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Treatment of Slaughterhouse Effluents by Planted Filter with *Echinochloa pyramidalis*

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Abstract

Slaughterhouse wastewater is among the most environmentally hazardous wastewater. These waters are discharged into the environment without treatment. The objective of this study is to evaluate the effect of different concentrations of slaughterhouse wastewater on the purification performance of *Echinochloa pyramidalis* planted filters. During the study, slaughterhouse wastewater was collected in 10 l polystyrene bottles in 14-days intervals and then characterized for physicochemical and bacteriological parameters according to the standard protocol. Four planted filter treatment devices with *Echinochloa pyramidalis* were mounted with four different concentrations of slaughterhouse wastewater T1: 25% wastewater + 75% tap water; T2: 50% wastewater + 50% tap water; tap; T3: 75% wastewater + 25% tap water and T4: 100% raw wastewater. The purification performances as well as the morphometric parameters were determined. The results obtained show values of MES (54115 ± 745 mg/L); nitrate (3225.75 ± 448.91 mg/L); COD (13592.17 ± 2007.31 mg/L) and CF (523,333.8 ± 35,555,909 CFU/100 mL) very high compared to the discharge standards. Treatment T1 showed the best performance. However, the values obtained are always above the standards. Hence, the need for optimization or post-treatment of slaughterhouse effluents to reduce as much as possible the pollutant loads of these wastewaters before their discharge.

Subject Areas

Environmental Sciences

Keywords

Slaughterhouse Wastewater, *Echinochloa pyramidalis*, Purification Performance, Planted Filter

1. Introduction

Water is used for domestic, agriculture and industrial purposes. The slaughterhouse uses water for washing and cleaning operations of the meat, pipes, machines and floors. Slaughterhouses are one of the most water-intensive industries in the world [1]. Slaughterhouses and meat processing plants are part of a large industry worldwide, where the composition of the wastewater depends on the various practices in the slaughtering process. Wastewaters from slaughterhouses and meat processing industries have been classified by Environmental Protection Agency (EPA) as one of the most harmful to the environment [2]. The major environmental problems associated with this slaughterhouse wastewater are the large amount of suspended solids and liquid waste as well as odor generation [3]. Effluent from slaughterhouses has also been recognized to contaminate both surface and groundwater because during abattoir processing, blood, fat, manure, urine and meat tissues are lost to the wastewater streams [4]. Leaching into groundwater is a major part of the concern, especially due to the recalcitrant nature of some contaminants [5]. Discharging slaughterhouse wastewater without treatment contributes to greatly degrading the aquatic environment and pollution of irrigation water. The major characteristics of abattoir wastes are high organic content [6], sufficient organic biological nutrients, adequate alkalinity, relatively high temperature (20˚C to 30˚C) and free of toxic material [7]. Consequently, slaughterhouse wastewater requires significant treatment for a safe and sustainable release to the environment. Abattoir effluent is generally subject to stricter regulations than other types of agricultural wastewater, as abattoirs are classified as commercial operations and because of increased public health concerns related to animal-borne pathogens and specified risk materials. Abattoir wastewater is typically high in BOD_5, TSS, and *E. coli* [8]. There are various technologies for the treatment of abattoir wastewater, but they are limited due to the capital intensiveness, high retention time, and operating and maintenance costs that are often not affordable in developing countries [9] [10]. Constructed wetlands have gained increased acceptance as a low-cost technology for wastewater treatment [11]. In general, constructed wetlands have been shown to achieve significant mass reductions of 5-days biochemical oxygen demand (BOD_5), total suspended solids (TSS), and microbial indicator organisms [12]. Reductions of total dissolved solids (TDS) and nutrients, in particular nitrogen (N) and phosphorus (P), have been less consistent [13]. Compared with conventional mechanized wastewater treatment technologies, vertical flow planted filters have several advantages: lower construction and operating costs, easy maintenance, efficient and robust treatment with ecological benefits [14] [15]. Planted filters are suitable for tropical regions because the expected performance is better with higher temperatures and associated microbial activities [16]. However, the performance of planted filters is affected by factors such as, hydraulic load characteristics, vegetation type, substrate type, pollutant concentrations, and local environmental effects [16]-[18]. The industrial slaughterhouse of the Société de Développement et d'Exploitation des Productions Animales (SODEPA) is located in a working-class district of the city of Yaounde in Cameroon. Currently, this establishment slaughters on average around 40,000 - 50,000 heads of cattle per year and produces around 6000 m^3 of wastewater per year [19]. The treatment plant of this slaughterhouse has not been functional for several years due to recurring breakdowns, aging and poor maintenance. The floristic diversity in the area surrounding the slaughterhouse shows the Poaceae family as the most represented, with *Echinochloa pyramidalis* being the dominant species. It would, therefore, be interesting to evaluate the performance of a filter planted with *Echinochloa pyramidalis* for the treatment of slaughterhouse wastewater. There are few documented constructed wetland systems treating slaughterhouse wastewater in Cameroon. In addition, very few studies exist regarding the application of vertical sub-surface flow constructed wetlands (VSS-FCWs) to wastewater within the meat industry. This is despite the fact that VSS-FCWs have been proven to efficiently remove high organic loads, which are a major challenge for slaughterhouse wastewater [20]. The general objective of this work is to conduct a trial of slaughterhouse effluent treatment by *Echinochloa pyramidalis* planted filters by evaluating the effect of different concentrations of slaughterhouse wastewater on the purification performance of *Echinochloa pyramidalis* planted filters. More specifically, the aim is to determine the physico-chemical and bacteriological characteristics of raw wastewater from the SODEPA slaughterhouse; evaluate the purification performance of planted filters and determine the effect of different effluent concentrations on the growth parameters of *Echinochloa pyramidalis*.

