Evaluation of biogas yield from water leaf plant (Talinumtriangulare)

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Abstract: The exploitation of plant materials for renewable source of energy in form of biogas is of growing interest. Water leaf (Talinumtriangulare), an abundantly available underutilized herbaceous perennial plant in South-Western Nigeria was digested to assess its biogas yield. Water leaf (WL) and water hyacinth (Eichhorniacrassipes) alone, and mixtures of water hyacinth (WH) and WL at ratios 70:30, 50:50 and 30:70 (w:w dry basis) were digested to compare biogas yields. Fixed amount of cow dung was added to each treatment before digestion in batch-type anaerobic digesters for 70 days. The results of the study showed that feedstock mixture affected ($p \leqslant 0.05$) pH and biogas yield. WL proved to be prolific in biogas as it yielded approximately six times greater than WH. The mixture of WH and WL improved biogas yield than WH alone. The mixture WH:WL at ratio 30:70 produced the highest average yield of 363.7 cm^3/kg per fed day which was approximately 7.8 and 1.2 times greater than the yields obtained from WH and WL alone, respectively.

Keywords: Water leaf, water hyacinth, cow dung, co-digestion, biogas yield

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1 Introduction

Water leaf (*Talinumtriangulare*) is an herbaceous perennial, coalescent and glabrous plant widely grown in tropical regions as a leaf vegetable (Ezekwe et al., 2001). The plant is widely known and used among the people of Southern Nigeria (Abiose, 2003), tropical South America (Anderson, 1999) and in most African countries (Okafor et al., 1997). It has various values ranging from nutritional, medicinal to ornamental. The plant is soft, watery and consumed as a vegetable (either boiled or steamed) and constituent of a sauce in Nigeria. Water leaf (WL) is usually propagated by seed either by broadcasting, direct seeding or sowing in a seed box and then, transplanting. It flowers early year-round and is mainly self-pollinating. It is known to have no serious diseases or pests. Water leaf is fast growing and once established, easily re-seeds itself. It is abundantly available in most part of South-Western Nigeria even without being cultivated and has the potential of becoming an agricultural weed if not well managed. It was on this note that the present study was conducted to assess the energy value of WL in form of biogas for domestic cooking. Water hyacinth (*Eichhorniacrassipes*), unlike WL, is an aquatic plant which can live and reproduce freely on the surface of fresh waters or can be anchored in mud, making it the most successful colonizer in the plant world (Wolverton and McDonald, 1979). Water hyacinth (WH) has been regarded as an aquatic weed with an extremely rapid rate of proliferation of water bodies, adversely affecting the aquatic life. Several studies (Vaidyanathan, et al., 1985; Singhal and Rai, 2003; Almoustapha et al., 2009; Sullivan et al., 2010; Patil et al., 2012) have established that WH is prolific in biogas production. As a result, the study compared biogas production from WL and WH and also co-digested the two plants with a view to improving biogas production.

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2 Materials and methods

WL and WH plants harvested, and freshly excreted cow dung (CD) collected within 24 h were used for the anaerobic digestion experiment which was carried out in a laboratory at the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University, Nigeria.

2.1 Digestion set up

The batch-type anaerobic digestion set up was made up of five digesters, water tanks and water collectors, adapted using 0.025 m^3 plastic containers (0.250 m × 0.465 m surface dimensions), 0.010 and 0.005 m^3 rectangular plastic containers, respectively (Figure 1). The preference for plastic containers and the colour used was informed from previous studies (Kumar and Bai, 2005; Ogunwande et al., 2013). Plastics are not susceptible to corrosion and the yellow-coloured digester chosen (although arbitrarily) has been reported not permit significant ($p \leq 0.05$) heat exchange through the digester walls (Ogunwande et al., 2013). Each digester had drain plug fitted at the base through which samples were collected for pH analysis. A digital thermometer probe was fitted to each digester for substrate temperature measurement. The digester, water tank and water collector were inter-connected using rubber hoses with cork fitted tightly to prevent gas and water leakage.

