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Effect of mixing ratio of food waste and rice husk co-digestion and substrate to inoculum ratio on biogas production

Muhammad Rizwan Haider [a], Zeshan [a,*], Sohail Yousaf [a], Riffat Naseem Malik [a], Chettiyappan Visvanathan [b]

[a] Department of Environmental Sciences, Quaid-i-Azam University, Islamabad 45320, Pakistan
[b] Environmental Engineering and Management, School of Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand

HIGHLIGHTS

- Rice husk was co-digested with food waste to overcome VFA inhibition.
- Specific biogas yield decreased with the increase in rice husk proportion.
- Amount of fresh cow dung as inoculum affects co-digestion of the mixture.

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ABSTRACT

Aim of this study was to find out suitable mixing ratio of food waste and rice husk for their co-digestion in order to overcome VFA accumulation in digestion of food waste alone. Four mixing ratios of food waste and rice husk with *C*/*N* ratios of 20, 25, 30 and 35 were subjected to a lab scale anaerobic batch experiment under mesophilic conditions. Highest specific biogas yield of 584 L/kg VS was obtained from feedstock with *C*/*N* ratio of 20. Biogas yield decreased with decrease in food waste proportion. Further, fresh cow dung was used as inoculum to investigate optimum *S*/*I* ratio with the selected feedstock. In experiment 2, feedstock with *C*/*N* ratio 20 was subjected to anaerobic digestion at five *S*/*I* ratios of 0.25, 0.5, 1.0, 1.5 and 2.0. Specific biogas yield of 557 L/kg VS was obtained at *S*/*I* ratio of 0.25. However, VFA accumulation occurred at higher *S*/*I* ratios due to higher organic loadings.

1. Introduction

Huge amount of fossil fuel is used for energy generation in Pakistan which is not only an economic burden for the country but also increases global anthropogenic greenhouse gases emissions. Renewable bioenergy is an interesting alternative to meet the energy requirements of the country without extra economic burden and any significant environmental impacts. Municipal solid waste could be considered as significant biomass source as per capita waste generation rate ranges from 0.38 to 0.61 kg/day with an increasing rate of 3.4% annually in Pakistan (Joeng and Kim, 2007). About 55% of total collected municipal solid waste from cities is composed of organic material (Mahar et al., 2007). In this regard organic fraction of municipal solid waste is a potential source for energy production in Pakistan.

Single substrate anaerobic digestion of certain types of wastes is inhibited due to unbalanced nutrients in the feedstock, rapid acidification of digesters (Callaghan et al., 2002), low organic matter content, high nitrogen and heavy metals concentration, improper materials, and long chain fatty acids depending upon the substrate to be used that can inhibit methanogenic activity (Mata-Alvarez et al., 2014).

Moreover, anaerobic digestion of single highly biodegradable organic substrate may results in process failure in the absence of any buffering agent for pH adjustment and proper external nutrients addition (Demirel and Scherer, 2008). This problem could be overcome by the addition of another waste as co-substrate which may eliminate the need of any external nutrients and alkali addition for pH control (Bouallagui et al., 2009). This process of simultaneous digestion of multiple substrates is known as co-digestion. Interest of researchers in anaerobic co-digestion studies has increased in last few years. It improves biogas yield due to

* Corresponding author. Tel.: +92 51 9064 4140.
E-mail addresses: environmentalist43@gmail.com (M.R. Haider), zeshan90@gmail.com (Zeshan), rasy1023@hotmail.com (S. Yousaf), r_n_malik2000@yahoo.co.uk (R.N. Malik), visu@ait.ac.th (C. Visvanathan).

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provision of additional nutrients and pH regulation which improves efficiency of methanogens. A number of studies in literature has reported the improved biogas yield as a result of co-digestion of organic wastes such as fruit and vegetable waste and meat residues (Garcia-Peña et al., 2011), cattle manure and kitchen waste (Li et al., 2014), kitchen waste, corn stover and chicken manure (Li et al., 2013), food waste and landscape waste (Drennan and DiStefano, 2014) etc.

As Pakistan is an agricultural country, it has enormous sources of biomass that can be used for the production of renewable bioenergy such as crop residues and animal wastes. Rice husk is waste of rice milling which is normally used as boilers fuel, poultry bedding and animal feed. The average annual rice production for previous 5 years (2006–2011) was 5.93 million tons in Pakistan from which rice husk production was estimated to be 1.78 million tons, about 30% of the total rice production (Mirani et al., 2013). Rice husk is slowly biodegradable when subjected to anaerobic digestion owing to its high *C*/*N* ratio and relatively high lignin content. But, it could be used as a co-substrate to adjust *C*/*N* ratio of the high nitrogen substrate and to overcome the rapid acidification of the digester.

As food waste is the largest component of the organic fraction of municipal solid waste with high nitrogen, the current research work was intended to investigate the potential of food waste for biogas production by its anaerobic co-digestion with rice husk.

