Evaluation of Biogas Production from Anaerobic Co-digestion of Sewage Sludge with Microalgae and Agriculture Wastes

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Anaerobic digestion of biomass wastes could have a huge impact on renewable energy requirements. Moreover, it reduces biomass wastes and greenhouse gas emissions. To improve the performance of anaerobic digesters, the co-digestion of different biomass wastes, such as waste activated sludge, microalgae, and agriculture wastes including sawdust, wheat straw, and rice straw has been performed in this study. The results showed that sludge and microalgae have low carbon/nitrogen (C/N) ratios. Meanwhile, the addition of agriculture wastes to sludge and microalgae mixture increased the C/N ratio and improved biogas yield by 179%, 209%, and 265% in the cases of adding sawdust, rice straw, and wheat straw, respectively. Co-digestion with wheat straw showed the highest values of C/N for the feedstock (20.6) and biogas production. Moreover, it recorded the highest reduction values for total solids (48.1%), volatile solids (58.2%), and chemical oxygen demand (77.5%) as compared to the other wastes.

Keywords: Anaerobic digestion; Sludge; Microalgae; Rice; Wheat; Straw; Sawdust; Biogas

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INTRODUCTION

Biomass utilization as a source of energy is important from an energetic and environmental viewpoint (Said *et al.* 2013). Anaerobic digestion of biomass wastes could have a huge impact on renewable energy requirements. Moreover, it reduces biomass wastes, mitigates a wide spectrum of environmental undesirables, helps in air and water pollution control, and reduces greenhouse gas emissions (Manyi-Loh *et al.* 2013). To improve the performance of anaerobic digesters, the co-digestion of different biomass wastes, such as sewage sludge, microalgae, and agriculture wastes has attracted much attention in recent years (Solé-Bundó *et al.* 2017; Abdel Daiem *et al.* 2018; Olsson 2018).

Sewage sludge is a widely used substrate for biogas production. Because it is rich in nutrients, a maximum possible conversion of organic components into biogas can be achieved (Flisberg 2016). The high lipid and volatile solids content in its biomass make algae an attractive feedstock for the production of biogas (Prajapati *et al.* 2013). However, sewage sludge and microalgal biomass wastes are characterized by their high nitrogen content. On the contrary, agriculture biomass wastes such as sawdust, wheat straw, and rice straw have high carbon content (Weiland, 2010; Solé-Bundó *et al.* 2017; Oh *et al.* 2018). Therefore, anaerobic co-digestion of both types of wastes can perform better than the individual anaerobic mono-digestion (Liu *et al.* 2015).

Many studies have researched co-digestion of microalgae and sewage sludge (Wang *et al.* 2013; Mahdy *et al.* 2015; Olsson 2018). Others have studied co-digestion of sewage sludge with rice straw and microalgal biomass with wheat straw (Atta *et al.* 2016; Solé-Bundó *et al.* 2017; Abdel Daiem *et al.* 2018). These studies showed improvement in biogas production by applying a co-digestion process compared to mono-digestion of each substrate. On the other hand, few studies have researched the co-digestion of sawdust wastes with cow dung (Otaraku and Ogedengbe 2013; Madu and Onwuamaeze 2018). Furthermore, publications about the co-digestion of sewage sludge with a mixture of microalgal biomass and agriculture wastes are limited. From this background, the main objective of this study was to estimate the effect of anaerobic co-digestion of waste activated sludge—with a mixture of microalgae and agriculture wastes including rice straw, wheat straw, and sawdust—on biogas production.

EXPERIMENTAL

Materials

Waste activated sludge samples were obtained from the Altal-Alkabeer wastewater treatment plant, Ismailia Government, Egypt. Sawdust wastes from pinewood and samples of rice and wheat straw were collected from the El-Sharkia Government, Egypt. The samples were shredded and sieved to have a particle size of 2 mm.

