Use of water hyacinth (*Eichhornia crassipes*) to treat biogas effluent of a tapioca industry wastewater treatment system

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Abstract: This research aims to evaluate performance of a water hyacinth (*Eichornia crassipes* (Mart) Solms) pond used to treat biogas effluent of a tapioca industry wastewater treatment system. The water hyacinth pond which treats biogas effluent has been monitored for about two months. Wastewater samples were taken from influent and effluent of the water hyacinth pond. Parameters to be observed included wastewater quality parameters (pH, temperature, turbidity, BOD_5, ammonia, solids, evapotranspiration, discharge, and hydraulic retention time) and water hyacinth parameters (growth, population density, moisture, ash, nutrient contents). The results showed that water hyacinth improved some parameters of the biogas effluent to some extent. Within hydraulic retention time (HRT) of 53 days, pH increased from 7.0 to 7.2 and some reductions of turbidity by 27.1%, BOD_5 by 3.2%, ammonia by 10.5%, total solid (TS) by 13.1%, total filterable solid (TFS) by 11.4%, total suspended solid (TSS) by 35.2%. With water hyacinth population of 10.17 kg m^{-2}, evapotranspiration was 5.48 mm d^{-1}. The water hyacinth grew from 415 g m^{-2} to 3375 g m^{-2} within 41 days, meaning that daily increase rate of 72.2 g d^{-1} and relative growth rate of 5% d^{-1}. The doubling time of water hyacinth was 13.56 days. Annual nutrient uptake for carbon (C), nitrogen (N), phosphor (P), and potassium (K) by water hyacinth was found to be 7800, 699, 701, and 333 kg ha^{-1}, respectively.

Keywords: wastewater, biogas, environmental burden, organic matter, Indonesia

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1 Introduction

Cassava is one of the leading agricultural commodities in Lampung Province, as evidenced by the large areas of cassava plantation. In 2016 plantation area for cassava in Lampung reached 247,571 ha with production quantity of 6.48 million ton of cassava tubers (BPS-Statistics of Lampung, 2017). This large cassava production has borne many cassava processing businesses, both large and small companies. Our study revealed 71 units cassava-based industries are in operation throughout Lampung Province with a total capacity of 5.2 million ton cassava tubers annually. Most them process cassava into tapioca starch. In addition, there are four small scale tapioca industries (called ITTARA) run by community with capacity up to 80 ton fresh cassava tubers per day (Hasanudin et al., 2011).

Tapioca industry uses a lot of water in its production process (4.3 to 5 m^3 per ton of cassava root). As a result, the tapioca extraction process produces a lot of wastewater at a range of 2.82 to 4.94 m^3 t^{-1} depending on level of adopted technology. The wastewater was high in organic matter with COD and BOD_5 value of 20,433 and 11,466 mg L^{-1}, respectively (Hasanudin et al., 2011). Some cassava mills have installed biogas digester to treat

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wastewater while producing biogas that can be used as renewable energy to generate electricity or to dry cassava flour. The effluent resulted from biogas digester, however, still contains organic matter at a concentration that is not allowable to be released into water stream directly. In fact, this effluent need to be further treated in a series of ponds to decrease its COD value until a value that can be discharged into the river.

Processing wastewater from food industry can be performed by physical, biological, or chemical treatments. Wastewater treatment processes, especially those containing organic compounds, generally use biological processes by utilizing the activity of microorganisms in a series of ponds to decompose the organic compounds. This wastewater treatment process requires a large ponds and need long residence time (Said, 2002). Another treatment that attracts attention is phytoremediation by using aquatic weeds such as water hyacinth and water lettuce (Mohd et al., 2018; Rezania et al., 2015; Victor et al., 2016).

Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic weed with a very fast growth rate and propagation. Most problems associated with water hyacinth are its interference with navigation of water flow, altering the oxygen level of the water, encourage the build-up of snails, and provide or enhance breeding places for certain disease-carrying mosquitoes, as well as the risk it poses of mechanical damage to hydroelectric systems (Gupta et al., 2012; Nayanathara and Bindu, 2017). Beside of its negative impacts, there are many possible applications of water hyacinth including aquaculture, energy and fertilizer production, animal feedstock, raw material for local industries, and wastewater treatment (Ojeifo et al., 2000). The ability of water hyacinth to decrease biological oxygen demand (organic load) and nutrient levels makes it suitable for wastewater treatment. Water hyacinth grows double in 5 to 15 days and in just eight months 10 plants can produce population of 655,330 individuals (Gupta et al., 2012). In one-hectare pond of water hyacinth is estimated to produce 226.9 ton of dry matter biomass per year (Greco and Freitas, 2002). This has triggered to the exploration of its potential use as a biological treatment for domestic and industrial wastewaters.

Phytoremediation using water hyacinth is recently attractive as a method to treat wastewater resulted from different sources, such as domestic activities (Qin et al., 2016; Valipour et al., 2015), residential (Adewumi and Ogbiye, 2009), cassava mills (Felani and Hamzah, 2007), sewage (Dar et al., 2011; Jamuna and Noorjahan, 2009; Kumar and Garde, 1989), livestock (Lu et al., 2008), tofu industry (Fadhillah et al., 2017; Fitrihidajati et al., 2018), mine industry (Mohd et al., 2018; Saha et al., 2017), dyeing and textile industry (Priya and Selvan, 2017; Ugya et al., 2019), refinery and petrochemical industry (De Casabianca et al., 1995; Ismail and Beddri, 2009; Ugya and Imam, 2015). The benefits of water hyacinth include its ability to absorb nutrients and heavy metals and inorganic substances in polluted waters (Priya and Selvan, 2017; Rezania et al., 2015). Water hyacinth can reduce the value of BOD, COD, C, and N in tapioca wastewater, and increase the pH value (Felani and Hamzah, 2007).

The treatment of wastewater using water hyacinth is very feasible to develop because of its inexpensive cost (capital and operational). The operation does not require special skills for the operator. Moreover, the biomass of water hyacinth plants can be used to produce various economic value products such as handicrafts, animal feed, and organic fertilizers. However, the performance of the water hyacinth system in terms of wastewater treatment needs to be studied first. Many wastewater treatment using water hyacinth is carried out, but its performance may vary with different wastewater sources. This study aims to evaluate the performance of water hyacinth pond to further treat wastewater effluent resulted from a biogas digester facility in a community-scale cassava mill.

2 Materials and methods

2.1 Description of the wastewater treatment system

Research was conducted at the wastewater treatment facility of Semangat Jaya Trading Company (PD.

Semangat Jaya). It is a small scale community-based cassava mill operated since 1998 in the village of Bangun Sari, District of Negri Katon, Pesawaran Regency, Lampung Province (Figure 1). The company is operated with a daily capacity of 30 to 80 ton fresh tubers. Wastewater comes from cassava washing step, grating process, tapioca settling pond, and juice of cassava pulp (*onggok*) pressing. After passing through the sedimentation basin, all waste water is flowed into the biogas digester in order to undergo anaerobic decomposition process and produces biogas fuel. The effluent from the biogas digester is then discharged into the water hyacinth pond as influent through a 3-in. PVC tube. The water hyacinth in the pond was already mature with a normal density population (Figure 2). The pond was constructed by excavating the earth with a depth of 6 m and surface area of 25 m × 36 m. With a side slope 3:1 and freeboard of 40 cm, the pond is able to store 4343 m^3 wastewater. The treated effluent from the water hyacinth pond is discharged into a storage pond and then pumped for irrigation of vegetable gardens.

