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Optimization of anaerobic co-digestion of olive mill wastewater and liquid poultry manure in batch condition and semi-continuous jet-loop reactor

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HIGHLIGHTS

- Anaerobic co-digestion of OMW with LPM was studied.
- Optimum proportion of LPM was evaluated by determining BMP.
- LPM at proportion of 30% (v/v) enhanced methane yield of OMW digestion.
- A jet-loop reactor has been successfully used for semi-continuous co-digestion.
- One-stage system stability was observed until an OLR of 9.5 g COD/L/d.

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ABSTRACT

Anaerobic co-digestion of olive mill wastewater (OMW) with liquid poultry manure (LPM) was investigated in a jet-loop reactor (JLR) as a new approach for upgrading the efficiency of bioprocess. Optimum proportion of LPM was evaluated by determining biochemical methane potential. Methane yields were compared by applying one way ANOVA method followed by post hoc Tukey's test with a 0.05 significance level. Results demonstrated that the addition of LPM at proportion of 10% and 30% (v/v) improved methane yield of OMW digestion but differences between these mixtures and raw OMW are not significant. JLR results confirmed that the proportion 30% LPM gives the optimum condition for excellent stability of digester. Methane production was significantly high until an organic loading rate of 9.5 g COD/L reactor/day. Overall; this study indicates the technical feasibility and effectiveness of using JLR as one-stage anaerobic system for the co-digestion of OMW and LPM.

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1. Introduction

In the southern Mediterranean region, Tunisia is the most famous country in olive cultivation, more than 30% of the cultivable land is devoted to the cultivation of olives (1.68 million ha). There are about 65 millions olive trees and 1702 olive oil mills, while the average olive oil production for the cultivation period of 2012–2013 reached 240,000 tons (Data base, Tunisian Ministry of agricultural and hydraulic resources). Sfax region is one of the largest olive production areas in Tunisia where the olive oil is predominantly extracted using two processes: the continuous and the discontinuous (Ammar et al., 2005).

Olive mill wastewater (OMW) is the liquid fraction produced during olive-oil extraction process. High chemical oxygen demand (COD) of OMW coupled with its phenol content inhibits the natural organic load degrading capability of the micro-flora in water bodies (Tsioulpas et al., 2002). So, direct discharge of OMW into receiving media is not permissible due to its deterioration effect to the environment. Since 1997, the produced OMW in Sfax has been mainly stored in evaporation ponds to preserve the environment as required by the Ministry of Environment and Territory Management (Jarboui et al., 2010). However, long-term uncontrolled disposal of raw OMW on soils may affect soil properties and subsequently enhance the risk for groundwater contamination (Kavvadias et al., 2010).

Abbreviations: AD, anaerobic digestion; BMP, biochemical methane potential; C/N, carbon to nitrogen ratio; COD, chemical oxygen demand; CODs, soluble chemical oxygen demand; CODt, total chemical oxygen demand; HRT, hydraulic retention time; OLR, organic loading rate; TKN, total Kjeldahl nitrogen; TS, total solids; JLR, jet-loop reactor; VFA, volatile fatty acids; VS, volatile solids; VSS, volatile suspended solids.

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In other hand, OMW can be regarded as a resource to be recycled. Bioenergy content of OMW is significantly high because of high COD: 100–200 g/L (Khoufi et al., 2006) that can be converted to biogas rich of methane. However, several factors affect the anaerobic digestion (AD) process performance and stability; among them phenolic compounds concentration, feed compositions and more specifically the ammonia concentrations are considered to be vital. Nitrogen is generally low in OMW. The carbon-to-nitrogen-to-phosphorus ratio is around 100:1.77:0.94, respectively, for OMW (Gelegenis et al., 2007). Consequently, the AD of OMW requires provision of an extra nitrogen source. The high cost of non-sustainable, inorganic nitrogen sources such as urea and other compounds suggests the use of alternative organic sources of nitrogen such as pig slurry (Martinez-Garcia et al., 2009), cheese whey (Dareioti et al., 2009), cow manure (Dareioti et al., 2010) and activated sludge (Athanasoulia et al., 2012). Poultry manure has higher nitrogen contents compared with various types of nitrogen-rich organic wastes; many authors report ammonia inhibition of biogas production particularly when digesting manure under thermophilic conditions (Bujoczek et al., 2000). To overcome the above problems, manure can be mixed with OMW at proportion that improves nutrient balance and the C/N ratio, which should be in the range 20–30 as recommended for stable operation of anaerobic digestion.

