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Research Paper

Increasing the tolerance to polyphenols of the anaerobic digestion of olive wastewater through microbial adaptation

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The valorisation of olive oil mill wastewater (OMW) through anaerobic digestion requires identifying the concentration of polyphenols (PP) that causes failure of the process of digestion. In addition, the advantages of the possible microbial adaptation, in terms of increased methane production, to significant concentrations of PP as well as the kinetics of OMW anaerobic degradation requires evaluation. To fill these knowledge gaps, anaerobic digestion batch tests were carried out on three blends of OMW and inoculum (digestate from a biogas plant fed with agro-wastes) at a PP concentration of 0.5, 1.0 and 2.0 g l^{-1} in mesophilic conditions. Total inhibition of anaerobic digestion was found at a PP concentration of 2.0 g l^{-1} (non-adapted inoculum group). A positive effect of the adaptation to the substrate was, instead, observed for the blends with adapted inoculum at a PP concentration of 1.0 and 2.0 g l^{-1}. Methane yields increased by 70% (PP = 1.0 g l^{-1}) and 300% (2.0 g l^{-1}) in the group with adapted inoculum compared to the group with non-adapted inoculum. The results suggest that OMW should not be subject to anaerobic digestion at high PP concentrations (i.e. higher than about 1 g l^{-1}) due to the microbial inhibition detected. Moreover, given the benefits of the adaptation of the microbial population that was more evident at the highest PP concentration tested, it is advisable to allow the progressive adaptation of the digestion to OMW feeding. Thanks to the increased methane yield, because of the improved microbial tolerance to inhibiting compounds, the anaerobic digestion of OMW could be a viable and environmentally sound solution for the treatment of agro-industrial wastewater.

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Nomenclature

OMW	Olive Mill Wastewater
PP	Polyphenols
TS	Total Solids
TVS	Total Volatile Solids
DM	Dry Matter
COD	Chemical Oxigen Demand
BMP1	Series of tests carried out with raw digestate as inoculum
BMP2	Series of tests carried out with adapted digestate and BMP1 as inoculum
T_{50}	Time needed to get 50% of the maximum methane yield
T_{90}	Time needed to get 90% of the maximum methane yield
B	Methane production of the 1st-order kinetics model
B_0, M, y	Cumulative methane production of the 1st-order kinetics, Gompertz or logistic models
k	Constant of the 1st-order kinetics or logistic models
t	Time for digestion of the 1st-order kinetics, Gompertz or logistic models
P	Methane potential of Gompertz model
R_m	Maximum methane production rate of Gompertz model
λ	Lag phase period of Gompertz model
a, b	Constants of logistic model
WW	Winery waste
PW	Pig waste
OMSW	Olive mill solid waste
AW	Abattoir wastewater
LPM	Liquid poultry manure

1. Introduction

The olive oil industry, which is one of the most traditional agricultural industries in the Mediterranean region, generates large amounts of residues: a very wet, plastic olive cake, the so-called “olive pomace”, and a liquid stream, called “olive oil mill wastewater” (OMW), which is produced by the wastewater generated during the different stages of the process in olive oil production and by the water used for cleaning purposes (Moreno, González, Cuadros-Salcedo, & Cuadros-Blázquez, 2017). On a broad scale, olive processing produces 50% wastewater, 30% solid residues and 20% olive oil (Komnitsas & Zaharaki, 2012). The major environmental problems associated with olive oil extraction mills are related to both the large volumes of water required and the ineffective management of OMW and olive pomace (Dourou et al., 2016). OMW composition presents a large diversity depending on several parameters, such as the variety of olives and their maturity, the region of origin, and especially the technology used for oil extraction (Roig, Cayuela, & Sanchez-Monedero, 2006). However, OMW is always characterised by high concentrations of several organic compounds (e.g. organic acids, tannins and phenolic compounds), which make it difficult to treat due to its resistance to biodegradation (Turano, Curcio, Paola, Calabrò, & Iorio, 2002) causing serious environmental concerns when its management is not environmentally sound. For instance, OMW discharged into water courses can lead to water body deterioration with significant damages to the aquatic life (Karaouzas, Skoulikidis, Giannakou, & Albanis, 2011), while pollution of groundwater, soil contamination, production of unpleasant smells, as well as the toxicity of vegetation are also possible in case of uncontrolled disposal and/or insufficient treatment of OMW (Aggelis et al., 2003). Therefore, due to its polluting power and to the increasing severity of the applicable legislation (Gómez, Zubizarreta, Rodrigues, Dopazo, & Fueyo, 2010), the disposal of residues from oil extraction has become a major concern for olive oil producers. The need to apply suitable management practices, which are able to combine environmental and economic sustainability for olive oil facilities, is now clear.

Currently, the methods applied for OMW treatment are either physico-chemical (e.g. simple evaporation, reverse osmosis, ultrafiltration, coagulation, oxidation, thermal drying and advanced oxidation processes) or biological (aerobic treatment, composting, vermicomposting together with other agro-industrial residues), but the majority of these techniques are complex and expensive and the results obtained are often poor (Gómez et al., 2010; Komnitsas & Zaharaki, 2012; Dourou et al., 2016).

Anaerobic digestion has been proposed as a promising technology for the valorisation of olive oil residues through biofuel production (i.e. biogas) (Ponsá, Gea, & Sánchez, 2011; Sheng et al., 2013), since this process can be carried out by applying relatively inexpensive and simple reactor designs and operating procedures (Tekin & Dalgıç, 2000). However, researchers must overcome many issues (such as low pH and nitrogen content, alkalinity, presence of inhibiting compounds) for this technology to be applied to OMW (Orive, Cebriàn, & Zufía, 2016). Most researches have attributed the related problems observed during anaerobic digestion to the presence of polyphenols (PP). However, these experiments were often carried out using synthetic wastewater containing cellulose or acetate as main substrate (Chapleur et al., 2016; Madiguo, Poirier, Bureau, & Chapleur, 2016; Wang, Gabbard, & Pai, 1991) or even PP as substrate (Fedorak & Hrudey, 1984; Field & Lettinga, 1987). High concentrations of PP in the anaerobic digestion of OMW lead to very low biogas and methane production rates and consequent reduced treatment efficiency. Moreover, the reduced energy yield reduces the economical convenience of the anaerobic digestion of OMW.

In general, typical PP concentrations of OMW are in the range of 0.5–24 g l^{-1} (Borja, Pelillo, Rincòn, Raposo, & Martìn, 2006; Gonzalez-Lopez, Bellido, & Benitez, 1994), but severe methane yield reductions have been noticed already at PP concentrations of about 0.5–2 g l^{-1} (Borja, Banks, Alba, & Maestro, 1996; Fedorak & Hrudey, 1984). This means that raw OMW should be either co-digested with other organic substrates or fed with limited loads to the digester.

The scientific literature reports of many experimental tests concerning the anaerobic digestion of olive residues, often in co-digestion with other substrates. For instance, as co-substrates, Fontoulakis, Drakopoulou, Terzakis, Georgaki,