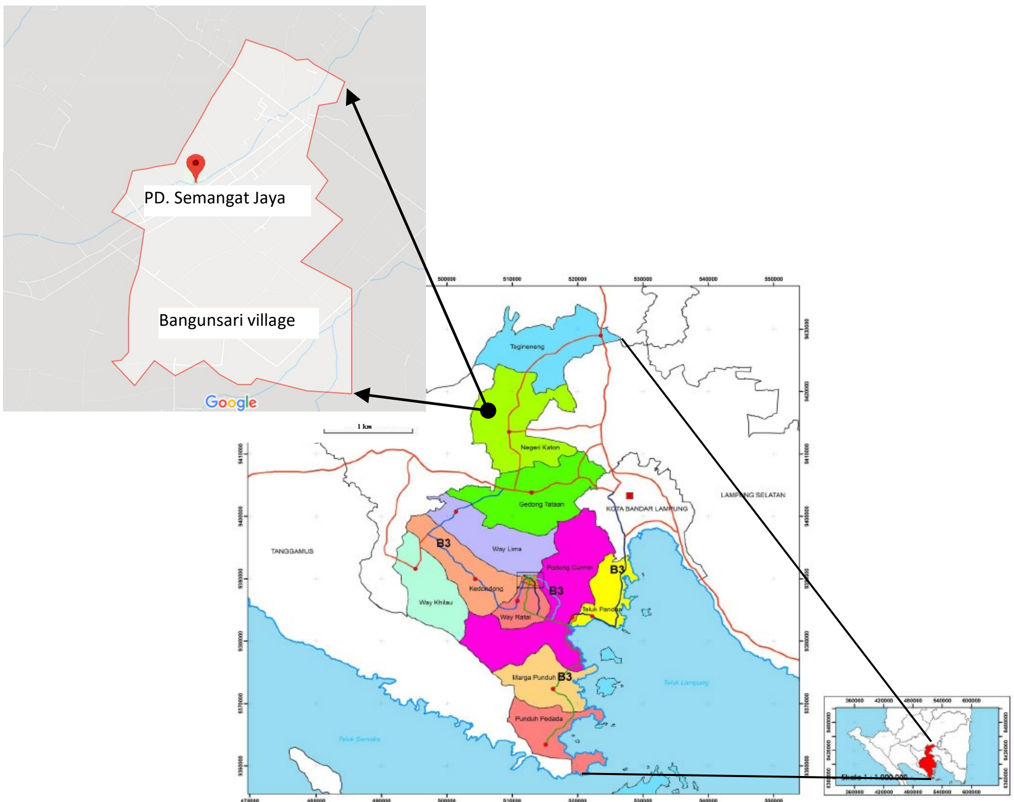

Figure 1 Location of the research (PD. Semangat Jaya, Bangun Sari Village, District of Negeri Katon, Pesawaran Regency, Lampung Province)

2.2 Experiment procedure

The research was begun by making five wooden plots 1m × 1m with a depth of 10 cm. Two wooden plots without base were used to observe and measure the growth rate of water hyacinth. The other three plots, 20 cm depth with plastic base, were used to measure evapotranspiration of water hyacinth. Five spots on the water hyacinth pond were selected and the existing water hyacinth was cleared out in order to place the five wooden plots. Three plots with plastic base were initially filled with 50 liters of wastewater, and were measured periodically by using a graduated cylinder in order to monitor water loss through evapotranspiration. Each of all five plots was cultivated with 415 grams of young water hyacinth (around 20 seedlings as presented in Figure 2). The growth rate of water hyacinth was performed weekly by taking all the plants from the two plots without base, draining all the water from the plants and then weighing the plants. The plants were returned back to the plots for the next measurement. Growth rate was expressed in daily increase rate (*DIR*) (De Casabianca, 1985), daily relative growth rate (RGR%) and biomass doubling time (DT) (Gutiérrez et al., 2001) defined as the following:

$$DIR = [(B_1 - B_0)/(t_1 - t_0)] \times 100/B_0 \quad (1)$$

$$RGR = (\ln B_1 - \ln B_0)/(t_1 - t_0) \quad (2)$$

$$DT = \ln 2/RGR \quad (3)$$

where B_0 (g) and B_1 represent biomass values (in gram) at time t_0 and t_1 (in day). The information of growth rate can be used to plan a control or harvesting program for water hyacinth.

Water hyacinth evapotranspiration was evaluated twice a week at 09:00–10:00 AM by measuring water loss in the three plots with plastic base by using a graduated cylinder The water level was returned back to the original level by adding wastewater. The volume of wastewater added to the plots was recorded as a double check for the accuracy of measuring water level by a ruler. Evapotranspiration was estimated from the difference of water levels in two consecutive measurements corrected by the amount of precipitation during the observation period. The rain water thickness was observed using a simple ombrometer placed near the pond.