Most of OMW co-digestion studies have been performed in 100–250 mL serum vials or 0.75–18 L tank reactors (Gelegenis et al., 2007; Angelidaki and Ahring, 1997; Angelidaki et al., 1997). Various types of digesters were tested, namely completely-stirred tank reactor (Athanasoulia et al., 2012; Dareioti et al., 2010), up-flow anaerobic filter (Marques, 2001) and up-flow anaerobic sludge blanket reactor (Angelidaki et al., 2002). In the field of biochemical engineering, it was necessary to introduce new equipment for realization of such processes. Examples of such devices are JLRs. These reactors also improve the running of many processes, which are traditionally encountered in chemical industry (Yildiza et al., 2005). The primary element of the JLR is a tank with a draft tube, in which the nozzle is installed. The application of a nozzle, for feed stream introduction, allows thorough liquid mixing, eliminating the need of usage of mechanical mixer in the reactor (Ludwig et al., 2012). This type of reactor has not been tested for AD of OMW. Furthermore, it is still not established what load of OMW and LPM mixture can be permitted in continuously operated digester.

This article focuses on the anaerobic co-treatment of OMW (production period October–March) and LPM (production period whole year) as two representative types of agro industrial wastewaters produced in Sfax (Tunisia) and other Mediterranean countries. The specific aim of the present work was to investigate biochemical methane potential (BMP) assays for raw OMW alone and mixed with varying amounts of LPM. Methane yields of batch anaerobic fermentations were compared by applying one way ANOVA method followed by post hoc Tukey's test. Finally, the results were verified on pilot-scale using a JLR with a 100 L capacity.

2. Methods

2.1. Wastewaters and inocula

All wastewaters used in this work were sourced locally. OMW was collected from an olive oil production plant equipped with a three-phase olive oil extraction process, located in Sfax (Tunisia). Liquid poultry manure (LPM) was obtained from a poultry farm located also in Sfax. A small sample from each wastewater was separated at the day of collection, while the rest of the quantity was immediately refrigerated to 4 °C until further utilization. They were digested in their original form; which means that they were not subjected to any alteration. The most important characteristics of the two substrates used for anaerobic co-digestion experiments are compiled in Table 1.

Table 1
Main characteristics of OMW and LPM (average of three samples).

Characteristics	Unit	OMW	LPM
pH		4.8 ± 0.06	8.15 ± 0.07
Conductivity	mS/cm	17.5 ± 0.5	38.8 ± 0.4
Total COD	g/L	150.0 ± 15	97.5 ± 9
Soluble COD	g/L	110.0 ± 5	41.4 ± 3
BOD_5	g/L	37.5 ± 4	5.83 ± 3
TS	g/L	52.16 ± 6	49.3 ± 9
TSS	g/L	34.7 ± 4	39.2 ± 3
TKN	g/L	0.95 ± 0.06	7.86 ± 1
Total phosphorus	g/L	3.8 ± 0.4	4.6 ± 0.3
Alkalinity	mg $CaCO_3$/L	1550 ± 15	5423 ± 20
Total phenols	g/L	8.9 ± 0.05	0.09 ± 0.03

A semi-pilot anaerobic bioreactor, operating at mesophilic condition and on OMW, provided an active biomass holding a content of 4.2% TS (Total solids) and 2.3% VS (volatile solids). This anaerobic stock culture was used as inocula in BMP assays and JLR.

2.2. Biochemical methane potential (BMP) assays

In order to determine the anaerobic biodegradability of each substrate (OMW and LPM) and the effect of different mixtures on biogas production, BMP tests were performed. Seven feed stock mixing ratio (OMW/LPM: 100:0, 90:10, 70:30, 50:50, 30:70, 10:90, 0:100, based on volume) were studied.

The anaerobic batch experiments were carried out under mesophilic conditions (37 ± 1 °C) for 65 days, using 120 mL glass bottles as reactors. Each bottle was fed with an appropriate amount of a substrate mixture and inocula, keeping a VS ratio (VS substrate to VS inocula) at 1:1 in all setups. A further BMP test (control) was conducted on the inocula, to estimate the volume of methane resulting from the fermentation of the organic solids contained in the anaerobic sludge. Based on the initial VS contents of OMW, LPM and inocula, a sufficient amount of deionized water was added in each condition to adjust the working volume inside the batch system to 60 mL. In order to reproduce the real conditions in a full scale plant no micro and macronutrients were added.

After adjusting pH to 7.2, all bottles were purged with a gas mixture of 75% N_2 and 25% CO_2 for 3–4 min to supply anaerobic conditions. The serum bottles were then incubated in a temperature-controlled room. The bottles were shaken once a day during the incubation period. Biogas produced in each serum bottle was measured daily using a gas displacement device. Before each biogas volume measurement, a sample was taken from the headspace of bottle using a 250 μL pressure-tight syringe and the sample was immediately analyzed by gas chromatography.

All experiments were run as triplicate and the mean values of net biogas production and methane content were calculated. The biogas and methane yields at the end of each test were calculated by dividing the cumulative gas or methane volume by the mass of substrate TS in the feedstock loaded into the bottle at the start-up.

2.3. Jet-loop reactor

The jet-loop reactor (JLR) used in this study consisted of a cylindrical stainless reactor, having double wall and working volume of 70 L (Fig. 1). A polyvinylchloride (PVC) draft tube with a nozzle was installed in the middle of the reactor. Effluent is continuously injected into the JLR through a jet by using a cycle pump. The

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