2. Method

The experimental studies were conducted from June to October 2023 at the site of the experimental station of the University of Yaounde 1. The climate which is of the Guinean equatorial type, is characterized by the existence of 4 seasons with an average rainfall of 1600 mm. The experimental device consists of a series of 04 50-L pilots (container in the shape of a troque of 0.5 m in diameter and 0.5 m in height). Wastewater was collected at the slaughterhouse (SODEPA). 250 L of liquid effluent were collected during the four campaigns. Subsequently, this wastewater was transported to the experimental site to supply the different planted filters consisting of four treatment units: T1 (25% slaughterhouse effluent + 75% tap water), T2 (50% slaughterhouse effluent + 50% tap water), T3 (75% slaughterhouse effluent + 25% tap water) and T4 (100% slaughterhouse effluent). Each unit received a daily hydraulic load of 5 L of wastewater to be treated for three months. This supply method ensures optimal water distribution by improving the oxygenation of the system [21]. The plants were sown on a filter bed composed of three layers of materials of increasing particle size from top to bottom (**Table 1**).

Table 1. Substrate used in experimental tanks (Kengne *et al.*, 2008).

Substrate	Diameters (mm)	Heights (cm)	Porosity (n)	Uniformity coefficient (Cu)
Sand	0.3-2	10	40.30	3.55
Fine gravel	5-15	20	47.73	1.67
Coarse gravel	15-25	20	50.00	1.37

In accordance with the works of Paré *et al.* [22], the aeration of the system was improved by inserting vertically into the substrate a perforated piezometric tube made of polyvinyl chloride, measuring 0.60 cm in diameter and 50 cm in height. Each pilot unit was equipped with a tap to collect the percolate generated according to each treatment. The percolate was collected after a retention time of 5 days on a weekly basis for the entire duration of the study.

2.1. Harvesting and Transplanting Cuttings into Filters

The young shoots of *E. pyramidalis* used were harvested in a pond located below the buildings of the University of Yaoundé 1. After harvest, these young shoots were transformed into cuttings of 20 - 30 cm in height, from the root to the second internode. Within 24 hours of harvest, the cuttings were transplanted at a rate of 05 cuttings per treatment unit. For about two weeks, the cuttings were constantly irrigated.

2.2. Physicochemical and Bacteriological Characterization of Slaughterhouse Effluents

Monitoring the physicochemical and bacteriological quality of raw wastewater and percolate according to each treatment consisted of determining parameters such as temperature, pH, salinity, oxidation-reduction potential (Eh), Total Dissolved Solids (TDS) and electrical conductivity which were measured in situ using a HACH brand multiparameter. Other parameters including Suspended Solids (SS), color, Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), nitrate ions (NO_3^-), phosphate ions (PO_4^{3-}) were measured at the Plant Biotechnology and Environment Laboratory of the University of Yaoundé I following standard procedures [23].

2.3. Measurement of Bacteriological Parameters

Fecal coliforms (FC) and Fecal Streptococci (FS) were determined by membrane filtration technique and enumerated according to the standard protocol described by [23].

2.4. Purification Yields

The purification efficiencies were evaluated after determining the concentrations of the physicochemical and bacteriological parameters at the inlet and outlet of the planted filter systems. These efficiencies were estimated using the formula:

$$\text{Abatement}(\%) = \frac{\text{Ce} - \text{Cs}}{\text{Ce}} \times 100$$

where Ce = Concentration of the parameter at the filter input and Cs = Concentration of the parameter at the filter output [24].

2.5. Effect of Different Wastewater Concentrations on the Growth of *Echinochloa pyramidalis*

Some morphometric parameters were determined according to each treatment, namely plant size, stem diameter, and density. Plant size was measured using a double decameter from the base of the rhizome to the level of the appearance of young terminal leaves. Stem diameter was determined using a caliper from the third internode. Plant density was assessed by systematic counting at each pilot.

2.6. Data Analysis

The collected data were subjected to the analysis of the mean and standard deviation using the R Studio software version 4.0.5. The means are compared with each other using the Duncan test at the 5% threshold. The graphical representations are made using the Graph Pad Prism software version 8.0.1 and Excel from the Microsoft Office Word 2016 software.

3. Results and Discussion

3.1. Quality of Raw Slaughterhouse Wastewater before Phytotreatment

According to Table 2, the raw abattoir wastewater used for this study possesses a very high content of suspended solids (SS) of values 54,115 ± 745 mg/L. These insoluble and slowly biodegradable SS represented 50% of the pollution charge in screened slaughterhouse wastewater, while another 25% originated from colloidal solids (Sayed *et al.*, 1988). The organic loading of the wastewater was quantified by the concentration of nitrate, COD and BOD which gives the values of 3225.75 ± 448.92 mg/L; 13,592.2 ± 2007.3 and 5,367,167 ± 2922.71 mg/L respectively. Abattoir wastewater contains very high nutrients and organic matter [25] as well as high loads of bacteria and parasites. Anionic concentration values of 383.2 ± 13.61mg/L were recorded for orthophosphate. For the pH, Salinity and Electrical Conductivity, the value recorded were 7.96 ± 1.32; 10.06 ± 9.56 ppt and 16.31 ± 14.60 ms/cm respectively. For a comprehensive analysis of the effluent characteristics, 11 quality indicators were determined, both physical, chemical and biological. Generally, the quality of raw wastewater far exceeds applicable regulations, reaching 8 to 14 times greater [26]. Raw wastewater can be characterized as high strength effluent dominated by organic matter in suspended form and low biodegradability index (BOD_5/COD = 0.395). The color of the raw wastewater is blackish (dark), and the pH is slightly acidic 6.7. It was possibly influenced by animal blood and organic matter fermentation. The high COD concentration observed was attributable to poor waste separation mechanisms that allowed blood to mix with the carcass processing water. This influenced the nature of the wastewater and the other study parameters. The values of the parameters measured in slaughterhouse wastewater in this study are higher than those obtained [27].