Figure 2 High density water hyacinth pond with one observation plot (out of five) introduced with 415 g water hyacinth seedlings prepared for the experiment

Measurement of water hyacinth population was carried out by sampling method at the beginning of the study. A 1m x 1m wooden plot was thrown over a stretch of water hyacinth pond. All the water hyacinth inside the wooden plot is taken, then the population is calculated and weighed. Observation of the water hyacinth population was repeated three times in different places.

2.3 Sampling and measurements

The discharge of wastewater into and out of the water hyacinth pond was measured at the beginning of the study, by using a bucket that its volume is known and counting the time using a stopwatch. Waste water samples in and out of the water hyacinth pond were taken twice a week, using sample bottles and were then taken to the laboratory for its quality analysis (BOD_5, ammonia, TS, TSS, and turbidity). The acidity of wastewater (pH) was measured onsite using pH meters (PHMETER, PH_009(I)). BOD_5 was analyzed using DO meter after incubation for 5 days at 20°C. Turbidity meter was used to measure water turbidity. Ammonia content was analyzed using the nessler method followed by spectroscopy at a wavelength of 425 nm.

Water hyacinth biomass was harvested at the end of the study (41st day) from July 27 to September 2. Water content of hyacinth biomass was measured gravimetrically using oven (Memmert type UM 500). Ash content was measured by incinerate hyacinth biomass using furnace (Barnstead International model FB1310M-33) at temperature of 550°C for 2 hours. At the end of the study, samples were sent to the Soil Laboratory, Soil Science Department, Faculty of Agriculture, University Lampung, for analysis of C, N, P, K content.

3 Results and discussion

3.1 Wastewater balance

Wastewater balance coming in and out of the water hyacinth pond treatment system is presented in Table 1. The daily flowrate of wastewater coming into the pond was 82 m^3. With pond volume of 4343 m^3 the hydraulic residence time is 53 days, meaning that the wastewater will be in the water hyacinth pond for 53 days before it discharging out into the storage pond. The table also reveals an average evapotranspiration of 7.3 m^3 d^{-1} which equivalent to 5.48 mm d^{-1} (± 1.33 mm d^{-1}). This value is in accordance with average evapotranspiration rate of 7.5 mm d^{-1} (DeBusk et al., 1983) to 8.58 mm d^{-1} (Van Der Weert and Kamerling, 1974). This value is, however, lower than

14.37 mm d^{-1} (3.96 in a week) reported by Timmer and Weldon (1967). The difference can be resulted from different climate conditions (especially temperature and wind) and plant conditions (size, age).

The table also shows that wastewater discharged out of the treatment pond as an effluent is only 43,546 L d^{-1}. Using water balance, it can be demonstrated that 34,051 L d^{-1} (41.3%) of the wastewater lost from the pond through seepage and percolation. This large amount of water loss is resulted from the earthed-ground without water-tight layer. In general, soils in Lampung contain high coarse gravels that greatly influence the water seepage into the soil through the wall and floor of the pond.

Table 1 Water balance in the water hyacinth pond wastewater system

Item	Value	%
Influent flowrate (L d^{-1})	82,440	100.0
Effluent flowrate (L d^{-1})	43,546	52.8
Evapotranspiration of the whole pond (L d^{-1})	4,843	5.9
Percolation and seepage (L d^{-1})	34,051	41.3

3.2 Wastewater quality

3.2.1 Acidity (pH)

Figure 3 shows difference between pH of influent and effluent of wastewater treated using water hyacinth pond. In general the pH of effluent (average 7.17) is little higher than that of influent (average 7.01).