Chlorella vulgaris and *Scenedesmus* microalgae were prepared and harvested in the lab. Two groups of Erlenmeyer flasks (5 flasks of each) were prepared, each of them containing 100 mL of sterile BG-11 media. One group was inoculated with *Scenedesmus* (5 mL for each flask), and the other group was inoculated with *Chlorella* (5 mL/flask). The inoculum of both organisms was equivalent (0.6 nm). The 250 mL Erlenmeyer flask, which contained 100 mL of sterile BG-11 medium and appropriate inoculum of *Scenedesmus* (5 mL) and *Chlorella*, was inoculated under a septic condition. All flasks were incubated under a photoperiod (16 light/8 dark) at 28 ± 2 ºC for 14 d. At the end of incubation period, the algal cells were harvested by a centrifuge unit at 5000 rpm. The cells were collected and washed two times by distilled water, and then they were preserved.

Methods

The batch reactor unit consisted of a reactor connected to gas collector with a polyvinyl chloride (PVC) tube. The gas collector was attached to an open jar by a tube with a valve. This measured the volume of water collected due to the pressure of the biogas produced. The reactor was placed in a glass basin equipped with a heater and a thermostat to maintain a constant temperature (35 ± 1 °C), as can be seen in Fig. 1. Six batch reactors were used in this experiment, and each reactor contained 2.5 kg of sludge. The first reactor only contained sludge. The microalgae (50% *Chlorella* and 50% *Scenedesmus*) were added to the other reactors at a 6% microalgae to sludge weight-based ratio. Moreover, rice straw, wheat straw, and sawdust wastes were added to the third, fourth, and fifth reactors, respectively, at a 3% microalgae to sludge weight-based ratio. In the sixth reactor, a 3% mixture of rice straw (1%), wheat straw (1%), and sawdust (1%) were added. The reactors were: activated sludge (AS), activated sludge/algae (ASA), activated sludge/algae/rice straw (ASAR), activated sludge/algae/wheat straw (ASAW), activated sludge/algae/ sawdust (ASAS), and activated sludge/algae/mixture of wastes (ASAM).

Total solids (TS), total volatile solids (TVS), chemical oxygen demand (COD), total nitrogen (N), and total carbon (C) were measured according to the procedure mentioned in the standard methods (APHA 1998). Phosphorous (P) and potassium (K) were measured according to Nation and Robinson (1971). The pH was measured using a pH ep, HI 98107 pocket-sized pH Meter. Table 1 presents the measured parameters.

Fig. 1. A photograph of the batch cells in the lab

RESULTS AND DISCUSSION

The physical and chemical characteristics of the different materials used in this study are summarized in Table 1. The waste activated sludge and microalgae had high COD values of 19.5 g/L and 15.0 g/L, respectively, and few-solid contents at 1.90% and 1.70%, respectively. Meanwhile, the sawdust, rice straw, and wheat straw contained high solids contents at 97.5%, 93.0%, and 93.5%, respectively. The majority of TS present were TVS for all waste types, as indicated in Table 1. A low C/N ratio of sludge (6.56) and algae (5.63) were detected. On the other hand, the C/N ratio was high for the other wastes, at 32.4, 77.3, and 98.4 for sawdust, rice straw, and wheat straw, respectively. These values indicated the importance addition of sawdust, rice straw, and wheat straw as anaerobic co-digesters due to their high carbon content that may improve the C/N ratio and enhance biogas production (Sosnowski *et al.* 2003). Furthermore, P and K were observed in the different materials constituent. They are considered as macronutrients and are required for proper functioning of biological processes in many microorganisms (Atta *et al.* 2016).

