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Scaled-up experimental biogas production from two agro-food waste mixtures having high inhibitory compound concentrations

Federico Battista [a], Debora Fino [a], Flora Erriquens [b], Giuseppe Mancini [c], Bernardo Ruggeri [a, *]

[a] Department of Applied Science and Technology, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino 10129, Italy
[b] Asja Ambiente Italia SPA, Via Ivrea 70, Rivoli, TO 10098, Italy
[c] Department of Industrial Engineering, University of Catania, Viale A. Doria 6, Catania 95125, Italy

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ABSTRACT

The most abundant agro-food wastes in Puglia (Italy) are derived either from olive oil production, e.g., olive pomace (OP) and olive mill wastewaters (OMW), or from diary activity, e.g., milk whey. All of these wastes have an acidic pH (3.5–5.5), high organic matter volatile solids, a (VS) higher than 50 g/L, and chemical substances such as total nitrogen (TN), total ammonia (TAN) and total phosphorous (TP), which are able to alter the properties of the soil and pollute aquifers in scenarios where they were released into the ground without any treatment. Two types of OP exist but have different chemical characteristics: OP from a two phase centrifugation (OPII) and OP from a three phase centrifugation (OPIII). These differ primarily in their water content, which is higher in OPIII, and in their polyphenol and ammonia content. In the present work, two mixtures of wastes from olive oil and dairy production were prepared and initially tested in a 50 L batch digester. Then, in a scaled up 2 m^3 anaerobic reactor a test in continuous mode was realized. Two feeds were tested: a first mixture containing OPII and a second mixture with OPIII. The tests were conducted in mesophilic conditions (35 °C) with a total solid (TS) content of approximately 10% *w/w* in continuous mode. The test including OPIII showed a productivity of 1.23 L_{CH4}/L d against 0.83 L_{CH4}/L d for the test with OPII, as a consequence of the higher organic content and the simultaneous effect of the minor inhibitory compound (ammonia and polyphenols) concentration in OPIII.

1. Introduction

Italy is well known for the excellence of its agro food products, which are imported worldwide. Olive oil, mozzarella, ricotta and other types of cheeses are major examples of the Italian culinary tradition and are produced primarily in the southern part of the country, in particular, Puglia. In fact, with approximately 1400 ktons of olive oil produced every year [1], this region accounts for over 40% of the national olive oil production [2]. Puglia is also the third largest region of dairy centers [3].

The main by-products of olive oil production are a liquid component, the olive mill wastewaters (OMW), and a semi solid component, the olive pomace (OP). The features of the latter depend on the technology used during olive oil production processes, which can involve a three-phase centrifugation (oil phase 20% *w/w* olive, aqueous phase 50% *w/w* olive and 30% *w/w* as the solid phase) [4] or a two-phase centrifugation that generates a "wet OP" with a water content up to 65% *w/w* [5]. All of these wastes have a significant environmental impact. They have a high organic concentration (COD > 250 g/L), high electrical conductivity, high concentration of polyphenols (usually 0.1–1 g/L), and a low pH (4–6), and they produce bad odors [6]. In particular, as reported by Bonari and Ercoli [7], the polyphenol content in OP is very variable and depends on several factors, such as the different varieties of olive trees, the climate conditions and the soil properties where the trees were grown. Anaerobic digestion (AD), which ensures a high degree of abatement of the organic load and the production of both stabilized sludge and a biogas that has a high energy value with low or no nutrient addition, may be a feasible method for treating these wastes [2]. AD is not only feasible in large-scale industrial

* Corresponding author. Tel.: +39 0110904647; fax: +39 0110904699.
E-mail address: bernardo.ruggeri@polito.it (B. Ruggeri).

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installations, but it can also be applied on a small scale. This creates opportunities for AD in developing countries and rural areas [8], thus making it an interesting prospect for the Puglia region, where agro-food activities are often managed by small local businesses.

Over the last decade, several experimental tests were conducted to determinate the OP and OMW biogas production yields. For example, operating in mesophilic conditions (35–38 °C) [5] and in batch mode [9], obtained a biogas production of 135 and 105 L/$Kg_{\Delta VS,}$ respectively, with a methane content percentage of 75% *v/v* and 50% *v/v,* respectively. A better biogas production was obtained with a continuously working reactor. In fact, Aveni [10] obtained a value of 300 $L_{CH4}/Kg_{\Delta VS}$.

The main waste from the dairy industry is milk whey. Although it has a high content of organic matter (approximately 60 g COD/L) [11], it is very difficult to use for the AD process because of the low pH (3–3.5) and the high protein and lactose contents of 7000 mg/L and 50 g/L, respectively [12], all of which inhibit methanogenic microorganisms. For these reasons, the byproducts derived from dairy activity have not been attractive for the AD process in previous years. To mitigate the effect of the acidic pH of cheese whey, Comino et al., 2012 [13] conducted codigestion tests with manure at different concentrations. They demonstrated that by increasing the whey concentration to 50% *v/v* in the feeding, the methane content in the biogas increased. However, at higher levels of whey, the biogas production was halted.