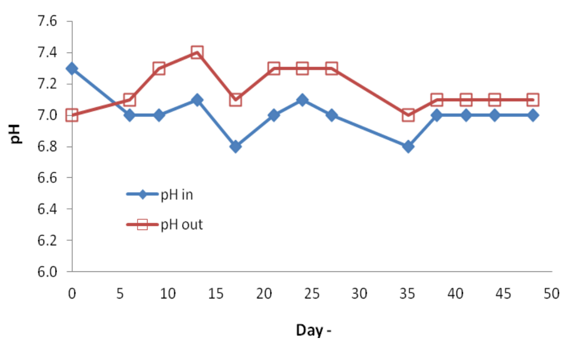

Figure 3 Degree of acidity (pH) of water hyacinth pond wastewater

The difference, however, is very small (0.16). This can be resulted from a fact that influent wastewater is already so close to the neutral region that the effect of water hyacinth is not significant. Haller and Sutton (1973) reported that water hyacinth increases the pH at pH range of 4-7 and decrease the pH at pH range of 8-12 (Haller and Sutton, 1973). Water hyacinth grows optimally at pH range of 6 to 8 (Téllez et al., 2008). However it survives in a wider range of acidity, from pH 4.0 to 10 (Haller and Sutton, 1973; Kriticos and Brunel, 2016). At both alkaline (pH > 10) and acidic (pH < 4) conditions, the growth of water hyacinth is inhibited.

According to the Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014 on the Quality Standard for Wastewater, especially those resulted from business and/or industrial activities of tapioca is demanded to have pH range of 6.0 to 9.0. Based on its pH value, wastewater resulted from biogas digester with or without post treatment using water hyacinth pond acts in accordance with the regulation. The results of wastewater treatment using water hyacinth show an increase in pH values that are in line with expectations, that waste treatment can raise the pH value.

3.2.2 Temperature

Water and air temperature can greatly influence water hyacinth growth and development. Optimum temperature for water hyacinth plants is in the range of 25°C–30°C (Kriticos and Brunel, 2016). During experiment, the average temperature of wastewater in the water hyacinth pond was 32.5°C with minimum and maximum value 28 and 34, respectively.

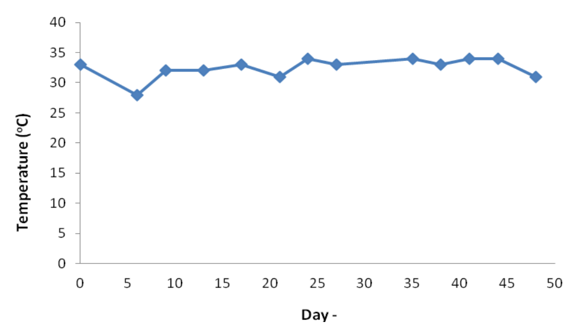

Figure 4 Wastewater temperature in the water hyacinth pond during experiment

A slight fluctuation of wastewater temperature (Figure 4) is caused by weather conditions which are sometimes cloudy or hot. The temperature of wastewater is usually higher than clean water, because of the intake of warm water from industrial activities. The range of wastewater temperature in our experiment is good for the growth of water hyacinth. Optimal water temperature for the growth of water hyacinth is 28°C–30°C (Magar et al., 2017). Zhang and Guo (2017) reported that in an early growth period, water hyacinths need effective accumulated temperature about 37ºC on average for growing one leaf (about 2 days at daily mean temperature of 28ºC) (Zhang and Guo, 2017).

3.2.3 Turbidity

The quality clearliness of water can be observed from its color. The color of wastewater originating from cassava washing process is generally brownish white with a suspension originating from impurities from cassava peel, while wastewater those derived from starch separation process is yellowish-white (Prayitno, 2008). The color of waste is caused by the presence of organic and inorganic materials, because of the presence of plankton, humus, metal ions (iron and manganese), and other materials. Turbidity is used to measure the degree to which the water loses its transparency due to the presence of suspended particulates. Water hyacinth, especially its roots, provide a suitable environment for aerobic bacteria and is useful to remove various impurities present in water including inorganic substances and other heavy metals (Magar et al., 2017).

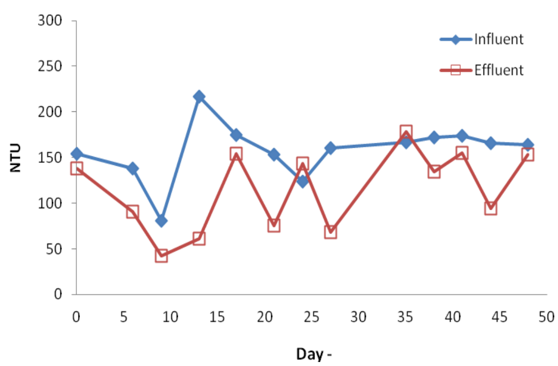

Figure 5 Turbidity value of wastewater entering and leaving the water hyacinth pond