Table 2. Physicochemical and bacteriological characteristics of wastewater from the SODEPA slaughterhouse.

Settings	Min	Max	Average
Temperature ˚C	26.2	29.63	28.13 ± 1.52
pH	6.79	9.46	7.96 ± 1.32
Conductivity (ms/cm)	5.5	36.4	16.31 ± 14.60
Salinity (ppt)	2.7	23	10.06 ± 9.56
Suspended matter (mg/l)	4362	6021	54115 ± 745
Nitrates (mg/l)	2855	3857	3225.75 ± 448.92
Orthophosphates (mg/l)	365	398	383.2 ± 13.61
Chemical oxygen demand (mg/L)	10,850	15,600	13,592.2 ± 2007.3
Biological oxygen demand (mg/L)	2300	9300	5367 ± 2922.71
Faecal streptococci (CFU/100 mL)	70,000	90,000	76,667.17 ± 9428
Faecal coliforms (CFU/100 mL)	10,000	97,000	90,500 ± 41,500

3.2. Physicochemical Quality of the Different Percolates Obtained Depending on Each Treatment

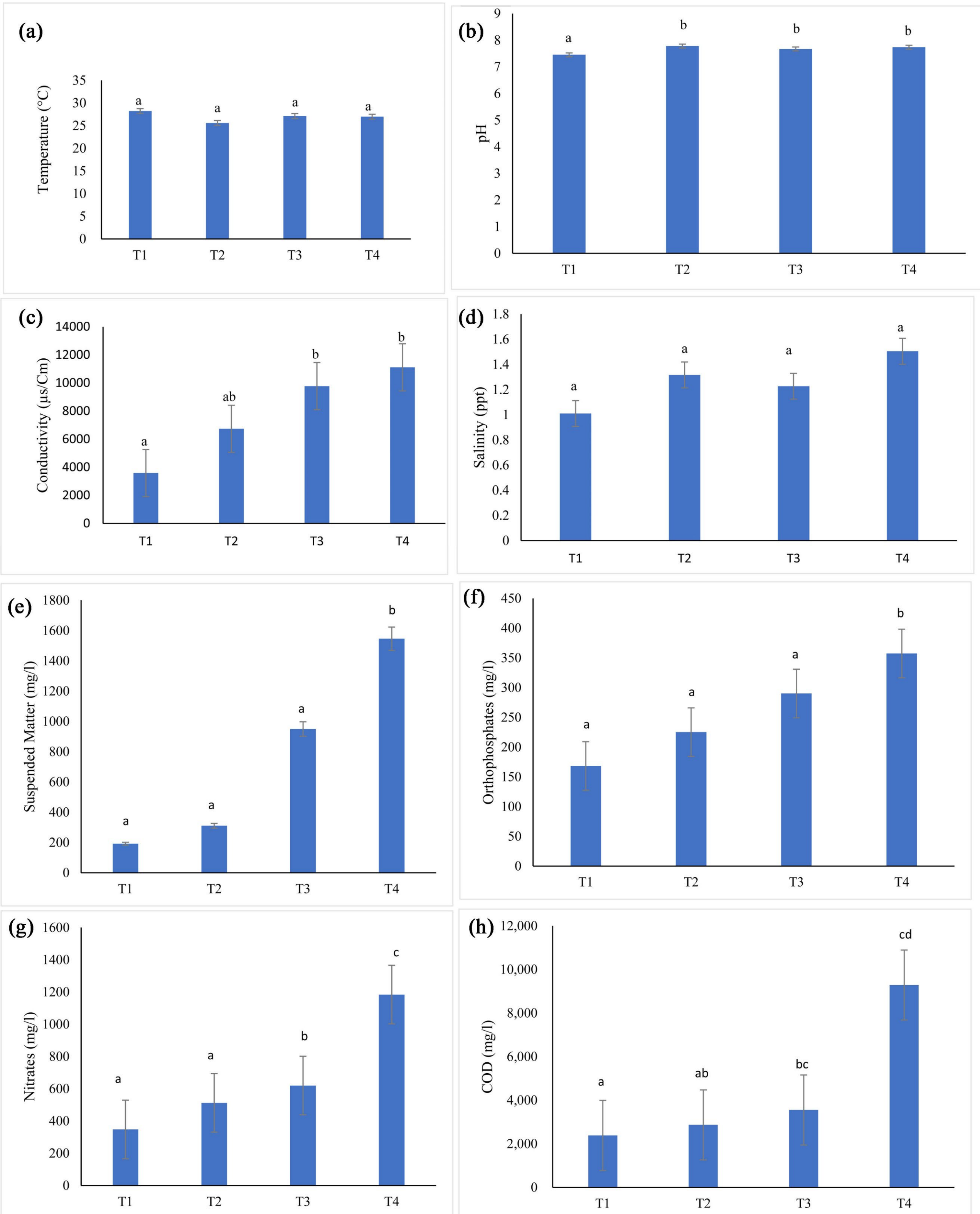
Table 3 presents the different results obtained for each treatment. In comparison with the raw slaughterhouse effluents; the values of the physicochemical parameters of the percolates show reduced concentrations for all the parameters measured. Among the treatments: T1 (25% slaughterhouse effluent + 75% tap water), T2 (50% slaughterhouse effluent + 50% tap water), T3 (75% slaughterhouse effluent + 25% tap water) and T4 (100% slaughterhouse effluent); **Figure 1(a)** shows no significant difference between the different treatments for the temperature parameter. The percolate from treatment T1 shows pH values lower than T2, T3 and T4 but **Figure 1(b)** shows a significant difference between T1 and the other treatments and no significant difference between T2, T3 and T4. For Electrical Conductivity T1 < T2 < T3 < T4. We can see from **Figure 1(c)** significant differences between T1 and T3/T4 and also between T2 and T3/T4. No significant difference was observed between the different treatments for the salinity parameter. The percolate from treatment T4 has a Suspended Matter value of 1546 ± 359 mg/L; followed by T3 (350 ± 142 mg/l) (See **Figure 1(d)**). For this parameter, a significant difference is observed between T4 and the other three treatments **Figure 1(e)**. The nitrate values have considerably decreased compared to the raw effluent

