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Assessing the agricultural reuse of the digestate from microalgae anaerobic digestion and co-digestion with sewage sludge

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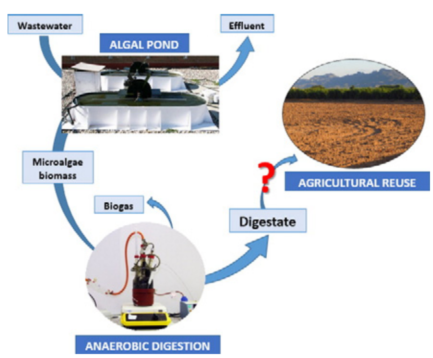
HIGHLIGHTS

- Digestates from microalgae anaerobic digestion and co-digestion were characterised.
- The main macronutrients were organic and ammonium nitrogen.
- Digestate hygenisation was achieved after the thermal pretreatment at 75 °C for 10 h.
- The stabilisation and dewaterability improved by co-digestion with primary sludge.
- Potential phytotoxicity increased after pretreatment but decreased by co-digestion.

GRAPHICAL ABSTRACT



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ABSTRACT

Microalgae anaerobic digestion produces biogas along with a digestate that may be reused in agriculture. However, the properties of this digestate for agricultural reuse have yet to be determined. The aim of this study was to characterise digestates from different microalgae anaerobic digestion processes (i.e. digestion of untreated microalgae, thermally pretreated microalgae and thermally pretreated microalgae in co-digestion with primary sludge). The main parameters evaluated were organic matter, macronutrients and heavy metals content, hygenisation, potential phytotoxicity and organic matter stabilisation. According to the results, all microalgae digestates presented suitable organic matter and macronutrients, especially organic and ammonium nitrogen, for agricultural soils amendment. However, the thermally pretreated microalgae digestate was the least stabilised digestate in comparison with untreated microalgae and co-digestion digestates. In vivo bioassays demonstrated that the digestates did not show residual phytotoxicity when properly diluted, being the co-digestion digestate the one which presented less phytotoxicity. Heavy metals contents resulted far below the threshold established by the European legislation on sludge spreading. Moreover, low presence of *E. coli* was observed in all digestates. Therefore, agricultural reuse of thermally pretreated microalgae and primary sludge co-digestate through irrigation emerges a suitable strategy to recycle nutrients from wastewater.

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1. Introduction

Microalgae-based wastewater treatment systems represent a cost-effective alternative to conventional activated sludge systems. The major advantage is that mechanical aeration is not required, since oxygen is provided by microalgae photosynthesis. Moreover, microalgae cultures are capable of removing nutrients (N, P) from wastewater by means of different mechanisms, such as assimilation or precipitation (Rawat et al., 2011). Furthermore, these systems can also combine wastewater treatment and bioenergy production if harvested microalgal biomass is downstream processed. In particular, anaerobic digestion is one of the most well-known processes to valorise organic waste generated in a wastewater treatment plant. Over the last decades, several studies on biogas production from microalgae have been carried out (Uggetti et al., 2017). They have demonstrated that some microalgae species have a resistant cell wall, which may hamper their bioconversion into methane. Microalgae cell wall disruption could be enhanced by applying pretreatment methods, being the most suitable those pretreatments with low energy demands (Passos et al., 2014). Besides, in the context of microalgae grown in wastewater, co-digestion of microalgae with sewage sludge is a profitable strategy, since the sludge is generated in the same process chain (Uggetti et al., 2017). This could optimise waste management and increase the organic loading rate of the digester (Mata-Alvarez et al., 2014).

Apart from biogas, microalgae anaerobic digestion also produces a digestate that can be reused in agriculture. Even though several studies have pointed out the necessity of recycling nutrients through digestate reuse to improve the sustainability of biogas production from microalgae (Collet et al., 2011), the properties of microalgae digestate for agricultural reuse have yet to be characterised. In general, anaerobic digestates have proper chemical properties for agricultural reuse (Rowell et al., 2001). For instance, they are rich in ammonia nitrogen, readily available for plant uptake, and other macronutrients such us phosphorus and potassium (Teglia et al., 2011a). However, depending on digestates properties, their reuse could be more addressed to improve or maintain the physico-chemical or biological properties of soils (soil amendment) or to boost the plants growing (fertilisers). In the first case, digestates with high organic matter, organic carbon and organic nitrogen content are preferred, while digestates with important mineral fractions have a higher potential for application as fertiliser (Nkoa, 2014).

