotechnology, University of Benin, Benin City. The chemicals used which are hydrochloric acid and aluminium sulphate (alum) were purchased from a chemical laboratory in Benin City, Edo State, Nigeria.Fresh sullage was collected using two plastic gallons of 10 litres capacity each from household sink (before disposal into the sewer) and stored in a refrigerator at 5°C until usage.Experiments were carried out atLuco Scientific Chemical Laboratory, Quality Control Unit of Ikpoba River Dam Water Treatment Plant and Water and Environmental Laboratory of Civil Engineering Department, University of Benin, all in Benin City, Edo State, Nigeria.

2.1 Preparation of Tigernut and Soybean Seeds Extracts

Tigernut and soybean seeds were dried to a constant weight in the oven at 260°C for about 30 minutes. They were sorted to remove bad ones and properly sealed on neatly labelled zip lock bags and stored at room temperature until usage. About 60g each of tigernut and soybean seeds were separately pulverised mechanically to fine powder using a stainless grain laboratory pulveriser and sieved to make them of appropriate size of about 600µm. The characteristics of the tigernut and soybean seeds powder are presented in Table 1.

Table 1: Proximate Analysis of the Tigernut and Soybean Seeds Used for the Study

Components (%)	**Tigernut (Dry Basis)**	**Soybean (Dry Basis)**
Moisture	7.65	7.69
Protein	5.70	32.60
Crude Fat	18.80	26.43
Crude Fibre	13.15	6.30
Ash	2.30	4.83
Carbohydrate	52.4	22.15

Plate 1: Tigernut and Soybean Seeds after Drying

Each type of powder (tigernut and soybean) was defatted using the soxhlet extraction method as described in Seghosime et al [28]. Each defatted powder was then extracted (to give 1% w/v solution) with 1M sodium chloride solution as described in Seghosime et al. [28]. Fresh solutions of tigernut and soybean seeds were prepared at everyday of use.

Plate 2: Tigernut and Soybean Seeds Powder after Defatting

2.2 Preparation of Aluminium Sulphate (alum) Solution

Alum solution was prepared to also give 1% w/v solution. Fresh solution of alum was prepared at every day of use.

2.3 Sullage Water

Wastewater from household sink was collected and stored in the refrigerator at 5°C until usage. The characteristics of the sullage water are presented in Table 2.

Table 2: Characteristics of the Sullage Water Used for the Study

S/N	Parameters	Values
1	Turbidity (NTU)	586
2	pH	7.80
3	Total Dissolved Solids (ppm)	602
4	Total Suspended Solids (%)	0.179
5	Biological Oxygen Demand (mg/l)	77.7
6	Chemical Oxygen Demand (mg/l)	316.8
7	Dissolved Oxygen (mg/l)	1.75
8	Nitrates (mg/l)	6.18
9	Phosphates (mg/l)	11.36

2.4 Coagulation/Flocculation Experiment (Jar Test Operations)

Jar test apparatus (Stuart Scientific Flocculator SW1, UK) with six stirrers, consisting of a rotation regulator of mixing rods was used for this study. The jar test to determine optimal dosage of the coagulants was conducted with different doses of the coagulants (Tigernut seed extract; Soybean seed extract; Alum solution). The sullage (500ml) was filled into six beakers of 600ml capacity each out of which five were dosed with different volumes of the coagulants and labelled according to the dosage of the coagulant added to it, while one beaker was left without addition of coagulant and labelled as control. The coagulant dosages used ranges from 5 to 25ml as shown in Table 4. The apparatus was coupled properly by putting the stirrers in the Jar test kits and lowering them into each beaker, thus ensuring that the beakers were well centred before the apparatus was turned on. The experimental conditions for coagulation/flocculation with the coagulants were: 1 minute of rapid mixing (100 rmp) followed by 30 minute of slow mixing (25 rmp).Then, the treated sullage was allowed to settle for 60 minutes after which the supernatant samples were withdrawn using a pipette (20ml) from 3cm below the liquid level for analyses. The samples were analysed for turbidity and pH. The optimal dosage was determined where it gives the least turbid water [37] and after determining the optimal dosage for each coagulant, that of the natural coagulant was combined with that of alum respectively (Alum solution + Tigernut seed extract; Alum solution + Soybean seed extract) in different proportions as indicated in Table 5 (with alum added first before the extract) and used separately to treat the sullage, maintaining the same aforementioned experimental conditions. The experiments were done in replicates to ensure consistency. At optimal dosages, samples were further analysed for Chemical Oxygen Demand (COD), Phosphates (P) and Nitrates ((NO_3^-). The turbidity reduction efficiency was calculated using the following equation [28, 38];