2.2 Feedstocks preparation

The plants were cut into <6 mm sieve size and mixed at WH:WL (w:w dry basis) ratios of 100:0 (WH alone), 70:30, 50:50, 30:70 and 0:100 (WL alone). Each mixture was adjusted to 8% total solids (TS) as recommended by Zennaki et al. (1996), with portable water. The CD was also diluted to 8% TS and screened using a 6 mm plastic mesh to remove gross solids.

Figure 1 Experimental set-up in the laboratory

Each digester was filled to 60% (15 dm^3) capacity with CD slurry to give sufficient liquid medium for biodegradation and to catalyse the breeding of methanogens after which the plant mixtures were loaded. Each treatment was replicated three times. The daily biogas production was measured by water displacement method (Archimedes' principle). The digesters were manually agitated once daily to ensure intimate contact between the microbes and the substrates, and to release gas bubbles that may have been trapped in the medium. The substrates were digested for 70 days during which ambient and substrates temperatures and biogas production were measured daily, while pH was measured weekly.

2.3 Analytical methods

Samples from the feedstocks were analysed at 105°C dry weight basis for: total solid (TS) content (drying at 105°C for 24 h); volatile solids (VS) content (ashing of TS at 550°C for 5 h in a muffle furnace); total nitrogen

(TN) content (regular-Kjeldahl method; (Bremner, 1996)); pH (1:10 w/v sample:water extract, using a pH meter, PN 209) and crude fibre (CF) content (AOAC, 1995). The total carbon (TC) content was estimated from the ash content according to the formula (Mercer and Rose, 1968):

$$TC\,(\%) = [100 - Ash\,(\%)]/1.8 \quad (1)$$

The initial carbon to nitrogen (C:N) ratio of each feedstock was estimated from the TC and TN concentrations, while those of the mixtures were theoretically estimated based on the TS contents of the feedstocks mixed. The initial properties of the feedstocks are summarized in Table 1.

Table 1 Initial properties of the individual feedstocks

Feedstock	Properties (% of TS)						
	TS	pH[a]	VS	TC	TN	CF	C:N ratio
WH	10.13	6.67	98.10	54.50	4.27	20.2	12.8:1
WL	7.21	5.80	98.16	54.53	4.62	0.95	11.8:1
CD	42.79	7.80	95.69	53.16	1.15	nd	46.2:1

Note:[a]1:10 w/v sample:water, nd: not determined.

2.4 Statistical analyses

The data collected were subjected to one-way analysis of variance (ANOVA) to determine the effects of feedstock mixture (FM) on substrate temperature, substrate pH and biogas yield. Duncan's Multiple Range Test was used to separate means that were significant. Pair-wise correlation of parameters was carried out to determine significant relationships. All analyses were performed at $p \leq 0.05$ using the Statistical Analysis System software (SAS, 2002).

3 Results and discussion

The study revealed that it is possible to produce biogas from WL and mixtures of WL and WH with CD slurry medium. The initial properties of the WL and WH showed that the former had higher moisture content than the latter (Table 1). However, the VS contents were narrow (≈ 98%) while WH had a higher C:N ratio. The initial TN contents and C:N ratios of the FMs were ≈ 1.25% and 42:1, respectively. The high values was due to the low nitrogen content of the CD used (Table 1). The results of the ANOVA and Duncan's multiple range tests are presented in Tables 2 and 3, respectively.

Table 2 ANOVA results showing the effect of feedstock mixture on measured parameters

Parameter	Source	DF	SS	MS	*F*-value	Pr>*F*
Temperature	Treatment	4	0.353	0.088	0.710	0.604
	Error	10	1.243	0.124		
pH	Treatment	4	0.469	0.117	4.995	0.018
	Error	10	0.235	0.023		
Biogas	Treatment	4	184008.155	46002.039	5.116	0.017
	Error	10	89919.731	8991.973		

Note: DF, degrees of freedom; SS, sum of squares; MS, mean of squares; Pr, probability value.