The cumulative biogas production from the different reactors is illustrated in Fig. 2. The rate of biogas production was elevated during the first 20 d of the reaction time. Then, the rate decreased with a higher reaction time up to 100 d. After that period of time, the rate of biogas production was negligible. Similar results were also found by Atta *et al.* (2016), Solé-Bundó *et al.* (2017), and (Flisberg 2016). The total biogas yield obtained from sludge mono-digestion reached 9.30 L. Meanwhile, co-digestion of sludge with microalgae lowered the value of biogas produced to 7.40 L. This may be attributed to microalgae having a lower C/N ratio (5.63) than that of sludge (6.56), which led to a lower C/N of the mixture compared to sludge alone. Moreover, algae contain a high percentage of proteins that degrade and release high ammonia levels that inhibit the production of biogas due to its toxicity to methanogens (Caporgno *et al.* 2015). Moreover, the hemicellulosic cell wall of this microalgae presents a high resistance to anaerobic bacterial degradation (Ward *et al.* 2014). On the other hand, the addition of sawdust to the sludge and microalgae mixture improved the C/N ratio from 6.52 to 15.97. In consequence, visible improvement in the produced biogas was detected, where the value reached 13.2 L. This result is similar to Madu and Onwuamaeze (2018), who showed an improvement in the C/N and biogas yield when sawdust was co-digested with cow dung. The rice straw analysis showed a high C/N ratio (77.3). As found by Atta *et al.* (2016), the addition of rice straw to the sludge and microalgae mixture improved both the C/N value and the biogas produced, which reached values of 19.9 L and 15.4 L, respectively. The co-digestion of wheat straw with sludge and microalgae mixture recorded the highest value of the biogas obtained (19.6 L). This was due to its very high C/N ratio (98.4), which enhanced the C/N ratio of the mixture (20.6). Moreover, the wheat straw addition allowed an increase in the organic load of the digestion by avoiding the stability problems that sludge and microalgae mixture may present, as suggested by Solé-Bundó *et al.* (2017). Meanwhile, the addition of the sawdust, rice straw, and wheat straw mixture to the sludge and microalgae mixture showed an improvement in the C/N ratio and the obtained biogas values, which reached 18.6 L and 14.2 L, respectively. However, these values were lower than the values obtained in case of rice straw and wheat straw. This may due to the addition of sawdust, which decreased the C/N ratio and consequently reduced the value of the obtained biogas. Thus, it can be concluded that the addition of agriculture wastes (carbon-rich substrates) to the sludge and microalgae mixture (which was rich in nitrogen) enhanced the biogas yield by 179%, 209%, 265%, and 192% for sawdust, rice straw, wheat straw, and a mixture of these wastes, respectively. This was mainly due to the avoidance of ammonia inhibition for the methane microorganisms and to attain an improvement of the C/N balance that ranged between (15.97 to 20.60). These values are within the optimal range of the C/N ratio for anaerobic digestion (15 to 30) (Weiland 2010; Flisberg 2016).

Table 1. Characteristics of the Raw Materials Used in this Study

Parameter	Sludge	Algae	Rice straw	Wheat straw	Sawdust
pH	7.10	7.10	N.D. **	N.D.	N.D.
COD (g/L)	19.50	15.00	N.D.	N.D.	N.D.
TS (%)	1.90	1.70	92.95	93.50	97.50
TVS (%) *	70.50	73.40	85.20	89.40	64.90
C (%) *	25.90	12.96	50.22	49.19	48.63
N (%) *	3.95	2.40	0.65	0.50	1.50
K (%) *	0.40	0.53	1.90	2.20	0.75
P (%) *	2.54	0.66	0.06	1.23	0.05
C/N	6.56	5.63	77.26	98.38	32.42

** Percentage from TS* *** N.D.: Not determined*

The addition of agriculture wastes to the sludge and microalgae mixture increased the initial TS, TVS, and COD contents, as indicated in Figs. 3a, b, and c, respectively. This was due to the higher organic matter in the mixture, as compared to the sludge and microalgae mixture. The initial values of TS, TVS, and COD for the different reactors were in the ranges of 1.89% to 4.52%, 1.33% to 3.59%, and 15.00 to 40.00 g/L, respectively.

These values decreased after digestion due to the degradation of organic matters and the conversion of them into biogas by anaerobic bacteria activation (Atta *et al.* 2016; Flisberg 2016). The reduction in the TS and TVS values for the rectors ranged from 22.8% to 48.1% and 33.1% to 58.2%, respectively. The highest reduction values were detected in case of co-digestion with wheat straw, followed by rice straw and sawdust, as demonstrated in Fig. 3a and b.

The reductions in the values of COD for sludge mono-digestion and co-digestion of sludge with microalgae were about 48.7% and 46.7%, respectively. In case of sawdust, rice straw, wheat straw, and their mixture addition, the destruction percent of COD reached 70.0%, 75.0%, 77.5%, and 71.4%, respectively. The highest reduction was recorded for co-digestion with wheat straw. These results are confirmed by the values of biogas obtained that were the highest in the case of wheat straw, followed by rice straw and sawdust wastes.