$$\text{Turbidity Reduction Efficiency (\%)} = \frac{T_0 - T_1}{T_0} \times 100 \quad \ldots\ldots\ldots (1)$$

Where;

T_0 =Initial Turbidity

T_1 = Final Turbidity

2.5 Analytical Method

All analytical methods correspond to standard methods [39]. The methods adopted for the sullage (both treated and untreated) analysis are presented in Table 3.

Table 3: Analytical Methods for Sullage Quality Parameters

S/N	**Parameter**	**Analytical Methods**
1	Turbidity	Spectrophotometry Method
2	pH	Digital pH Meter Method
3	Total Dissolved Solids (TDS)	Flame Photometric Method
4	Total Suspended Solids (TSS)	Flame Photometric Method
5	Chemical Oxygen Demand (COD)	Dichromate Method
7	Dissolved Oxygen (DO)	Winkler Titrimetric Method
8	Phosphates (PO_4^{3-})	Spectrophotometry Method
9	Nitrates (NO_3^-)	Spectrophotometry Method

III. RESULTS AND DISCUSSIONS

Results obtained from the study are presented in Table 4 to 7. Table 4 shows the effect of coagulant dosage on the sullage quality. Table 5 shows the effect of combination of seed extract and alum on the sullage quality. Table 6 indicates the optimal dosage performance of different coagulant on sullage quality. And Table 7 indicates the optimal dosage performance of combined coagulant on sullage quality.

Table 4: Effect of Coagulant Dosage on Sullage Quality

Coagulant	**Dosage (ml)**	**Turbidity Reduction (%NTU)**	**pH**
Tigernut Seed (TS)	0	3.75	7.77
	5	**96.08**	7.41
	10	85.84	7.26
	15	75.6	7.34
	20	65.7	7.08
	25	62.12	7.16
Soybean Seed (SS)	0	3.75	7.77
	5	79	7.06
	10	**87.71**	7.19
	15	72.01	7.07
	20	64.16	7.04
	25	55.97	6.93
Aluminium Sulphate (AS)	0	3.75	7.77
	5	**98.48**	4.45
	10	93.89	4.19
	15	91.96	3.84
	20	82.78	3.72
	25	85.6	3.63

From Table 4, results indicated that the dosages (optimal dosages) were better turbidity reduction efficiencies were achieved for each coagulant are: 5ml for tigernut seed (TS) extract, 10ml for soybean seed (SS) extract and 5ml for aluminium sulphate (AS) solution. The corresponding turbidity reduction efficiencies are 96.08% for TS extract, 87.71% for SS extract and 98.48% for AS solution. This values shows that the extracts from tigernut and soybean seeds gave comparable turbidity reduction efficiencies with alum (synthetic coagulant). Previous studies [28, 40] have shown that coagulation process can be ameliorated by extracting soluble proteins from plant seeds using sodium chloride,because of the intense force exerted by the salt in breaking the plant cells or tissues. This may be explained by the salting-in effect of proteins at higher ionic strength [40, 41, 42, 43]. The disparity between the coagulating activities of the seeds extracts (tigernut and soybean) and alum may be attributed to the mixture of organic compounds present in the seed extracts compared to the pure compound contained in alum (synthetic coagulant). It was observed that beyond the optimal dosage of the seeds extracts, turbidity reduction efficiency decreases with increased dosage which is in agreement with studies conducted by Muruganandam et al.[37] and Saharudin and Nithyanandam [44]. This phenomenon may be as a result of charge reversal and destabilisation of colloidal particles due to overdosing of coagulant [28, 37, 44]. It was further observed that higher turbidity reduction efficiencies were recorded with the use of TS extract compared to SS extract. This might be attributed to the protein and carbohydrate content of tigernut seed as protein and carbohydrate have been reported to greatly influence coagulation activities of plant based coagulants [40, 45, 46]. The high effectiveness of tigernut in reducing turbidity is in consonant with Mogus [47] who also recorded high turbidity reduction efficiency of >95% with tigernut liquid in water with initial turbidity (kaolin suspension) of 1000NTU. Results also revealed that the pH of the wastewater (sullage) treated with TS and SS extracts remains largely unaffected as values ranges from 7.08 to 7.41 for treatment with TS extract and 7.04 to7.19 for treatment with SS extract. This might be attributed to the buffering capacity of the seed extracts.

