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Acidogenic fermentation of the organic fraction of municipal solid waste and cheese whey for bio-plastic precursors recovery – Effects of process conditions during batch tests

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ABSTRACT

The problem of fossil fuels dependency is being addressed through sustainable bio-fuels and bio-products production worldwide. At the base of this bio-based economy there is the efficient use of biomass as non-virgin feedstock. Through acidogenic fermentation, organic waste can be valorised in order to obtain several precursors to be used for bio-plastic production. Some investigations have been done but there is still a lack of knowledge that must be filled before moving to effective full scale plants.

Acidogenic fermentation batch tests were performed using food waste (FW) and cheese whey (CW) as substrates. Effects of nine different combinations of substrate to inoculum (S/I) ratio (2, 4, and 6) and initial pH (5, 7, and 9) were investigated for metabolites (acetate, butyrate, propionate, valerate, lactate, and ethanol) productions.

Results showed that the most abundant metabolites deriving from FW fermentation were butyrate and acetate, mainly influenced by the S/I ratio (acetate and butyrate maximum productions of 21.4 and 34.5 g/L, respectively, at S/I = 6). Instead, when dealing with CW, lactate was the dominant metabolite significantly correlated with pH (lactate maximum production of 15.7 g/L at pH = 9).

1. Introduction

During the last decades many studies about anaerobic digestion (AD) treatment of biomass have been published with a view on underlying the effectiveness of treating those residues with the double benefit of reducing the amount of waste to be disposed and valorising those biomass as a bio-energy source.

AD process includes four sequential stages: hydrolysis, acidogenisis, acetogenesis, and methanogenesis. Up to now, full-scale applications have been mainly developed to maximise the yield of the last stage in order to obtain the valuable energetic gas to be used as a fuel, namely methane. However, during the initial steps of AD, before methanogenesis, many valuable products with a wide spectrum of possible uses can be gathered.

In a bio-based economy, biomass is the sustainable non-virgin feedstock to be converted into energy or into raw materials for products (Márquez Luzardo and Venselaar, 2012). According to the biocascading pyramid illustrated in Fig. 1, there are several routes through which it is possible to increase the resource use efficiency of biomass (Annevelink et al., 2017; Márquez Luzardo and Venselaar, 2012).

Therefore, in the view of a bio-refinery process, valorisation of putrescible organics via acidogenic fermentation opens a wide variety of routes starting from the different end-products namely hydrogen and biological metabolites. Many types of microorganisms and biochemical pathways are involved in the acidogenesis and, consequently, a large number of valuable products are usually formed (Arroja et al., n.d.).

Focusing the attention on the latter, volatile fatty acids (VFAs), ethanol and lactate are not only the optimal feed for methane production through archaea (Stoyanova et al., 2017) but can be valorised as sustainable precursors for bio-plastic production (Tang et al., 2017; Wu et al., 2016, 2015). In fact, these platform molecules can be versatile tool in many product formation routes with a higher added value than methane (Tamis and Joosse, 2015). This idea is at the base of the so called carboxylate platform concept (Agler et al., 2011; Holtzapple and Granda, 2009), which is aimed at supporting the conversion of organic feedstocks to short-chain carboxylates as intermediate feedstock chemicals, using hydrolysis and fermentation with undefined mixed cultures in engineered systems under anaerobic conditions (Agler et al., 2011; Angenent

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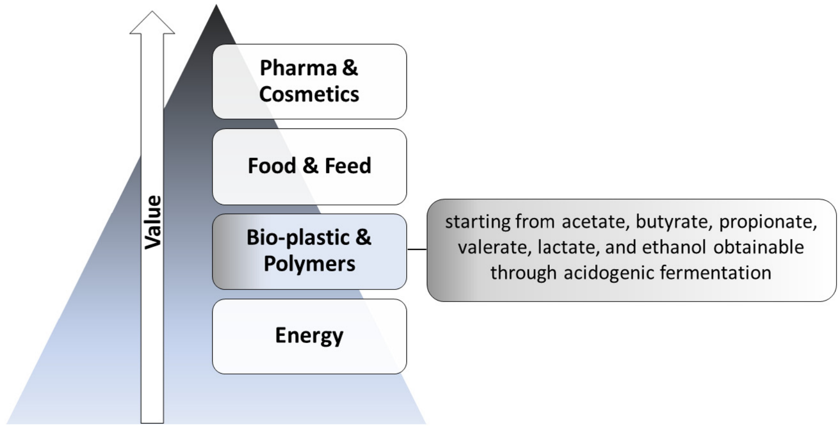

Fig. 1. Biocascading pyramid referred to biomass-based by-products (modified from Annevelink et al., 2017; Márquez Luzardo and Venselaar, 2012). The highlighted block is the main focus of the present study.

et al., 2004; Kleerebezem and Loosdrecht, 2007; Tamis and Joosse, 2015). Outputs can vary (Tamis and Joosse, 2015) from bio-polymers (Kleerebezem and van Loosdrecht, 2007; Reis et al., 2003), to medium chain length fatty acids (Grootscholten et al., 2014; Spirito et al., 2014) which might be used as antimicrobials (Woolford, 1975), up to corrosion inhibitors (Kuznetsov and Ibatullin, 2002) and other bio-based chemical production processes (Levy et al., 1981). In these terms, acidogenic fermentation becomes a tool to exploit discarded biomass (Wang et al., 2017) as a non-virgin feedstock, save limited natural resources, and reduce greenhouse gases emissions by lowering the amount of bio-waste to be discarded and row material to be processed.