Anaerobic digestion is often designed to achieve the maximum energy production, leading to a low stabilisation of the organic matter of the feedstock. As a consequence, digestates may be characterised by a high labile organic matter content and, thus, their agricultural reuse may face agronomic and environmental issues. In fact, it is known that by adding low-stabilised organic matter the soil microbial activity may be excessively stimulated. Indeed, it can produce high CO_2 fluxes from the soil, soil oxygen consumption with sequential nitrogen losses, and phytotoxicity phenomena (Pezzolla et al., 2013; Abdullahi et al., 2008). In addition, the digestate composition can highly vary depending on the feedstock or anaerobic digestion operating conditions. Even the application of a pretreatment on the feedstock previous to anaerobic digestion can influence the final composition of the digestate (Monlau et al., 2015a). Thus, the characterisation of a digestate before evaluating its potential applications is convenient.

When characterising new digestates, particular attention should be addressed to the macronutrients content, potential phytotoxicity and stabilisation of the organic matter. In vivo bioassays are useful to assess the potential phytotoxicity (Alburquerque et al., 2012; Zucconi et al., 1985). The quantification of CO_2 emissions and the water extractable organic matter (WEOM) in digestate amended soils are suitable strategies to assess organic matter stabilisation (Pezzolla et al., 2013; Said-Pullicino and Gigliotti, 2007). On the other hand, land application of anaerobic digestates may also introduce physical, chemical and biological contaminants into soils which may be up-taken by crops and endanger their long-term agricultural activity (Nkoa, 2014). For instance, European legislation on sewage sludge spreading (CEC, 1986) mainly regulates the heavy metals content in digestates to avoid their accumulation in amended soils. However, a more recent European Directive draft (CEC, 2003b) also proposes restrictions on the occurrence of bio-accumulative organic compounds and their hygenisation before being spread on soils. Consequently, the presence of these contaminants in digestates should be assessed if they are going to be reused in agricultural soils.

The aim of this study was to characterise for the first time the quality of microalgae digestates for agricultural reuse. To this end, the effluents from three different anaerobic digesters fed by untreated microalgae, thermally pretreated microalgae and thermally pretreated microalgae in co-digestion with primary sludge were analysed. The main parameters evaluated were organic matter, macronutrients and heavy metals content, hygenisation, potential phytotoxicity and organic matter stabilisation.

2. Material and methods

2.1. Digestate origin and sampling

The microalgal biomass used in this study consisted of a microalgae-bacteria consortia grown in a pilot raceway pond that treated wastewater from a municipal sewer, as described by Passos et al. (2015). Microalgal biomass was harvested from secondary settlers and gravity thickened in laboratory Imhoff cones at 4 °C for 24 h. The pilot plant was located at the laboratory of the GEMMA research group (Barcelona, Spain). According to optic microscope examinations (Motic BA310E, equipped with a camera NiKon DS-Fi2), predominant microalgae were *Chlorella* sp. and diatoms (Fig. 1).

In order to improve microalgae biodegradability, a part of the harvested and thickened biomass was thermally pretreated at 75 °C for 10 h, as suggested by Passos and Ferrer (2014). The pretreatment of microalgal biomass was carried out in glass bottles with a total volume of 250 mL and a liquid volume of 150 mL, which were placed in an incubator under continuous stirring at 75 °C for 10 h. Untreated (control) and pretreated microalgae were digested in lab-scale reactors under mesophilic conditions. Furthermore, the anaerobic co-digestion of pretreated microalgal biomass with primary sludge (25%–75% VS, respectively) was also evaluated. The thickened primary sludge was collected in a municipal wastewater treatment plant near Barcelona.

Thus, the following effluents from microalgae anaerobic digestion were analysed:

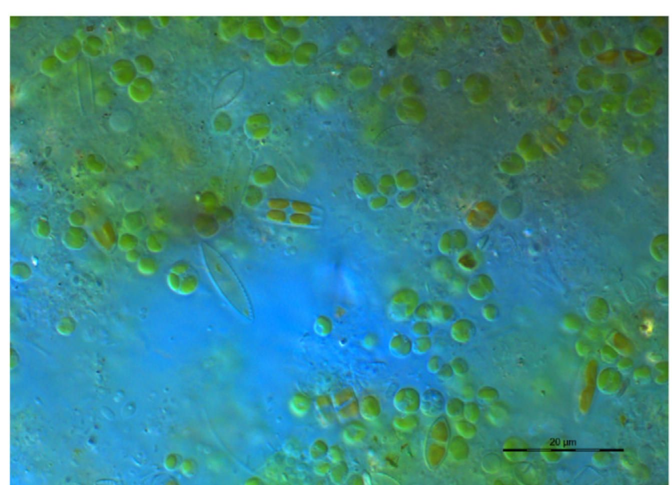

Fig. 1. Microscopic image of microalgal biomass mainly composed by *Chlorella* sp. and diatoms.

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