Table 3 Significant means separation using the Duncan's Multiple Range Tests

WH:WL ratio	Temperature, ^{o}C	pH	Biogas,cm^3/kg per fed day
100:0	29.2[a]	6.66[a]	46.6[a]
70:30	29.0[a]	7.08[b]	291.6[b]
50:50	28.9[a]	7.10[b]	186.0[a,b]
30:70	29.3[a]	7.12[b]	363.7[b]
0:100	28.9[a]	6.87[a]	294.7[b]

Note: Superscripts with the same letter are not statistically different at $p \leq 0.05$.

3.1 Temperature

The ambient temperature during the experiment ranged between 30.1^{o}C and 34.0^{o}C. Substrate temperature during digestion did not differ (p> 0.05) across the treatments. The average temperatures ranged from 28.9^{o}C to 29.3^{o}C (Table 3). The daily temperatures (ranging between 25.3^{o}C and 32.7^{o}C in all treatments) were averaged weekly and plotted as shown in Figure 2.It was revealed that temperatures of all FMs exhibited a sinusoidal pattern during digestion. The temperatures rose from between 27.0^{o}C and 28.2^{o}C in week 1 to between 28.5^{o}C and 29.6^{o}C in week 2 and fluctuated repeatedly before decreasing to final values between 27.8 ^{o}C and 28.5 ^{o}C in week 10. Although the ambient temperature

profile also exhibited a sinusoidal pattern, no significant (p> 0.05) correlation was established between it and any of the FM temperatures. Pairwise correlation of FM temperature and pH showed a significant ($p \leq 0.05$; R^2 = 0.67-0.72) relationship between the two parameters in all the FMs except WH:WL (50:50). This implied that temperature was related to pH during digestion.

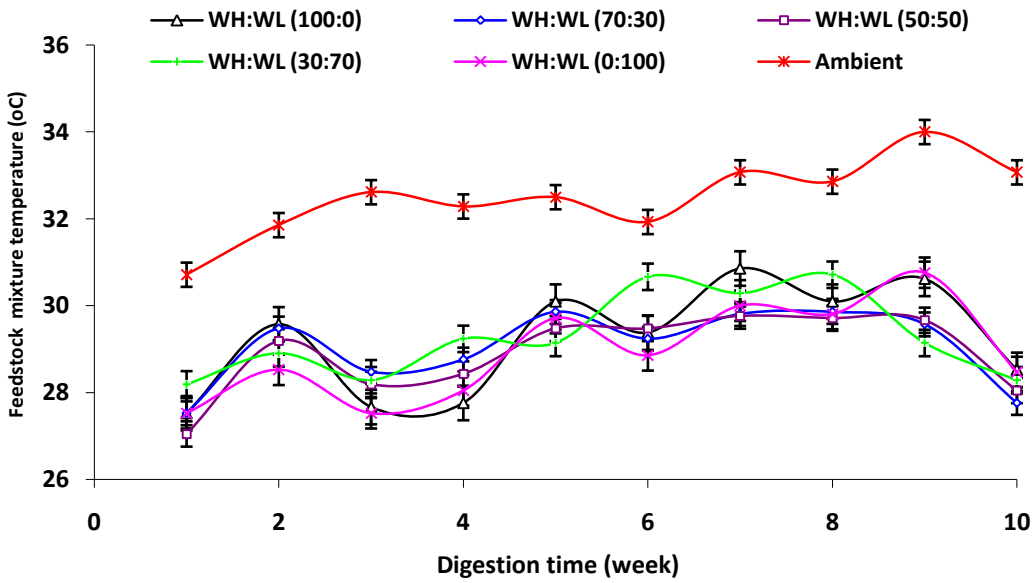

Figure 2 Variation of substrate temperature during digestion. Error bars show standard errors of means (n = 3)