The results of our study (Figure 5), show that, in general, water hyacinth pond can reduce wastewater turbidity. The average turbidity value of influent entering the water hyacinth pond is 157.26 NTU, and the average value of effluent is 114.69 NTU. This means that the efficiency of water hyacinth pond in decreasing the turbidity is 27% in average. Similar findings (25% reduction efficiency) has also been reported by Dhote and Dixit (2007). In a lower range (21.04 to 50.10 NTU), water hyacinth was reported to have much higher turbidity reduction efficiency (90.25% to 94.0%) (Khare and Lal, 2017). This reduction in turbidity is due to the root hairs as they have electrical charges of colloidal particles such as suspended solids and cause them to adhere on the roots where they are slowly digested and assimilated by the plant and microorganism (Brix, 1993; Wolverton, 1988).

3.2.4 BOD_5

Biochemical Oxygen Demand (BOD) is an indicator of organic matters that can be decomposed by microbes at a predetermined time period (5 days) and at a temperature of 20°C. The concentration of BOD_5 tapioca waste water (Figure 6) in water hyacinth pond has decreased. The average BOD_5 concentration of waste entering pond was 161.74 mg L^{-1} and the average concentration of BOD_5 outflow was 156.6 mg L^{-1}.

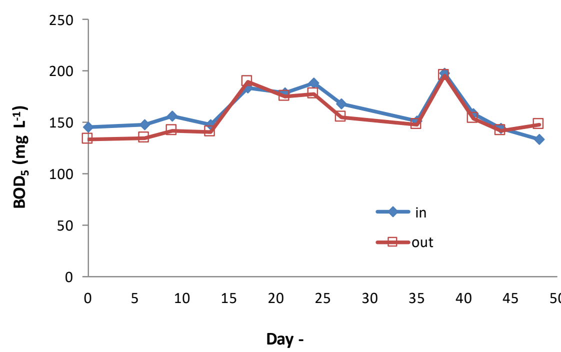

Figure 6 Concentration of BOD_5 tapioca liquid waste on water hyacinth pond

The decreasing BOD_5 value confirms that water hyacinth pond improves water quality of tapioca wastewater treatment. The efficiency of water hyacinth pond in BOD_5 reduction is very low (3%). Compared to other works, BOD_5 reduction efficiency from our experiment is considerably low. Saha et al. (2017) reported the introduction of water hyacinth in chromite mines wastewater is able to 50% BOD (Saha et al., 2017). Another study reported BOD reduction in the range of 40% to 70% in textile wastewater after introduction of water hyacinth within only 96 hours (Mahmood et al., 2005). The decrease in BOD_5 that occurs in wastewater treatment pond is due to decomposition by microorganisms and nutrient absorption by water hyacinth.

3.2.5 Ammonia

Figure 7 shows ammonia concentration of influent and effluent wastewater treated in water hyacinth pond. It reveals that water hyacinth pond decrease ammonia concentration of tapioca wastewater. Ammonia concentration in wastewater decreased from an average of 3.32 mg L^{-1} (influent) to 2.97 mg L^{-1} (effluent), which means the efficiency of the decrease was 10.5%.

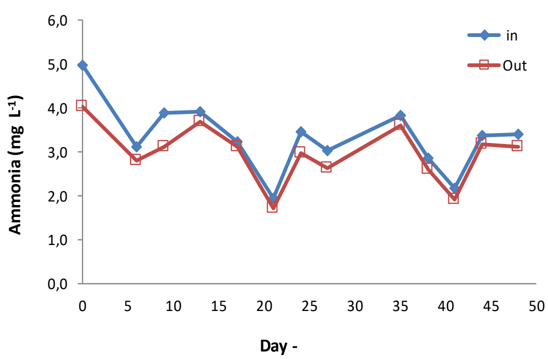

Figure 7 Ammonia value of tapioca wastewater treatment using water hyacinth

Hauser (1984) explained two main mechanisms for ammonia reduction in hyacinth pond systems including bacterial nitrification and plant uptake. Water hyacinths provide roots and other underwater parts to support bacteria conducting nitrification process. In this process, nitrogen is converted from the ammonia into nitrite and nitrate (Hauser, 1984). In an anaerobic environment, nitrate is reduced by a group of heterotrophic bacteria to gas nitrogen which then evaporates into the air. In addition to this process, ammonium nitrogen is also absorbed by the roots of water hyacinth which is then converted into biomass that is removed during harvesting water hyacinth plants.