The present study is based on a survey of the Puglia region concerning the residues from agriculture and farming activities. The residues were considered potentially interesting because of their abundance and availability throughout the year. In the survey, the following categories were considered: (a) wastes from the dairy industry such as whey, buttermilk, dairy waste water and by-products from cheese farms (121,000 tons/year); (b) wastes from the olive oil industry such as OP and OMW (620,000 tons/year); and (c) manure and sludge from animal farms (bovine, ovine and poultry farms) (7900 tons/year). The analysis of the region's agro-industrial production yielded very encouraging results in terms of abundance (particularly the abundance of the residues of olive oil production) and availability throughout the year (Fig. 1).

The aim of this work is to evaluate the methane production from the codigestion of olive oil and dairy byproducts to exploit the energetic potential of these abundant wastes, which are often released into the ground without any regulatory control, thereby increasing the risk of soil and aquifer pollution. In particular, a comparison between the OP derived from a two phase (OPII) centrifugation and OP derived from a three phase centrifugation (OPIII) has been realized to better understand what is the most profitable in terms of methane production and to determine the chemical features that influence the AD of agro-food wastes. These substrates were tested for the first time in two scaled-up reactors to evaluate not only their BMP but also the system's rheology behavior as well as some process problems such as foam formation. For this reason, a medium-scale reactor of 50 L was initially used in batch mode. After encouraging results were obtained, a continuous campaign was realized in a 2 m^3 scaled-up anaerobic reactor to simulate the full-scale application of the technology.

2. Materials and methods

2.1. Equipment

The mixtures of wastes from olive oil and a dairy production firm were first tested in a reactor having a working volume of 50 L according to the batch mode (Fig. 2a). The reactor has the pH and temperature controls. It has a heating and a cooling system to keep the working temperature at 35 °C. The reactor is also equipped with two pumps connected to HCl (2N) and NaOH (2N) bottles to maintain the pH in the range 6.8–7.2. The reactor was also equipped with a Rusthon turbine running at 100 rpm. A 50 L digester, which represents a medium-scale laboratory reactor, allowed us to evaluate the nature of other process aspects, such as the flow behavior, rheological problems of the reaction medium and, eventually, foam formation. After the 50 L reactor tests, the olive oil and dairy production wastes were tested using a pilot anaerobic digestion plant consisting of a pulper, where organic refuse was fed and a reactor. The pulper was used to physically pre-treat the substrates and to grind and mix the flow stream; an anaerobic reactor (Fig. 2b) with a total volume of 2 m^3 and a working volume of 1.8 m^3 were used. The pulper (196 L of total volume and 120 L of working volume) was equipped with a level control and a stirring system able to operate at 50 and 100 rpm. Organic wastes from the pulper tank were pumped by a centrifugal pump into the anaerobic reactor equipped with a thermostatic jacket and a pH controller. Two different pumps were used when necessary and were furnished with either HCl (2N) or NaOH (2N) solution to keep the pH in a neutral range (6.8–7.2). The operational conditions were 35 °C and gentle agitation (100 rpm). The produced biogas flowed into the collection line, which was equipped with a safety device break-flame, a water condenser to eliminate the water vapor and a gas counter, to reach a flexible storage balloon, where gas was stored at ambient atmosphere for safety reasons.

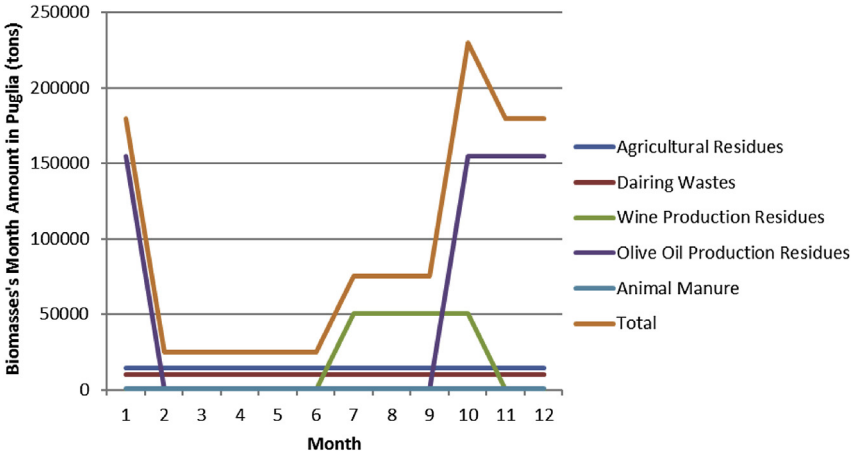

Fig. 1. Monthly available waste amounts in Puglia.