3.2 pH

The ANOVA results showed that FM had significant ($p \leq 0.05$) effect on the pH of the treatments (Table 2). The mean values (Table 3) revealed that WH and WL (100:0 and 0:100) had the same (p> 0.05) pH while WH:WL (70:30, 50:50 and 30:70) also had the same (p> 0.05) during digestion. The proximate analysis showed that the initial pH of WH and CD used were within the range of 6.0-8.0 considered suitable for bacteria involved in anaerobic digestion (Igoni et al., 2008). The pH of FMs dropped within the first week to between 6.0 and 6.6 and rose gradually afterwards to peak values (7.13-7.83) between weeks 7 and 9 (Figure3). However, the rise was characterised by intermittent drops in all the treatments. The initial drops in pH implied the production of volatile fatty acids (VFA) as the easily digestible fraction of the substrates was being hydrolyzed (Comino et al., 2009) while the increase in pH could be attributed to subsequent transfer and consumption of the VFA by methanogens (Macias-Corral et al., 2008). The fluctuation of pH during the experiment was due to the periodic accumulation of VFA and subsequent consumption by methanogens. WH:WL (100:0, 70:30 and 0:100) attained their peak values (7.13, 7.40 and 7.50, respectively) during week 7 while WH:WL (50:50 and 30:70) attained theirs (7.83 and 7.73) during weeks 9 and 8, respectively. Except for the least values of 5.97 (WH:WL (100:0) during week 4) and 5.83 (WH:WL (0:100) during week 2) and the peak values of WH:WL (50:50 and 30:70), the pH values recorded fell within the optimum range of 6.6-7.6 for biogas production (NRC, 1981; Ward et al., 2008). Nevertheless, the peak values recorded were still within 6.0-8.0 considered suitable for bacteria involved in anaerobic digestion. Also, the least values observed were within 5.5-6.5 reported for hydrolysis and acidogenesis during digestion (Yu and Fang, 2002; Kim et al., 2003). The final pH values (6.40-7.46) were within the range reported (6.0-8.5) for compatibility with most plants (Lasaridi et al., 2006). This indicated the suitability of the effluents for crop improvement.

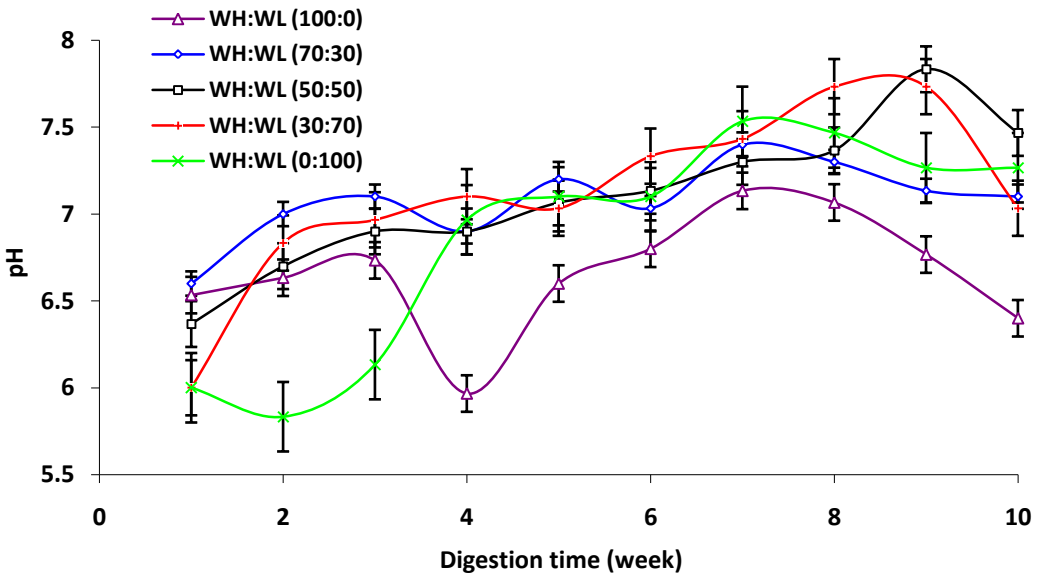

Figure 3 Variation of substrate pH during digestion. Error bars show standard errors of means (n = 3)