With a focus on the environmental problems related to plastic disposal, which are due to its non-degradable behaviour (Tripathi et al., 2013), attention is now paid on the development of completely biodegradable plastics such as bio-polyethylene (Bio-PE) (Isikgor and Becer, 2015; Önal et al., 2014), poly-lactic acid (PLA) (Daniels et al., 2014; Guo et al., 2014; Liang et al., 2015), polyvinyl acetate (PVA) (Chen et al., 2016; Sawatdeenarunat et al., 2017; Singh and Wahid, 2015), polyhydroxyalkanoates (PHA) (Amache et al., 2013). They all are polymers of biological metabolites namely ethanol, lactate, acetate, and VFAs (in general), respectively. In this sense, direct biological production of hydrogen through dark fermentation appears to be only a pre-treatment step within a larger bioenergy and biochemical production concept (Angenent et al., 2004).

Monomers recovery for bio-polymers production can be achieved starting both from agro-industrial and household organic wastes (Table 1) either through fermentation of carbohydrate-rich feedstocks by microbes, often genetically modified, or by chemical processing of animal fats and vegetable oils (Fuessl et al., 2012; Girotto et al., 2015). At present, amongst the various types of biodegradable plastics, PHA is one of the most promising (Girotto et al., 2015) and the waste biomass tested as potential non-virgin feedstock after their acidogenic fermentation pre-treatment have been many.

According to the characteristic of the fermented substrate and the process parameters settings, the yield of produced metabolites can vary also in terms of component percentage and quality. Acetate is mainly obtained when hydrogen partial pressure is maintained at low levels, while propionate and butyrate are formed during proteins hydrolysis and subsequent fermentation of amino acids, regardless hydrogen partial pressure (Agler et al., 2011; Nagase and Matsuo, 1982). Propionate is, instead, mainly produced when hydrogen partial pressure is quite high (Agler et al., 2011) and lactate fermentation dominates when applying mixed cultures

Table 1
Literature review of waste biomass tested as a substrate for bioplastic production.

Substrate	Biological metabolites after fermentation	Potential biopolymer	Reference
Cheese whey	Acetic, butyric and lactic acids	PVA, PHA, PLA	(Colombo et al., 2016; Oliveira et al., 2016; Patel et al., 2016; Valentino et al., 2015)
Corn stover	Acetic acid	PVA	(Zhao et al., 2014)
Dried sugar beet pulp, wheat bran and distiller's dried grains	Propionic and butyric acids	PHA	(van Aarle et al., 2015)
Food waste	Acetic, propionic, butyric, and valeric acids	PVA, PHA	(Reddy and Mohan, 2012; Shen et al., 2016; Tang et al., 2017; Yin et al., 2016a,b)
Food waste and rice straw	Lactic, butyric and acetic acids	PVA, PHA, PLA	(Chen et al., 2015)
Fruit and vegetable waste	Lactic acid and ethanol	PLA, Bio-PE	(Wu et al., 2016, 2015)
Fruit pomace and waste frying oil	Acetic, propionic, butyric, and valeric acids	PVA, PHA	(Follonier et al., 2014)
Spent coffee grounds oil	Acetic, propionic, butyric, and valeric acids	PVA, PHA	(Cruz et al., 2014; Obruca et al., 2015, 2014)
Tofu and egg white	Acetic, propionic, butyric, and valeric acids	PVA, PHA	(Shen et al., 2016)

for treating high concentrations of easily degradable substrates (Agler et al., 2011; Russell and Hino, 1985). Notwithstanding, there is not an accurate outline of the best acidogenic fermentation conditions yet which may vary from one substrate to another in order to recover the highest amount of biological metabolites. Among the several parameters affecting the process outputs (van Aarle et al., 2015) there are pH (Chen et al., 2015; Wu et al., 2016), organic load (Arroja et al., n.d.; Rincón et al., 2008), temperature, and inoculum as a single or mixed culture (Dahiya et al., 2015; Yin et al., 2016a, b). Moreover, stepping from batch (Rajagopal et al., 2014; Shen et al., 2016; Tang et al., 2017; Yin et al., 2016a,b) to CSTR (Chen et al., 2016; Krishnan et al., 2017; Wu et al., 2015) reactors highly influences the tests outcomes as well as the following full scale-up which has been put in operation nowhere yet. Indeed, theoretical

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