Table 5: Effect of Combination of Seed Extract and Alum on Sullage Quality

Coagulant	Proportion (%) Alum: Seed Extract	Dosage (ml) Alum: Seed Extract	Turbidity Reduction (NTU)	pH
Alum (AS)+ Tigernut (TS)	00:100	0,5	23	7.41
	20:80	1,4	3.98	4.71
	40:60	2,3	2.85	4.66
	60:40	3,2	3.19	4.57
	80:20	**4,1**	**2.74**	**4.56**
	100:00	5,0	8.9	4.45
Alum (AS)+ Soybean (SS)	00:100	0,10	83	7.26
	20:80	1,8	4.15	5.71
	40:60	2,6	4.78	4.79
	60:40	**3,4**	**4.07**	**4.61**
	80:100	4,2	8.76	4.62
	100:00	5,0	8.9	4.45

Results from Table 5 revealed that treatment of sullage with combination of extract (either TS or SS) and alum solution resulted in significant turbidity reduction much lower than treatment with alum solution alone. ForAS+ TS extracts, the optimal dosage combination obtained was alum-4ml, tigernut-1ml for initial turbidity of 586 NTU which correspond to turbidity reduction of 2.74 NTU while forAS+ SS extracts, the optimal dosage combination obtained was alum-3ml, soybean-4ml for initial turbidity of 586 NTU which correspond to turbidity reduction of 4.07 NTU. These values are within the acceptable limit of 5NTU for drinking water [48, 49].Combination of coagulants (inorganic-inorganic or inorganic-organic) increases the polymer species concentration and promotes good properties of coagulant [50, 51]. Hence, composite coagulants can improve coagulation-flocculation efficiency[50, 51],they also exhibit good stability better than primary single coagulant [52], as the increase molecular size enhance the aggregating ability. Thus, these values are indicating that the seed extracts work better as coagulant aid (for alum) or as composite coagulant (when combined with alum). Results also revealed that, although the pH of the treated water was affected, but it was not as largely affected like when alum alone was used for treatment as values ranges from 4.56 to 4.71 for AS+ TSextractsand from 4.62 to 5.71 for AS+ SS extracts, thus few chemicals will be required for pH adjustment. These results further suggested that the combination use of alum and the seed extracts respectively will reduce the dose of chemicals (either alum or pH adjuster) which in turnminimizes the toxicological effect of these chemicals and the cost of water treatment.

Table 6: Optimal Dosage Performance of Different Coagulant on Sullage Quality

Coagulant	Optimal Dosage (ml)	COD		NO_3^-(mg/l)	PO_4^{3-}(mg/l)
		COD (mg/l)	%COD Reduction		
Tigernut Seed (TS)	5	74.4	76.52	4.08	7.72
Soybean Seed (SS)	10	72.2	77.21	3.98	6.37
Aluminium Sulphate (AS)	5	38.2	87.94	3.84	5.73

Table 7: Optimal Dosage Performance of Combined Coagulant on Sullage Quality

Coagulant	Proportion (%) Alum: Seed Extract	Dosage (ml) Alum: Seed Extract	COD		NO_3^- (mg/l)	PO_4^{3-} (mg/l)
			COD(mg/l)	%COD Reduction		
Alum (AS)+ Tigernut (TS)	80:20	4,1	25.6	91.92	2.22	4.87
Alum (AS)+ Soybean (SS)	60:40	3,4	52.4	83.46	3.28	5.07