3.3 Biogas yield

Daily and cumulative yields were measured for each treatment. The results of the analysis showed that FM had significant ($p \leq 0.05$) effect on the biogas yields recorded (Table 2). The mean values indicated that WL alone produced approximately six times greater biogas yield than WH alone (Table 3). The higher yield may be attributed to the lower CF and slightly higher TN contained in the WL (Table 1). It was observed (Table 3) that the co-digestion of WL and WH improved biogas yield than the digestion of WH alone. WH:WL (70:30, 50:50 and 30:70) produced the same ($p > 0.05$) yield of biogas. However, WH:WL (30:70) produced the highest yield (363.7 cm^3/kg per fed day). Biogas production started in all the FMs within 24 h (except WH:WL (70:30)). The one day lag experienced by WH:WL (70:30) could be attributed to the time needed by the microbial flora in the WH richest mixture to acclimatize to the altered environmental conditions. The total number of non-production days was highest in WH alone with 42 days followed by WH:WL (50:50, 70:30 and 30:70) with three, two and one days, respectively. The no-production may probably be as a result of methanogens undergoing a methamorphic growth process by consuming methane precursors produced from the initial activity (Lalitha et al., 1994). Interestingly, WL alone had consistent production throughout the experiment. The daily productions showed that peak yields (808.8, 808.0, 762.2, 441.7 and 430.2 cm^3/kg per fed day) were observed on days 29, 15, 34, 10 and 49 in WH:WL (0:100, 30:70, 70:30, 100:0 and 50:50), respectively. The differences in peak periods were attributed to the differences in the degree of biodigestibility of the FMs (Odeyemi, 1982). The daily yields for each FM were averaged weekly (Figure 4) to assess the weekly productions. The yields were characterised by inconsistent increase and decrease in biogas production. The peak production periods were observed in weeks 2, 5, 7, 3 and 5 in WH:WL (100:0, 70:30, 50:50, 30:70 and 0:100), respectively. The yields indicated that as the peak periods, WH:WL (100:0, 70:30, 50:50, 30:70 and 0:100) had produced 53.3%, 62.9%, 70.0%, 30.9% and 45.5%, respectively of their total biogas yields. WH alone exhibited early production compared to WL alone. By weeks 2, 5 and 8, WH alone had produced 53.3%, 75.7% and 95.0%, respectively of the total yield while WL alone had produced 8.3%, 45.5% and 81.9%, respectively of the total yield.