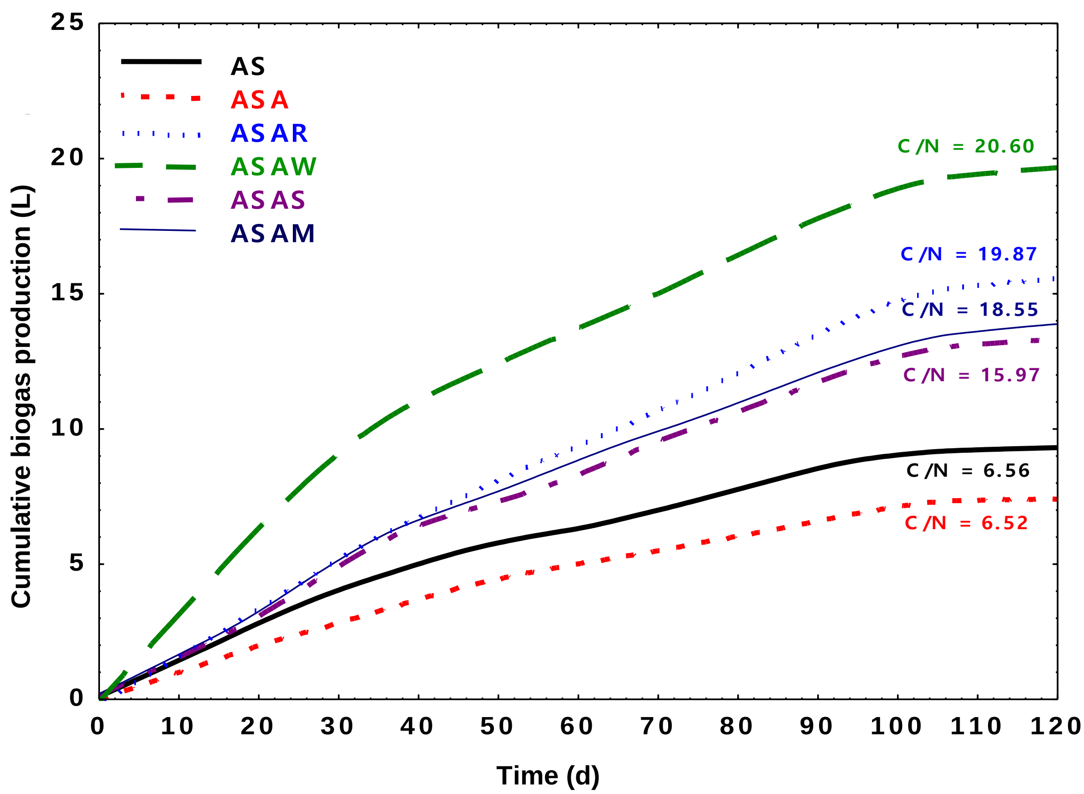

Fig. 2. Cumulative biogas production for the different reactors

The pH values varied during the digestion process due to biological conversions, where acidogenic bacteria produce high volumes of organic acids. This causes acid accumulation that could upset the system, and, under normal conditions, this pH reduction is buffered by the bicarbonate produced by methanogens and ammonia formation that guard against the accumulation of excess volatile acids (Abdel Daiem *et al.* 2018). Consequently, pH values for the digested materials showed no considerable difference respecting to their values before digestion, as indicated in Fig 3d. Moreover, these values ranged from 7.1 to 7.3, which are required for good performance and stability in anaerobic digestion process, as well as to obtain maximal biogas yield (Liu *et al.* 2008).