3.2.6 TS, TSS, and TFS

The physical properties of wastewater include total solids (TS), suspended solids (SS), and filterable solids (FS) content. TS is composed of materials or particles floating, settling, colloidal in solution. SS is solids that will be suspended in wastewater, and will settle to the bottom of the pond for a long time. FS is solids in the volume of certain wastewater that passes through the filter paper pores. TFS is the difference between TS and SS. Figure 8 shows that TS content of influent wastewater in general is higher than that of wastewater effluent leaving the water hyacinth ponds. The TS concentration decreased from an average of 1293.46 mg L^{-1} (influent) to 1123.43 mg L^{-1} (effluent), which means the efficiency of the decrease was 13%. Figure 9 reveals that SS content in influent is higher than that of effluent. The SS concentration in wastewater decreased from an average of 88.31 mg L^{-1} (input) and 57.23 mg L^{-1} (output), which meant the efficiency of the decrease was 35%. The highest SS reduction occurred at water hyacinth age of 2–3 weeks after planting. The root system of water hyacinth acts in filtration process. Just like filtration process, as suspended solids go through the plant roots, they are trapped, gathered, and ultimately settle due to gravitation force or metabolized by microorganisms, while particulate matter goes down to the nethermost (Valipour et al., 2015).

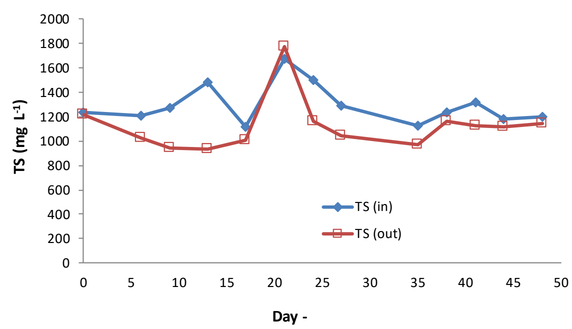

Figure 8 Total solid content in tapioca wastewater treatment using water hyacinth pond

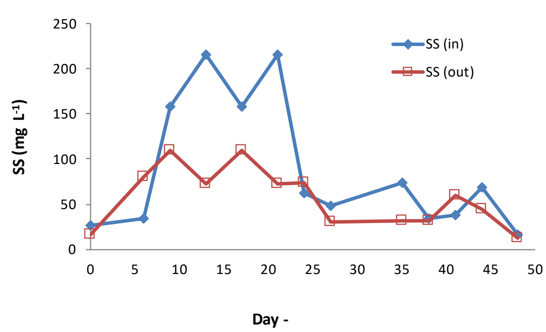

Figure 9 Suspended solid content in tapioca wastewater treatment using water hyacinth pond

3.3 Water hiacinth

3.3.1 Hyacinth Population

The sampling results show that average water hyacinth population in the pond is 14 plants m^{-2} with fresh mass weight of 10.17 kg m^{-2} or 102 ton ha^{-1}. This value is comparable to those reported Sahai and Sinha (1970) where seasonal biomass density differed markedly, ranging from 5.922 ± 0.445 to 12.47 ± 4.32 kg fresh matter per m^2 (Sahai and Sinha, 1970). The weight of water hyacinth per square meter greatly depends on the number of hyacinth plant density. Under normal conditions loosely packed water hyacinth can cover the water surface at relatively low plant density (10 kg m^{-2} wet weight) and it can reach maximum density of 50 kg m^{-2} wet weight (Rodrigues et al., 2014). De Casabianca (1984) found to a range of on-site biomass (in fresh weight) maintained in the basins of 13 kg m^{-2} during the first period and 30-33 kg m^{-2} during the second and third periods (De Casabianca, 1985).