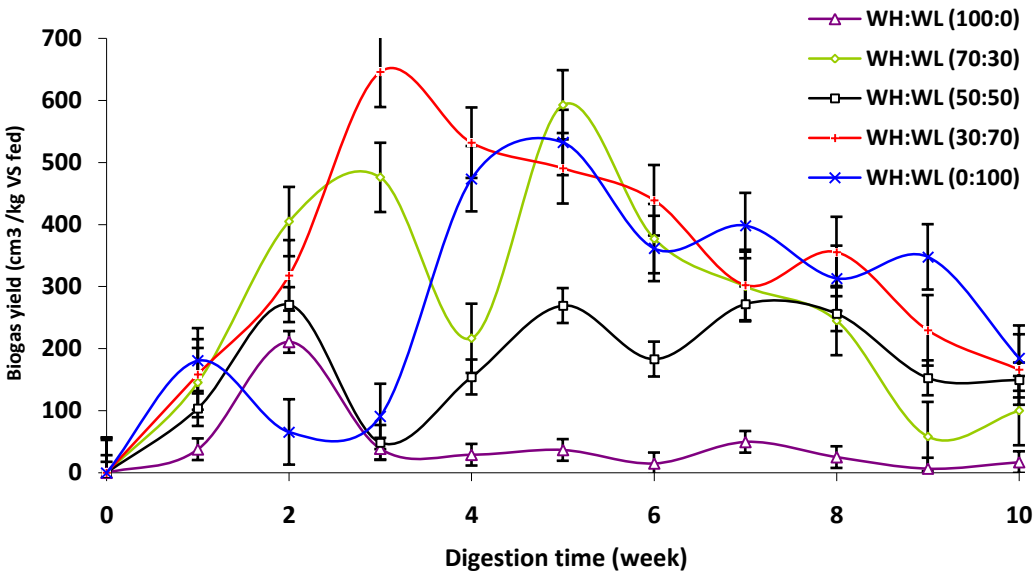

Figure 4 Variation of weekly biogas yield during digestion. Error bars show standard errors of means (n = 3)

The cumulative yields (Figure 5) showed that WH:WL (30:70) maintained the highest yield from about week 3 to the end of the experiment while WH alone which had the least yield had a crawling production.

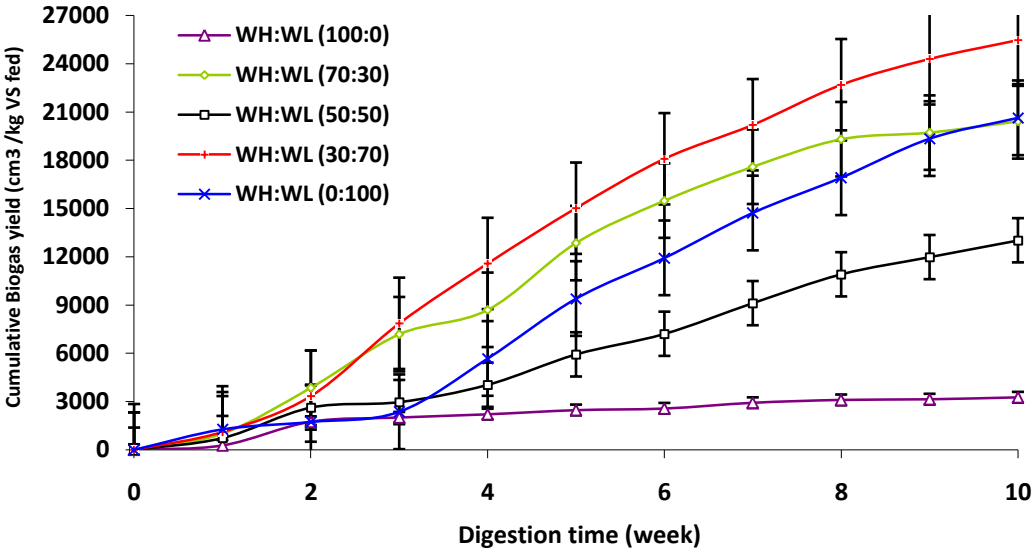

Figure 5 Cumulative biogas yield during digestion

4 Conclusions

The biogas yield from WL was assessed and compared with WH, an established prolific biogas feedstock. The anaerobic digestion of WL and WH alone with a fixed amount of CD showed that WL produced approximately six times greater biogas yield than WH. The co-digestion of WH and WL at different mixtures with fixed amount of CD was observed to improve ($p \leq$ 0.05) biogas yield than the digestion of WH alone. The mixture of WH and WL at 30:70 produced the highest average yield of 363.7 cm^3/kg per fed day which was approximately 7.8 and 1.2 times greater than the yields obtained from WH and WL alone, respectively. The study concluded that WL is feasible for biogas production and more prolific in biogas than the widely known WH feedstock.

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