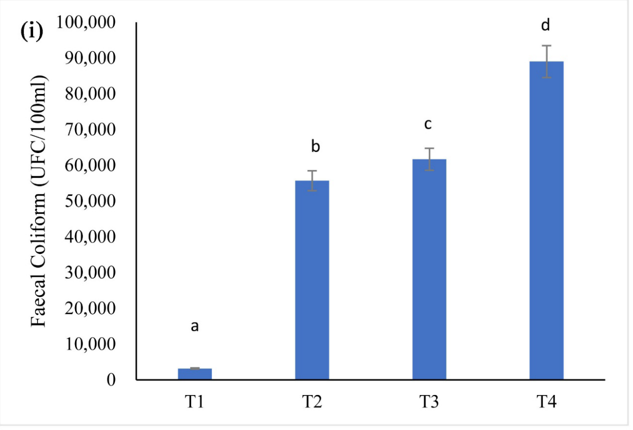
Table 3. Contents of physicochemical and bacteriological parameters according to the different treatments.

Settings	T1	T2	T3	T4	Slaughterhouse effluent	Who/ Minepde
Temperature (˚C)	25.14 ± 1.45	25.60 ± 1.63	27.13 ± 2.56	26.98 ± 2.31	28.13 ± 1.52	30
pH	7.45 ± 0.291	7.78 ± 0.014	7.67 ± 0.21	7.74 ± 0.11	7.96 ± 1.32	6 - 9
Conductivity (mS/cm)	3.59 ± 3.742	6.75 ± 5.08	9.78 ± 9.28	11.12 ± 10.9	16.31 ± 14.60	
Salinity (PPT)	1.01 ± 0.78	1.32 ± 0.28	1.23 ± 0.053	1.51 ± 0.3	10.06 ± 9.56	
Suspended matter (mg/l)	192 ± 30.54	310.68 ± 129.54	950 ± 142.89	1546.33 ± 359.34	54115 ± 745	
Nitrates (mg/l)	347.71 ± 162	512.50 ± 240.5	620.09 ± 287.70	1183.98 ± 645.1	3225.75 ± 448.92	<50 mg/l
Orthophosphates (mg/l)	168.33 ± 83.16	225.25 ± 45.97	290.25 ± 33.54	357.50 ± 35.94	383.2 ± 13.61	
COD (mg/l)	2384.75 ± 2118.13	2861.25 ± 2208.53	11052.04 ± 9499.06	9287.13 ± 7251.63	13592.2 ± 2007.3	≤50 mg/l
BOD_5 (mg/l)	1493.75 ± 692.98	2575 ± 1418.19	2583.33 ± 1200.2	2660.21 ± 2129.99	5367 ± 2922.71	≤200 mg/l
Biodegrability index (BI) BOD5/COD	0.63	0.89	0.23	0.29	0.39	
Faecal streptococci (CFU/100ml)	733.33 ± 169.97	1500 ± 244.95	25833.33 ± 6059.89	50000 ± 6531.97	76667.17 ± 9428	≤1000 CFU/100ml
Faecal coliforms (CFU/100ml)	3166.67 ± 235.7	5559.56 ± 942.81	61666.67 ± 2357.02	89000 ± 1414.2	90500 ± 41500	≤2000 CFU/100ml

(32,225.75 ± 448.92 mg/L). Treatment T1 (347.71 ± 162 mg/L) < T2 (512.50 ± 240.5 mg/L) < T3 (620.25 ± 287.50 mg/L) and <T4 (1183.98 ± 645.1 mg/L). Figure 1(g) shows significant differences between treatments T1, T3 and T4 on the one hand and between T2 and T3/T2 and T4 on the other hand. For orthophosphate, Figure 1(f) shows a significant difference between treatment T4 and treatments T1, T2 and T3.