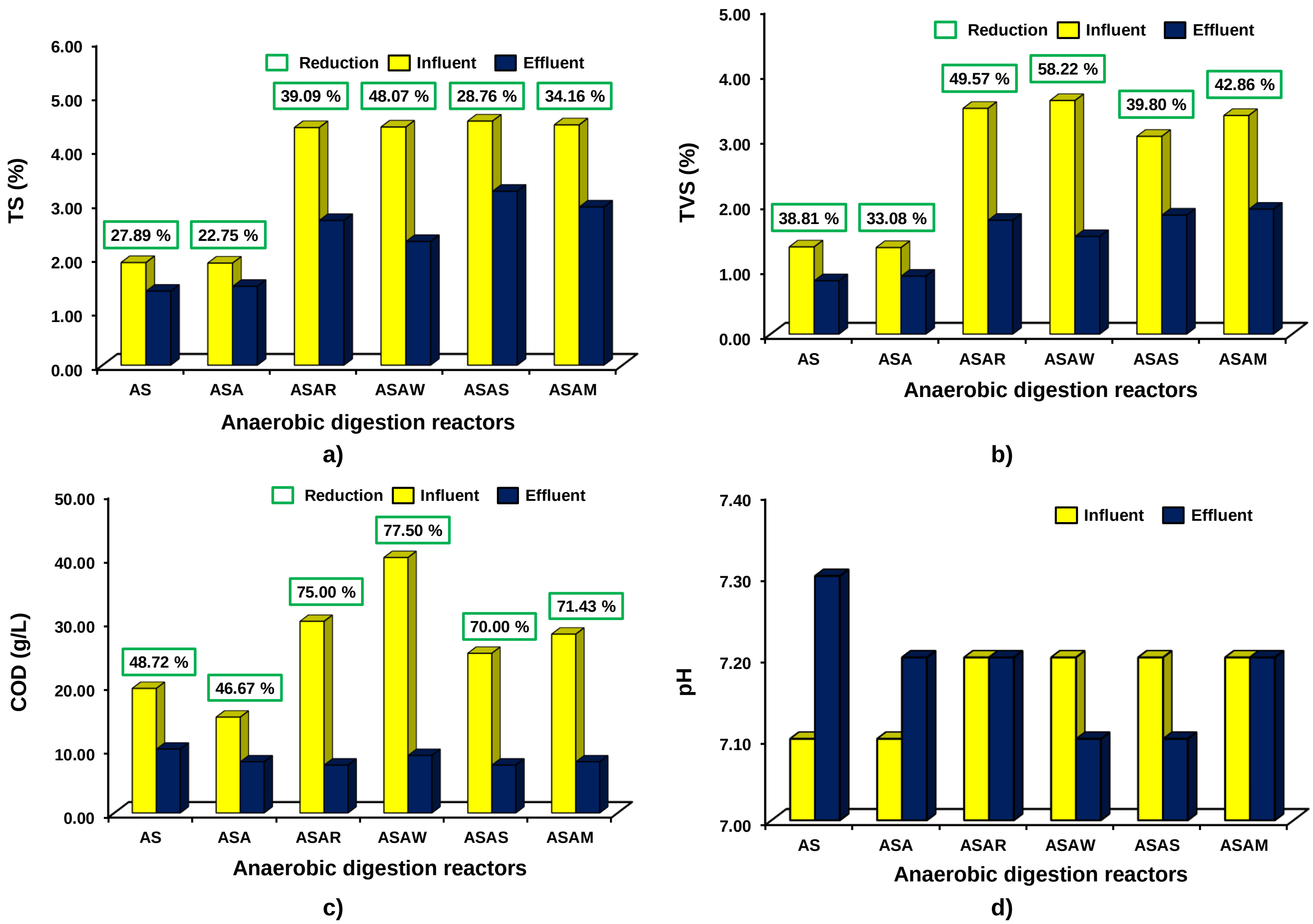

Fig. 3. Characteristics of the influent and effluent; a) TS, b) TVS, c) COD, and d) pH

CONCLUSIONS

1. The addition of agriculture wastes (sawdust, rice straw, and wheat straw) to a sludge and algae mixture increased the C/N ratio from 6.5 to values between 16.0 and 20.6.
2. Improvements in the biogas yield by 179%, 209%, and 265% by adding sawdust, rice straw, and wheat straw, respectively, were found.
3. Co-digestion with wheat straw showed the highest value for biogas production, as well as the highest reduction in TS (48.07%), TVS (58.22%), and COD (77.50%).

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