Startup of anaerobic digestion system is delicate and vital stage for successful operation. For this purpose, certain amount of inoculum is added to digester along with the substrate to provide necessary microorganisms to initiate the digestion process. Rate of biodegradation, the lag time and the possible degradation of substrate depends upon concentration of microorganisms (Elbeshbishy et al., 2012). Therefore, substrate to inoculum ratio is an important parameter in anaerobic digestion. In this study, second experiment was conducted to investigate the optimum amount of inoculum required for the startup of anaerobic reactor using cow dung as inoculum because it is the only easily available source of inoculum in the study area.

The objectives of this study were to evaluate the potential of anaerobic co-digestion of food waste and rice husk along with the effect of mixing ratios of food waste and rice husk on biogas yield and process stability. Further, effect of substrate to inoculum ratio for startup and stable anaerobic reactor operation using fresh cow dung as inoculum was also investigated. This study will provide information for successful anaerobic digestion of food waste and rice husk and will also provide information for startup of anaerobic reactors in areas where standard anaerobic inoculum is unavailable.

2. Methods

The research work carried out in this study consisted of two lab scale experiments. In experiment 1, four mixtures of co-substrates food waste and rice husk having *C*/*N* ratios of 20, 25, 30 and 35 were evaluated for their biogas production. In experiment 2, co-substrate mixture with maximum biogas production selected from experiment 1 was subjected to anaerobic digestion with varying amount of inoculum resulting in different *S*/*I* ratios.

2.1. Substrates and inoculum

Food waste and rice husk were used as substrates in this study. Food waste was collected from canteens and hostel mess of Quaid-i-Azam University, Islamabad. Food waste was collected in polythene bags every day for a period of 1 week and stored in refrigerator at 4 °C. It included cuttings of vegetables and fruits as well as left-over cooked food, which makes most of the organic fraction of municipal solid waste. All the collected food waste was then mixed together to get a representative sample.

It was manually screened to remove any inorganic material like bones, stones, polythene bags and citrus material like lemon residues. The mixed and sorted food waste was manually chopped to a size of 10 mm and was then stored at 4 °C until its use. Rice husk was obtained from a small scale rice Sheller in Faisalabad city. Cow dung adapted to 37 °C for 45 days under anaerobic condition, named as acclimatized cow dung, was used as inoculum for experiment 1. Fresh cow dung was used as inoculum for experiment 2.

2.2. Experimental setup

Two experiments were conducted in laboratory glass bottles of 1L volume, which served as batch mode anaerobic reactors. The batch reactors were placed in a thermostatically controlled water bath to achieve the required temperature of 37 °C. Each of these reactors was connected to a tedlar bag of 2 L volume by a plastic pipe, which was used to collect the produced biogas. The volume of biogas collected in the tedlar bags was measured by water displacement method on daily basis. Mixing was provided to all reactors by manually shaking for 1 min twice a day during first 15 days and thrice a day thereafter.

2.3. Experimental conditions

2.3.1. Experimental conditions for experiment 1

In experiment 1, four mixtures were prepared by mixing the fresh co-substrates in varying proportions. Mixing ratios of food waste to rice husk on the basis of VS was 10.5:1, 1.26:1, 0.46:1 and 0.17:1. Composition of mixtures has been given in Table 1. These mixing ratios were prepared to get desired range of *C*/*N* ratio. With this composition, four mixtures M1, M2, M3 and M4 got *C*/*N* ratio of 20, 25, 30 and 35 respectively. Four reactors were loaded with respective amounts of four mixtures to obtain feed total volatile solids of 2.88 g VS/L. Each reactor was then filled with 4.56 g VS of acclimatized cow dung as anaerobic inoculum to obtain a constant *S*/*I* ratio of 0.5, and the remaining working volume was filled with water. Control reactors were also prepared by loading the same amount of inoculum and filling the rest of working volume with water, which were used to calculate biogas production from inoculum alone. Substrates mixtures were prepared by theoretically calculating *C*/*N* ratios from following formula using TOC and TKN values of food waste and rice husk obtained previously from chemical analysis.

$$C/N = \frac{FW(TS \times TOC) + RH(TS \times TOC)}{FW(TS \times TKN) + RH(TS \times TKN)}$$

where FW = weight of food waste fresh matter (g), RH = weight of rice husk fresh matter (g), TS = total solids (% of fresh matter), TKN = total kjeldahl nitrogen (% TS), TOC = total organic carbon (% TS).

Monitoring of reactors for pH and VFAs was done by taking reactor samples after every 15 days. Inoculum and substrates were analyzed for TS, VS, TKN and TOC before experiment and substrate mixtures were prepared based on this characterization.

Table 1
Composition of substrate mixtures used in experiment 1.

Mixtures	Food waste (g FM[a])	Rice husk (g FM)	*C*/*N* ratio
M1	200	3.6	20
M2	200	30	25
M3	200	81	30
M4	200	218	35

[a] FM – fresh matter.