The raw effluent has a COD value of 13,592.2 ± 2007.3 mg/L. Only treatments T1 and T2 showed lower values of 2384.75 ± 2113 mg/L and 2861.25 ± 2208.53 mg/L respectively. T3 and T4 have high values close to that of the effluent namely 11,052.04 ± 9499.06 mg/L and 9287.13 ± 7251.63 mg/L respectively. Figure 1(h) shows significant differences between the different treatments. The BOD_5 values were reduced in treatment T1 compared to treatments T2; T3 and T4. For the values of faecal streptococci (FS), Table 3 shows that treatments T1 (733.33 ± 169.97 CFU/100 ml) and T2 (1500 ± 244.95 CFU/100 mL) have lower values than those of T3 (25,833.33 ± 6059.89 CFU/100 mL) and T4 (50,000 ± 6531.97 CFU/100 mL). Similarly for faecal coliforms (FC) with T1 (3166.67 ± 235.7 CFU/100 mL) and T2 (5559.56 ± 942.81 CFU/100 mL) lower than T3 (61,666.67 ± 2357.02 CFU/100 mL) and T4 (89,000 ± 1414.2 CFU/100 mL). Figure 1(i) and Figure 1(j) show significant differences between treatments. The planted filter system in this study demonstrated remarkable efficiency in reducing the concentrations of various parameters measured in raw effluents. The removal of nitrogenous compounds in planted filter systems mainly relies on several biological processes, including ammonification, nitrification, nitration, and denitrification [28]. These processes are inherently dependent on the oxygen content of the surrounding environment.





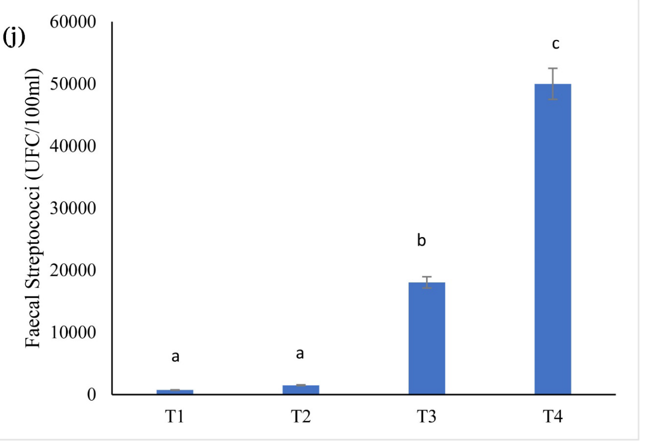


Figure 1. Percolates concentration according to different treatments. (a) Temperature, (b) pH, (c) Electrical Conductivity, (d) Salinity, (e) Suspended Matter, (f) Orthophosphate, (g) Nitrate, (H) COD, (i) Faecal Coliform, (j) Faecal Streptococci.

Furthermore, the reduction of nitrogen forms can be attributed to various mechanisms, including plant uptake, adsorption to the surface of substrate particles, and volatilization/denitrification

The efficient removal of COD and BOD_5 depends on the biodegradation of organic matter, orchestrated by heterotrophic bacteria in the rhizosphere [29]. Treatment T1 showed a high reduction in COD and BOD_5, due to the assimilation by plants of essential nutrients present in the filter and to the diluted hydraulic load compared to treatment T3 and T4. This not only promotes optimal plant growth, but also an increased contact between the organic matter present in the percolates and the mineralizing microorganisms of the rhizosphere [30]. Macrophytes, in their role as photosynthetic oxygenators and specific dissolved salt absorbers, have proven their ability to reduce BOD_5 in effluents [31].

3.3. Purification Efficiency of the Different Treatments Applied to the *Echinocloa pyramidalis* Planted Filter

Figure 2 shows the evolution of purification performances for each treatment according to each physicochemical parameter.

The MES are 85.79% for T1; 88.51% for T2; 76.58% for T3 and 71.40% for T4. The COD is 74.67percentage for T1; 79.65%for T2; 54.67% for T3 and 26.76% for T4. The BOD_5 is 69.91% for T1; 55.76% for T2; 56.21% for T3 and 38.95% for T4. The PO_4^{3-} is 29.86% for T1; 29.92% for T2; 24.22% for T3 and 19.66% for T4. Nitrate is 45.62% for T1; 59.93% for T2; 67.80% for T3 and 53.72% for T4. The FS are 86.05% for T1; 77.81%for T2; 83.79% for T3 and 51.03% for T4. The FCs are 84.1% for T1; 73.80%for T2; 72.26% for T3 and 72.05% for T4.

The best yields are observed with treatments T1 and T2. Treatment T4 shows low reduction percentages. The observed bacteriological purification performances, particularly in treatments T1 and T2, can be explained by the adequate availability of essential elements to support microbial metabolism. This reduction is consistent with the results obtained in similar systems by [32] and [33].

