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Research article

Understanding the anaerobic biodegradability of food waste: Relationship between the typological, biochemical and microbial characteristics

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ABSTRACT

In this study, an extensive characterisation of food waste (FW) was performed with the aim of studying the relation between FW characteristics and FW treatability through an anaerobic digestion process. In addition to the typological composition (paper, meat, fruits, vegetables contents, etc) and the physico-chemical characteristics, this study provides an original characterisation of microbial populations present in FW. These intrinsic populations can actively participate to aerobic and anaerobic degradation with the presence of *Proteobacteria* and *Firmicutes* species for the bacteria and of *Ascomycota* phylum for the fungi. However, the characterisation of FW bacterial and fungi community shows to be a challenge because of the biases generated by the non-microbial DNA coming from plant and by the presence of mushrooms in the food. In terms of relations, it was demonstrated that some FW characteristics as the density, the volatile solids and the fibres content vary as a function of the typological composition. No direct relationship was demonstrated between the typological composition and the anaerobic biodegradability. However, the Pearson's matrix results reveal that the anaerobic biodegradation potential of FW was highly related to the total chemical oxygen demand (tCOD), the total solid content (TS), the high weight organic matter molecules soluble in water (SOL_W>1.5 kDa) and the C/N ratio content. These relations may help predicting FW behaviour through anaerobic digestion process. Finally, this study also showed that the storage of FW before collection, that could induce pre-biodegradation, seems to impact several biochemical characteristics and could improve the biodegradability of FW.

1. Introduction

Nowadays, one third of the global food production is wasted (Gustavsson et al., 2011). In fact, 1300 billion tons of food waste (FW) are produced each year, emitting roughly 3.3 billion tons of CO_2Eq. This emission represents 9.6% of global CO_2 emissions (WEDODATA, 2015). The food wastage is evidenced at all stages of the food supply chain. In developing countries, most of the food wastage occurs in early stages (production, transport) (80–95%), meanwhile, in industrialized countries, the proportion of FW at the consumer level is higher (30–40%) (Gustavsson et al., 2011). In this context, several countries are working both on increasing prevention of FW and on reducing FW landfilling and promoting strategies of valorisation, mainly via biological fertiliser and bioenergy production (Sidaine and Gass, 2013).

FW shows a high potential to produce methane (CH_4) by anaerobic digestion (AD). In average, about 460 normal litres (NL) of CH_4 can be produced per kilogram of volatile solids (VS) of FW (Fisgativa et al., 2016). This represents almost twice as much as the methanogenic potential of cattle manure (270 $NLCH_4$ $kgVS^{-1}$) and sewage sludge (255 $NLCH_4$ $kgVS^{-1}$) (Peu et al., 2012). FW shows also high VS content (about 88% of the total solids (TS)), a good moisture content (about 77% of the wet weight (WW)), a balanced carbon-to-nitrogen ratio (C/N) (18.5) and high carbohydrates and proteins content (36%VS and 21%VS respectively) (Fisgativa et al., 2016). These characteristics make FW a very suitable substrate to be valorised toward AD process. However, several authors stated instabilities in anaerobic treatment of FW caused by rapid production of volatile fatty acids (VFA) and total ammonia nitrogen (TAN), especially at high organic loading rates (OLR) (>9 $kgVS^{-1}$ m^{-3} d^{-1}) (Deublein and Steinhauser, 2011; Jabeen et al., 2015; Mata-Álvarez, 2003; Scano et al., 2014). The accumulation of

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these metabolites results in instabilities of the anaerobic digestion mechanisms, which are especially harmful to the methanogens microorganisms.

In addition, recent studies showed that the initial characteristics of FW impact the development of the AD process (Bayard et al., 2015; Fisgativa et al., 2016). Values of TS, VS, chemical oxygen demand (COD), C/N ratio, cellulose (CEL) and lignin content (LIG) among others, can be used as indicators of the FW biodegradability (Bayard et al., 2015; Fisgativa et al., 2016; Triolo et al., 2011). Nevertheless, most of these characteristics present very high variations (some with coefficients of variations above 100%) within FW, making difficult to predict them without specific laboratory analyses for each FW substrate. Fisgativa et al. (2016) attempted to relate variations of FW characteristics with geographical origin, collection source and season of collection. They suggested specific average values for some characteristics as TS or CEL content. However 76% of the characteristics variations were not explained by these categories. Thus the investigation of new factors as the typological composition could help a better understanding of the causes of variation of FW characteristics. This need of complementary analytical parameters for FW was also underlined by Bayard et al. (2015) who suggested to study the content of microorganisms or the fractionation of water-soluble molecules in order to provide further information on the anaerobic biodegradability of FW.