Results from Table 6 and 7 indicate that apart from turbidity, the coagulants considered can further reduce other pollutants (COD, PO_4^{3-},NO_3^-) present in the wastewater. These results showthatat optimal dosage of the coagulants, there was a significant reduction in the COD of all treated samples with initial COD value of 316.8mg/l. Although the values obtained are above acceptable limit of 10mg/l for drinking water, however they are within acceptable limit of 75mg/l for effluent discharge [49]. The % COD reduction efficiencies of TS extract, SS extract, and ASsolutionare; 76.52%, 77.21% and 87.94%. These values are higher than the 68.5% obtained with *Moringaoleifera* seed extract for sullage wastewater [53] and they show that the seed extracts gave comparable % COD reduction efficiencies with alum.It was observe that samples treated with the seed extracts (respectively) in combination with alum gave higher % COD reduction efficiencies than samples treated with the seed extracts (singularly), % COD reduction efficiencies of the seed extracts in combination with alum are; 91.92% (for AS+ TS extracts) and 80.30% (for AS+SS extracts). This disparity may be attributed to the fact that the seeds are organic products and as such may have the tendencies of increasing the organic content of the wastewater [4, 54] which couples with the inorganic content to increase the COD of the treated samples. It was further deduced from the results that sample treated with AS+ TS extracts gave the highest % COD reduction efficiency of 91.92%.

From Table 6 and 7, results further revealed a decrease in the levels of Nitrates and phosphates for all treated samples with initial values of 6.18mg/l and 11.36mg/l. The values obtained are well within WHO (2017b) acceptable limits for both drinking water andeffluent discharge.These elements (Nitrates and phosphates) may have absorbed into the flocs formed during coagulation (with the coagulants considered) which are then removed bysedimentation [55]. It was observed that TS extracts gave higher values of Nitrates and phosphates (4.08mg/l and 7.72mg/l) than others. This may be attributed to the fact that Tigernut seeds contain proteins with Nitrogen and Phosphorus as its major constituents [33]. Also, AS+TS extracts gave the lowest values of Nitrates and phosphates (2.22mg/l and 4.87mg/l). Hence, the seed extracts (singularly or in combination with alum) have noticeable effect on nutrients (Nitrogen and Phosphorus)

IV. CONCLUSION

In this study, tigernut and soybeans seeds extracts (singularly or in combination with alum) have demonstrated high potentials in treating domestic wastewater (sullage). Both seed extracts showed a noticeable effect on turbidity, COD, Phosphates and Nitrates. Among the seed extracts, tigernut seed (TS) extract gave the highest turbidity reduction efficiency while soybean seed (SS) extract gave the highest drop in COD, Phosphates and Nitrates. The pH of the sullage treated with the seed extracts remains largely unaffected due to the buffering capacity of the seed extracts. Combining the advantages of both the seed extracts (respectively) and alum (AS) solution yielded better results. Tigernut seed extract in combination with alum solution (AS+TS) gave the overall best results with all the parameters within WHO acceptable limits for both drinking water and effluent discharge except for pH. However, result of pH suggested that few chemicals will be required for pH adjustment. This combination will reduce the dose of chemicals (either pH adjuster or alum), thus minimise the toxicological effect and production of non- biodegradable sludge. Therefore, the performance of the seed extracts (singularly or in combination with alum) are satisfactory, thus they have coagulating capabilities and are suitable for domestic wastewater treatment. This could help to reduce the impact of untreated wastewater in poor developing countries (particularly in rural areas). These seeds are available in abundance, cheap, non-toxic and eco-friendly because of their biodegradable nature.

It is further recommended that other simple methods which could extract more coagulant chemicals from the seeds should be determined. This could improve the performance of the seed extracts in wastewater treatment.

Competing Interests

Authors have declared that no competing interests exist.

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