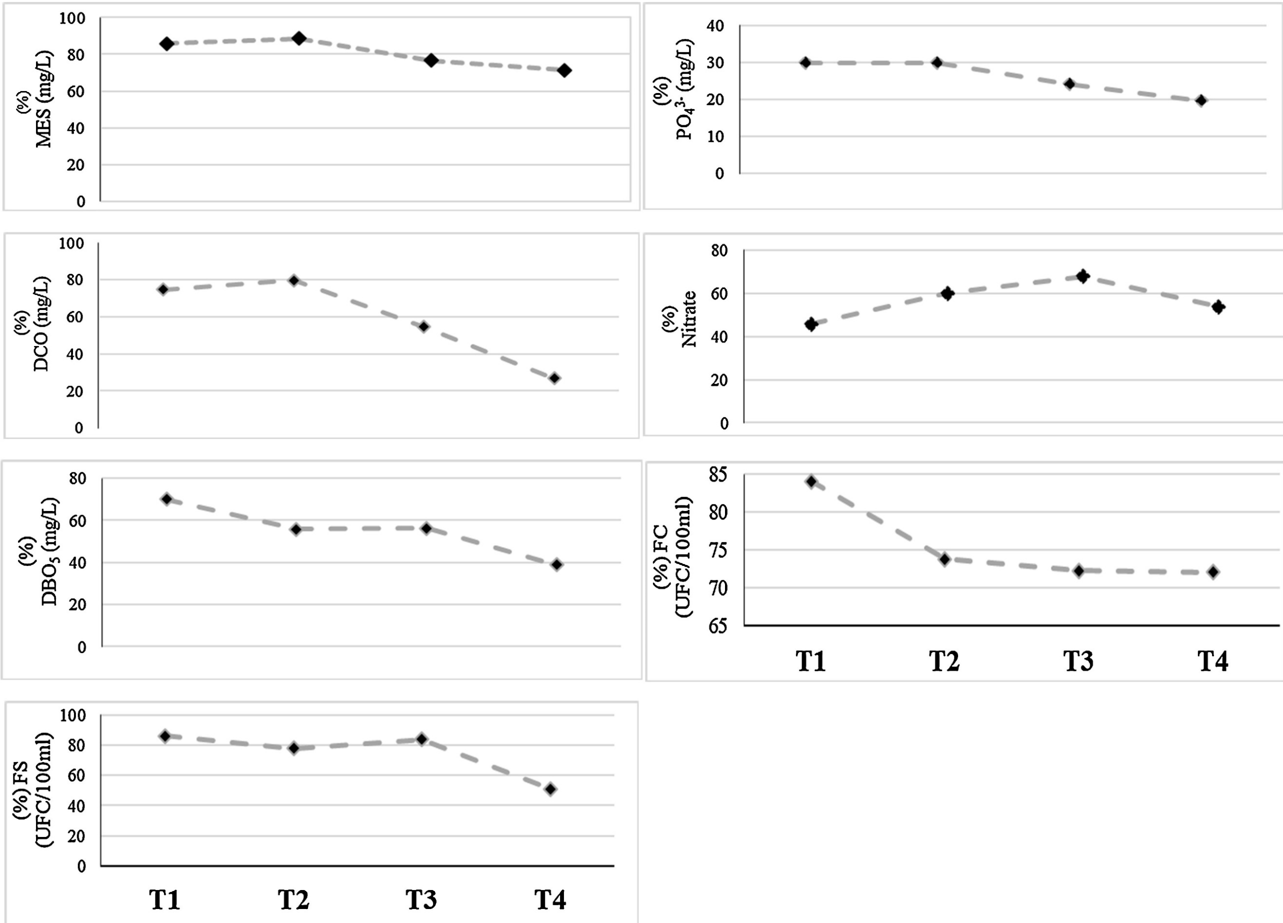


Figure 2. Purification yields of different percolates depending on the parameters measured and different treatments.

The results obtained by [34], revealed that the removal of effluent parameters increased with increasing retention time of wastewater in constructed wetland. The maximum removal efficiency of constructed wetland with *Typha latifolia* for the parameters of phosphate, COD, BOD_5, nitrate, TDS and TSS were 85.8%, 77.5%, 93.3%, 68%, 71.3% and 88.7% respectively. It was concluded that the constructed wetland performed well for the treatment of slaughterhouse wastewater. A research site was established at a small-scale abattoir in Great Village, Nova Scotia, Canada [35]. At the site, a 58.5 m^2 two-celled surface flow constructed wetland with *Typha latifolia* was constructed. Mass removal during two years of continuous monitoring was BOD_5 (95%). [36] showed in their study by using anaerobic baffled reactor technology with predetermined hydraulic retention time (HRT) to treat slaughterhouse wastewater containing BOD_5 and COD. The study employed two HRTs. Undiluted and diluted slaughterhouse wastewater was used. The HRT of the 2 h and 6 h applications demonstrated a strong correlation in reducing BOD_5 and COD levels in slaughterhouse wastewater. The most efficient values for the BOD_5 and COD parameters were achieved at an HRT of 6 h. For BOD_5, undiluted slaughterhouse achieved a peak efficiency of 62.31%, while diluted slaughterhouse reached 87.37%. Regarding COD, both undiluted and diluted slaughterhouse wastewater exhibited their highest efficiencies with values of 66.98% and 92.69%, respectively. These results can justify those obtained with the T1 and T2 treatments. Hydraulic retention time is generally known to have a positive linear relationship with pollutant removal efficiency [37]. The higher performance observed for overall pollutant removal at HRT 5 in the current study is further supported by [38] who observed that longer retention time allowed for increased contact between microbial communities and the wastewater. The longer retention time of 5 days in the current study greatly increased removal efficiency of some pollutants compared to 1 and 3 days retention times in the study of [27]. Improved buffering capacity of adsorbing organic media from longer remaining periods of five days also slightly increased NH_4-N nitrification. TSS (Total suspended solid) and BOD_5 were found to perform better under a longer retention time of 5 days. On the contrary [39] found that the highest pollutant removal rates were achieved after a short time. However, [34] obtained significant reductions in pollutants observed after 9 days retention time but the average effluent concentrations of certain parameters did not meet maximum permissible limit standards for safe discharge of industrial wastewater in land water surface. The phosphate removal is shown in **Figure 2**. It was found that the removal of phosphate increased with increasing retention time. The deposited sediments and macropytes present in wetland did major role in phosphate removal. The initial nitrate concentration of slaughterhouse wastewater was 3225.75 ± 448.92 mg/L (**Table 2**). Constructed wetland reduced the nitrate significantly from the wastewater (59.93% for T2 and 67.80% for T3). Denitrification, adsorption and incorporation into cell mass were the key processes for the reduction of nitrate in constructed wetland.