3.3.2 Hyacinth growth rate

The development of hyacinths cultivated in plots without plastic base is presented in Figure 10. The composition of water hyacinth biomass harvested at the end of the experiment (41 days old) is presented in Table 2. The figure reveals that water hyacinths grow linearly from 415 g m^{-2} to 3375 g m^{-2} for 41 days cultivation. This means that daily increase rate (*DIR*) of 72.2 g m^{-2} d^{-1} and relative growth rate (*RGR*) of 0.05 per day or 5% d^{-1}. Assuming each square meter was cultivated 20 plants, the *DIR* for a single hyacinth is 3.61 g d^{-1} or 25.27 g $week^{-1}$. This result is in close correlation with the water hyacinth increase rate (33 g $week^{-1}$) reported recently by Magar et al. (2017). Based on our results we can calculate the doubling time (*DT*) as 13.56 days and estimate annual production of water hyacinth to be 300 t ha^{-1}. Some swampy areas in South America was reported to have annual productivity of water hyacinth about 350-1700 t ha^{-1} (Ndimele et al., 2011). In integrated harvest systems the average dry biomass production of water hyacinth varies between 40.5 to 47 t ha^{-1} y^{-1} or 30.6 to 35.2 g m^{-2} d^{-1} was reported (De Casabianca, 1985).

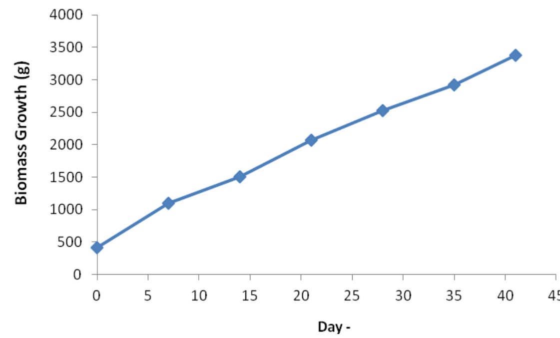

Figure 10 Average growth of water hyacinth in 1-m^2 plots

Table 2 Water hyacinth plants characteristic

Composition	Unit	Value
Water content (average)	% (wb)	92.2
* Leaf	% (wb)	88.5
* Stem	% (wb)	92.7
* Root	% (wb)	95.4
Ash (average)	% (db)	7.61
* Leaf	% (db)	7.70
* Stem	% (db)	11.16
* Root	% (db)	3.98
Element (average)		
* Carbon (C)	% (db)	37.94
* Nitrogen (N)	% (db)	3.40
* Potashium (K)	% (db)	3.41
* Fosfor (P)	% (db)	1.62

3.3.3 C, N, P, and K uptake

Based on biomass daily increase rate (*DIR*) of 72.2 g m^{-2} d^{-1} and elemental composition of water hyacinth (Table 2), we can calculate the annual nutrient uptake to be 7800 kg C ha^{-1}, 699 kg N ha^{-1}, 701 kg P ha^{-1}, and 333 kg K ha^{-1}. Nutrient uptake by water hyacinth of our results are significantly lower as compared to the work of De Casabianca (1985) who reported annual nutrient removal by water hyacinth as 2668 g m^{-2} for carbon, 314 g m^{-2} for nitrogen and 60.5 g m^{-2} for phosphorus which is corresponding to 26,680 kg C ha^{-1}, 3140 kg N ha^{-1}, and 605 kg P ha^{-1}.

4 Conclusion

Water hyacinth cultivated in a pond of effluent from cassava wastewater digester has a normal population density with 10 plants m^{-2} and biomass weight of 10.17 kg m^{-2}. The water hyacinth pond is effective to improve the quality of wastewater to some extent. Within HRT of 53 days, water hyacinth pond increases pH from 7.0 to 7.2 and reduces turbidity by 27.1%, BOD_5 by 3.2%, ammonia by 10.5%, TS by 13.1%, and TSS by 35.2%. Water hyacinth grows with daily increase rate of 72.2 g d^{-1}, relative growth rate of 5% d^{-1}, doubling time of 13.56 days, and evapotranspiration of 5.48 mm d^{-1}. Water hyacinth biomass grows from 415 g m^{-2} to 3375 g m^{-2} within 41 days. Annual nutrient uptake by water hyacinth was found to be 7800 kg C ha^{-1}, 699 kg N ha^{-1}, 701 kg P ha^{-1}, and 333 kg K ha^{-1}.

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