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Research article

Evaluation of biomethane potential from by-products and agricultural residues co-digestion in southern Italy

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ABSTRACT

The suitability of the co-digestion of feedstock-mixtures (by-products and agricultural residues) depends on their ability to produce biogas. In this study, the effects of mixing five feedstocks (citrus pulp, olive pomace, poultry manure, Italian sainfoin silage and opuntia fresh cladodes) on anaerobic digestion for biogas production have been investigated by carrying out biomethane potential (BMP) tests on six different mixing ratios of the selected five biomasses.

The BMP test results demonstrated that all the six studied feedstock-mixtures could be potentially used for renewable energy generation by biogas plants. More in detail, two mixing ratios of the studied feedstock-mixtures showed the best biomethane potential of 249.9 and 260.1 Nm^3CH_4/tVS, respectively.

Since this research study made it possible to screen the suitability and technical feasibility of the feedstock-mixtures analysed, the results provide the basis for subsequent pilot scale evaluation of anaerobic digestion in Mediterranean area, where by-products and agricultural residues are profuse and necessary to produce advanced biofuels.

1. Introduction

Renewable bioenergy is an interesting alternative to meet the world energy requirements without extra economic burden and any significant environmental impacts. Biogas as one of renewable energy sources attracts increasing attention due to its capabilities of waste treatment and energy recover (Esposito et al., 2012). A typical onsite consumption of biogas regards its conversion to electrical and thermal energy via a co-generation process (Tchobanoglous and Burton, 1991; Shen et al., 2015). Recently, biogas is subjected to an up-grading process that aims at biomethane production (Chinnici et al., 2018).

In Italy, which is the third world biogas producer, after China and Germany, the biogas sector was significantly developed in the regions of northern Italy, where the biogas is produced also by using dedicated energy crops (i.e., maize silage) that arise social, economic and environmental problems related to the competition between food/no food products (Fabbri et al., 2010, 2013; Sgroi et al., 2015; Santi et al., 2015). As a consequence, recently, a new concept to produce biogas was developed by Dale et al. (2016), well known as Biogasdoneright® model.

Biogasdoneright® model is based on a system of sustainable intensification of crop rotation and provides the development of double cropping, by introducing sequential crops after ordinary autumn-winter cultivations. The sustainability of this model depends on the use of digestate to both reduce, or complete replace chemical fertilizers required for cultivation, and limit soil consumption, soil erosion and desertification. Moreover, it is possible to contribute for reducing greenhouse gas emissions and increasing soil organic matter by recycling the nutrients (e.g., N, P and K) contained in by-products used for biogas production (Dale et al., 2016; Valenti et al., 2016; Selvaggi et al., 2018a, 2018b).

By following the Biogasdoneright® concept, it is necessary to evaluate the availability for biogas production of agro-industrial by-products that otherwise are currently intended for disposal. By-products disposal leads to economic and environmental concerns mainly due to high transportation costs of the wastes, lack of disposal sites and technical difficulties to store for a long time organic wastes because of fermentation processes (Valenti et al., 2017a). Therefore, the very challenging goals fixed by the European Union focus on moving toward high recycling targets, paving the road from a linear economy to a circular economy as a real answer for the challenge of globalization (EU, 2014). According to the food waste hierarchy (Papargyropoulou et al., 2014), the first level of attention is directed toward the need to prevent the formation of waste; the following next steps concern the

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reuse or recovery and recycling of suitable materials and afterwards the energy recovery through a thermochemical or biological process; only at the end, when there are no more alternatives, it is allowed the disposal of residuals into a landfill. Therefore, the goal of a correct waste management is not only to reduce the disposed waste volumes, but also to make use of it in various ways and among them for energy production. In this context, growing concerns about energy security, environmental impact and increasing energy cost for wastewater treatment have re-instated the anaerobic digestion process to the center of the scientific spotlight, as a major renewable energy production technology and as one of the most promising technologies for waste management (Isci and Demirer, 2007; Fountoulakis et al., 2008; Khanal et al., 2008; Dinuccio et al., 2010; Iacovidou et al., 2012; Jenicek et al., 2013; Karthikeyan and Visvanathan, 2013; Nghiem et al., 2014; Girotto et al., 2015; Pham et al., 2015; Sawatdeenarunat et al., 2015; Pellera and Gidarakos, 2016; Pergola et al., 2018), only in the last few years, little attention was given to the production of biogas by anaerobic digestion (Barber, 2012).

Anaerobic co-digestion of different organic residues has been widely investigated to enhance anaerobic digestion performance of biogas production and total solids reduction (Liu et al., 2009; Gou et al., 2014; Mata-Alvarez et al., 2014). In detail, co-digestion offers several benefits over traditional monodigestion when applied (Pavan et al., 2007; Wang et al., 2013), such as the optimisation of digester stoichiometry by obtaining an optimum C:N ratio which can positively influence the digestion process (Wickham et al., 2016).

Moreover, the economic viability of co-digestion can be significantly enhanced through the contribution of supplementary revenue from gate fees (i.e. commercial charges for waste disposal), and the sustainability of waste management practise could be also improved (Kim and Kim, 2010; De Luca et al., 2017).