Studies on microbial populations in anaerobic digesters and compost treating food waste were reported recently (Li et al., 2015; Lim et al., 2013; Wang et al., 2016). However, the understanding of relationships between food waste initial microbial populations and anaerobic biodegradability is still limited due to the lack of references. Characterisation of raw FW microbial community may provide useful information about the start-up of FW biodegradation. 16S rRNA-targeted Next-Generation Sequencing (NGS) technology provides comprehensive characterisations of complex microbial consortia (Ju and Zhang, 2015).

Therefore, the purpose of this work is to provide an extensive characterisation of FW, searching to compare and complement the FW characteristics found in literature. In particular 16S rRNA-targeted NGS was employed to determine the microbial populations. Moreover, a statistical analysis was performed to highlight relationships between the physicochemical and biochemical characteristics of FW on one hand, and the typological composition and anaerobic biodegradability of FW (biogas potential) on the other hand. These relations may help predicting FW behaviour through AD.

2. Materials and methods

2.1. Food waste collection and sampling

For this study, FW samples were collected from 3 different sources near to Rennes, France: a collective catering (RIA) and a vegetarian restaurant (VEG) producing respectively 17 and 11 tons of kitchen waste per year, and the separated biowaste from a municipality (BIO) that collects 45 tons per week of organic waste from households, bakeries, restaurants and public institutions. These 3 sources of waste were chosen because they share similar global physicochemical characteristics (Fisgativa et al., 2016) but have different typological compositions (absence of meat in the waste of the vegetarian restaurant and more diverse compositions in the separated biowaste). These variations in the typological composition may influence the microbial community structure and biodegradability of FW.

Each source of FW was sampled twice, at two weeks intervals. A method of quartering was used to constitute a 17 kg sample in order to perform the laboratory analyses. In the case of the restaurants, the whole production of kitchen waste and dishes leftovers of the day of sampling was collected to constitute the samples. Concerning BIO the sampling was made from around 400 kg of waste on the composting plant where the collected waste is delivered. Manual sorting of biodegradable plastic bags was performed. Because of the collection frequency on the territory (once or twice a week), FW from BIO showed clear signs of biodegradation in the storage bins before sampling.

2.2. Samples preparation

The scheme of samples preparation is presented on Fig. 1. Fifteen kilograms of FW were stored at 4 °C up to 2 days until the typological sorting and the free air space (FAS) and density measures were performed. Two kilograms were frozen with liquid nitrogen, ground at 2 mm and stored at −20 °C in order to be used later for physicochemical, biochemical and elementary analyses. Additionally, about 5 g of ground wastes were further milled with liquid nitrogen for 1 min with a ball mill (300 Dangoumill, Prolabo) up to obtain a homogeneous powder and stored at −80 °C for molecular microbiology analyses.

In order to determine the characteristics of the water soluble matter, a water extraction was performed at room temperature on

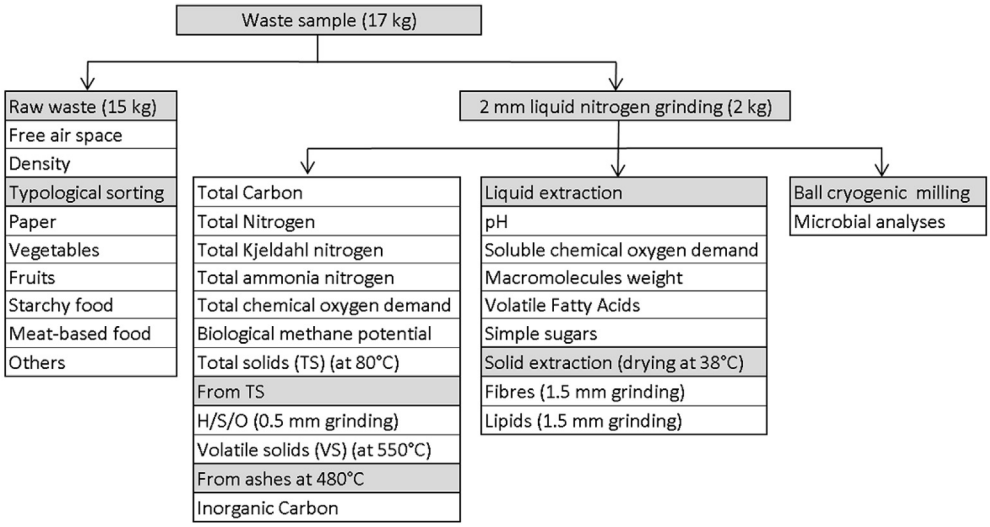

Fig. 1. Scheme of sample preparation.