Hydraulic loading rates (HLR) is known to substantially impact treatment efficiency of wetland systems, particularly in tropical regions. This is attributed to suitability of temperature for rapid organic matter breakdown [40]. The study used hydraulic loadings of 5 L per day for each treatment. [27] in their study suggest that reduced loads under longer retention and feeding interval gave better results for BOD_5 and TSS (Total suspended solids). This observation can justify the low yields obtained in the case of treatments T3 and T4.

For the Biodegradability Index, BI > 0.5 means easily biodegradable, 0.4 - 0.5 shows average biodegradability and 0.2 - 0.4 indicates slow biodegradation. BI is the ratio of BOD_5 and COD as a measure of the biodegradability of wastewater and leachate from different treatments [41] [2]. The results of raw wastewater measurements reveal a BI value of 0.39 (slowly biodegradable). Generally, wastewater from a slaughterhouse has a ratio between 0.3 and 0.6. Hence, the biological treatment process will be slow and several additional processes are needed to accelerate the biodegradation. The results showed that the BI value for the four treatments were 0.63; 0.89; 0.23 and 0.29 respectively for T1, T2, T3 and T4, indicating that it was easily biodegradable for T1.

The results of faecal streptococci and faecal coliforms in this study are superior to those obtained by [2] for the characterization of effluents from the Etoudi slaughterhouse. Their results clearly show that coliforms and faecal streptococci are present at high concentrations, 7800 and 4300 CFU/100 ml, respectively. The authors strongly emphasized the implementation of constructed wetlands as a tertiary treatment unit in case of slaughterhouse effluent [42]. Our study showed for FS: 86.05% for T1; 77.81% for T2 and 83.79% for T3 and for FC the best yields are obtained with T1 (84.1%). Microbiological results can be judged as satisfactory, taking into account that no disinfection process was incorporated in the treatment system. Several studies have reported good results in slaughterhouse wastewater treatment. The use of gravel planted with *Typha domingensis*, *Typha orientalis*, *Phragmites australis*, and *Scirpus validus* can reduce TSS (83% - 89%), turbidity (58% - 67%), total N (14% - 56%), and total P (37-61%) on hydraulic retention time between 2.7 and 3.6 days [2].

3.4. Response *of Echinocloa pyramidalis* to Different Wastewater Inputs in Planted Filters

The observation of Figure 3 shows that treatments T1 and T2 are favourable for good plant growth. All morphological parameters (plant size, collar diameter; leaf area and density) change each week depending on the hydraulic load and retention time. Treatment T0 here corresponds to watering with tap water in one of the filter devices planted with *Echinocloa pyramidalis* to monitor its growth in comparison with treatments T1, T2, T3 and T4. The average plant height after

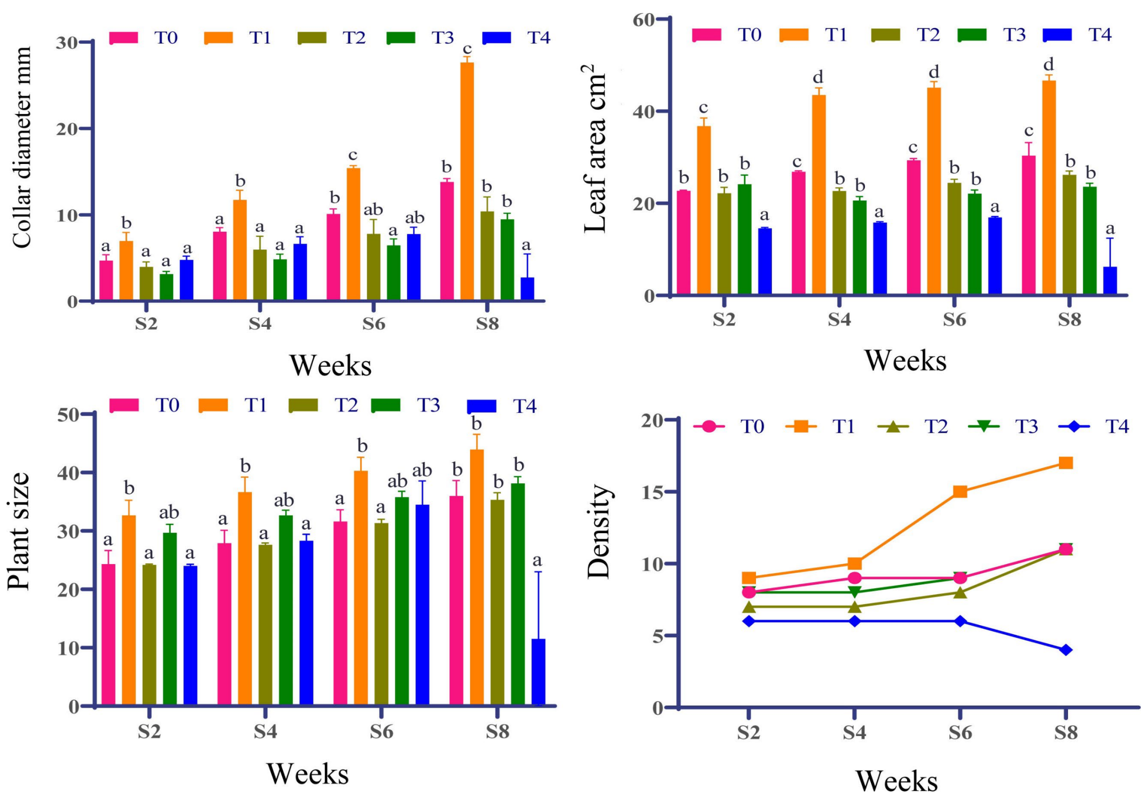


Figure 3. Morphological parameters measured for each treatment.

application of raw wastewater is highly variable depending on the different hydraulic loads. T1 shows a height of 37 cm. The diameter at the stem collar varies from 0.2 cm to 1.4 cm. The average plant density increased from 5 plants to a maximum of 17 plants at T4. Significant differences are observed between the different treatments. Treatment T4 shows the lowest values (See **Figure 3**).