In particular, co-digestion allows the diversion of agro-industrial wastes from landfill, thus limiting greenhouse gas emission while facilitating energy recovery through biogas production (Holm-Nielsen et al., 2009). Despite the attractive attempts to optimize co-digestion, several technological challenges associated with its implementation still persist (Giuliano et al., 2013; Mata-Alvarez et al., 2014; Haider et al., 2015; Koch et al., 2015). Usually, a main basic feedstock (e.g., animal manure or sewage sludge) is mixed with a minor amount of a secondary feedstock (e.g., crop residues, silage or food wastes) to feed the digester (Lehtomaki et al., 2007; Aboudi et al., 2017; Kurahashi et al., 2017; Zhang et al., 2017). Only a few studies have reported that multiple feedstocks were used to carry out co-digestion (Callaghan et al., 2002; Muradin and Foltynowicz, 2014; Wickham et al., 2016; Tasnim et al., 2017; Valenti et al., 2018b). In particular, Tasnim et al. (2017) ran a co-digestion on mixed cow manure, sewage sludge and water hyacinth that had better gas production than the co-digestion of cow manure and kitchen wastes. Callaghan et al. (2002) optimized a co-digestion process using three feedstocks of cattle manure, chicken manure, and fruit/vegetable wastes. Muradin and Foltynowicz (2014) studied the economic performance of a commercial biogas plant receiving nine organic residues (corn silage, potato pulp, spent vinessa waste, fruit and vegetable pomace, cereals, plat tissue waste, municipal sludge and soya oil). Wickham et al. (2016) evaluated the biomethane potential of sewage sludge and organic waste co-digestion in different mixing ratio. Valenti et al. (2018b) by applying batch and semi-continuous co-digestion approaches, investigate, for the first time, the effect of mixing six feedstocks (citrus pulp, olive pomace, whey, corn silage, cattle and poultry manure) available in Sicily on methane production for bioenergy generation.

All these studies demonstrated successful biogas production from multiple organic residues.

By considering diversity and availability of agricultural residues and biomasses, more and more biogas plants intend to use multiple feedstocks to improve their digestion process performance and require lab-scale testing approaches to determine the feasibility of such operations. Biomethane potential (BMP) test as a simple lab-scale method has been widely used to evaluate digestibility of feedstocks and conclude the maximum methane yield of single, or few combined feedstocks (Chynoweth et al., 1993; Angelidaki et al., 2009; Esposito et al., 2012; Stromberg et al., 2015).

Several agricultural activities of the southern Italy generate multiple agricultural residues with different quantities (Chinnici et al., 2015; Valenti et al., 2018a; Selvaggi et al., 2018b). In this context in Sicily, which is the largest island of the Mediterranean basin, the development of the biogas sector could be fostered by using the huge number of by-products available in this region (Selvaggi et al., 2018c). Therefore, the study of possible anaerobic digestion of multiple feedstocks is urgently needed to satisfy the electricity demand of the agricultural sector in Southern Italy. This study aims to screen five Mediterranean biomasses with regards their potential use as co-substrates for further biogas production. In detail, poultry manure, Italian sainfoin silage (*Hedysarum Coronarium* L.) and opuntia fresh cladodes and, among the main available agro-industrial by-products, olive pomace and citrus pulp, have been selected for testing six different feedstock-mixtures. BMP assessment and co-substrate characterisation are conducted for comparative analyses with varying compositions. Moreover, this study could allow the definition of preferred mixing conditions to enhance biogas production of anaerobic co-digestion of multiple feedstocks by finding out the suitable mixing ratio. The adopted approach and the obtained results could facilitate developing biogas production in Mediterranean area as well as in other regions with different sources of organic residues.

2. Materials and methods

2.1. Feedstocks and seed

By analysing both the by-products and agricultural residues actually used by the biogas plants and their availability within the study area, i.e. Sicily, five feedstocks were selected as possible matrices for co-digestion process. All the considered biomasses, i.e., olive pomace (without olive mill wastewater), citrus pulp, Italian sainfoin silage, opuntia fresh cladodes and poultry manure were collected in Sicily by the Department of Agriculture, Food and Environment of Catania University and shipped to the Research Center for Animal Production (Centro Ricerche Produzioni Animali - C.R.P.A.) of Emilia-Romagna region in coolers.

Among the agro-industrial by-products, citrus pulp and olive pomace (three phase) were selected as co-substrates since they are highly available due to the relevant production of citrus fruits and olives cultivation in the Mediterranean areas (Pergola et al., 2013; Cerruto et al., 2016; Valenti et al., 2016, 2017b; 2017c, 2017d).

A blender was used to reduce particle size of individual samples. After size reduction, all samples were kept frozen prior to use. The characteristics of individual feedstocks were listed in Table 1.

The seed was the liquid filtrate after liquid/solid separation of the anaerobic digestion effluent from a commercial anaerobic digester located in Emilia-Romagna region. The adopted feeds for this digester were cattle manure and agricultural residues. The characteristics of seed were also listed in Table 1.

Six feedstock-mixtures (FMs) of the selected five biomasses were prepared for the BMP test based on the current feedstock-mixture used in biogas plants within Mediterranean areas, and taking into account the amounts and the availability of the considered agricultural residues and by-products (Table 2).

The characteristics of each FM were reported in Table 3.

2.2. Biomethane potential experimental equipment and protocol of feedstock-mixtures (FMs)

The Biomethane Potential (BMP) test is a biological test that allows