The macrophytes like *Echinocloa pyramidalis* are cost-effective universally available aquatic plants and with their ability to survive adverse conditions and high colonization rates, are excellent tools for studies of phytoremediation. The feasibility of using CW to remove pollutants from slaughterhouse wastewater was tested using three macrophytes. *Typha latifolia*, *Thalia geniculata* and *Colocasia esculenta* achieved maximum heights of 2.1 m, 1.4 m, and 0.7 m respectively for the three species within 3 months of establishment in a Pilot-Scale Horizontal Subsurface Flow Constructed Wetland [43]. *Thalia geniculata* was a more suitable plant to treat slaughterhouse wastewater because of its higher above ground biomass yield. From a density of 28.6 shoots/m^2 at start of the study, 80 shoots/m^2 were obtained after 3 months of establishment for the cell planted with *Typha latifolia*; 97.1 shoots/m^2 for the cell planted with *Thalia geniculata* and 57.1 shoots/m^2 for the cell planted with *Colocasia esculenta*. The plant above-ground biomass yield for *Thalia geniculata* was the highest with a value of 4.57 kg dry biomass/m^2. The values of the above-ground biomass obtained for *Typha latifolia* and *Colocasia esculenta* were 2.86 and 1.71 kg dry biomass/m^2 respectively. The above-ground biomass yield for Thalia geniculata was approximately 1.6 times that of *Typha latifolia* and approximately 2.7 times that of *Colocasia esculenta*. [44] showed in their work that the three plants namely, Water Hyacinth (*Eichhornia crassipes*), Duckweeds (*Lemna minor*), filamentous algae were cultivated in three identical tubs, with a depth of 20 cm, having 12 L slaughterhouse wastewater. The growth parameter of plants was investigated at the interval of five days for 30 days. It was found that all three plants Water Hyacinth (WH), Duckweeds (DW), and filamentous algae are an invasive aquatic plant that can double itself in 5-15 days in favorable conditions. In one month WH, DW and algae produced 547 g/m^2, 330 g/m^2, and 209 g/m^2 biomass and covered all available surface of the tub. After 20 days, all available surfaces of the tubs were covered and an inhibition was seen in the growth. Another study was carried out on the morphological characteristics and treatment potential of *Cyperus papyrus*, *Typha domingensis*, *Miscanthidium violaceum*, and *Phragmites mauritianus* receiving slaughterhouse wastewater in Kampala, Uganda, in experimental mesocosms. All planted mesocosms achieved significantly higher removals for nitrogen, phosphorus and organic matter than unplanted mesocosms [45]. Among macrophytes, *C. papyrus* depicted highest pollutant uptake. *C. papyrus* achieved the highest biomass (31.0 kg dry weight/m^2), compared to *T. domingensis* (7.5 kg dry weight/m^2). *C. papyrus* had the largest total root surface area (200,634 cm^2) in experimental mesocosms measuring 960 cm^2. In our study *Echinocloa pyramidalis* responds well to the different treatments applied thanks to its large biomass and its great capacity for adaptation (Visiy *et al.*, 2022). Quality of treated effluent proved phytoremediation as an effective technology for abattoir wastewater treatment using locally available macrophytes and eventual application for irrigation purpose [38].

4. Conclusion

The results of the study revealed that the constructed wetland had an ability to treat slaughterhouse wastewater. It was clear from the results that there was a significant reduction in the concentration of above discussed parameters with different dilution hydraulic loading rates and short retention time. The physicochemical and bacteriological composition of the effluents from the slaughterhouse and the different percolates presents a very large variability. The T1 treatment (25% of slaughterhouse effluent diluted to 75% of water) strongly influences the morphometric parameters of *Echinocloa pyramidalis* which achieved high removal for all variables, due to its superior growth characteristics such as high biomass. Decrease in nutrients in effluent wastewater is attributable to plant uptake, nitrification-denitrification processes (for nitrogen) and adsorption on to plant roots (for phosphorus). Each treatment (T1, T2, T3 and T4) showed reduction in concentrations of suspended matter, nitrate, orthophosphate and organic matter represented by the measurement of Biological Oxygen Demand and Chemical Oxygen Demand. Phytoremediation using vertical flow constructed wetland is an effective green technology for the treatment of slaughterhouse wastewater. Proper selection of locally available plants will ensure survival and better treatment performance. Five days retention achieved the pollutant reduction over all the treatment. Less hydraulic loads gave best results for COD removal. The application of vertical flow constructed wetland for organic matter treatment would work well in tropical regions. However, to match the high-strength characteristics of complex recalcitrant pollutants, treatment through combined processes is found to be more effective than stand-alone treatment. Updates to the treatment train should incorporate a form of anaerobic digestion. Future research should focus on optimization of combined processes under varying environmental conditions.

Conflicts of Interest

The authors declare no conflicts of interest.

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