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Research article

Volatile fatty acids production from food wastes for biorefinery platforms: A review

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ABSTRACT

Volatile fatty acids (VFAs) are a class of largely used compounds in the chemical industry, serving as starting molecules for bioenergy production and for the synthesis of a variety of products, such as biopolymers, reduced chemicals and derivatives. Because of the huge amounts of food waste generated from household and processing industry, 47 and 17 million tons per year respectively only in the EU-28 Countries, food wastes can be the right candidate for volatile fatty acids production. This review investigates all the major topics involved in the optimization of VFAs production from food wastes. Regarding the best operative conditions for the anaerobic fermenter controlled pH in the neutral range (6.0–7.0), short HRT (lower than 10 days), thermophilic temperatures and an organic loading rate of about 10 kgVS/m^{3}d, allowed for an increase in the VFAs concentration between 10 and 25%. It was also found that additions of mineral acids, from 0.5 to 3.0%, and thermal pretreatment in the range 140–170 °C increase the organic matter solubilisation. Applications of VFAs considered in this study were biofuels and bioplastics production as well as nutrients removal in biological wastewater treatment processes.

1. Introduction

The more and more impacting problem of global warming, due to the increase of greenhouse gases in the atmosphere, encouraged the emerging of the "biorefinery" concept. Biorefinery represents an innovative approach in the environmental management, where products at the end of their service life or waste materials are seen as valuable resources for the production of high added value bio-products or biofuels and are produced from renewable sources, possibly from organic wastes (Nghiem et al., 2017). Among them, Food Wastes (FWs) represent the optimal candidates for the biorefinery processes (Alibardi and Cossu, 2015). Food and Agriculture Organization (FAO) estimated that one third of world food production is lost or wasted along the food supply chain including the final steps like households, restaurants, and canteens. EU-28 Member States produced approximately 89 million tons of food waste in 2012 (Braguglia et al., 2018), (Lucifero, 2016). In particular, the sectors contributing to FWs production are households (47 million tonnes ± 4 million tonnes) and processing industry (17 million tonnes ± 13 million tonnes) (Stenmarck et al., 2016). Very often these FWs are disposed of in landfill or sent to incineration with null or limited recovery of resources and high emission of greenhouse gases and toxic compounds in the atmosphere and in the soil in both the cases (Ren et al., 2018). A sustainable alternative is the FWs exploitation for the production of Volatile Fatty Acids (VFAs). These are linear short-chain aliphatic mono-carboxylate compounds, having from two (acetic acid) to six (caproic acid) carbon atoms. Due to their functional groups, VFAs are extremely useful for the chemical industry: carboxylic acids are precursors of reduced chemicals and derivatives (esters, ketones, aldehydes, alcohols and alkanes) in conventional organic chemistry (Dahiya et al., 2015). Moreover, they are also well-known substrates for the production of biofuels like methane and hydrogen as well as biopolymers, such as polyhydroxyalkanoates (PHAs) (Raganati et al., 2014; Domingos et al., 2017).

Nowadays, VFAs are mainly produced through oxidation or carboxylation of chemical precursors, such as aldehydes and alkenes, deriving from petroleum processing (Riemenschneider, 2000). The biorefinery approach for VFAs production contemplates the fermentation process provided both by pure culture of specific anaerobic bacterial strains, and by Mixed Microbial Cultures (MMCs) (Dai et al., 2017).

Although MMCs may lead to lower yields in terms of VFAs, they have several advantages, since non-sterile conditions are needed, and risk of contamination is decreased (Bhatia and Yang, 2017). At the same time, MMCs can metabolize a wide spectrum of organic molecules, being able to face with the heterogeneous composition of FWs in terms of carbohydrates, proteins and lipids (Jankowska et al., 2015). VFAs production through MMCs is made possible by different metabolic

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List of abbreviations:

C/N	carbon – nitrogen ratio
COD	total chemical oxygen demand
HAc	acetic acid
HBu	butyric acid
HCa	caproic acid
HPr	propionic acid
HRT	hydraulic retention time
HVa	valeric acid
iso-HBu	*iso*-butyric acid
iso-HCa	*iso*-caproic acid
iso-Hva	*iso*-valeric acid
MMC	Mixed Microbial Cultures
OLR	organic loading rate
PHA	poly-hydroxy-alkanoates
sCOD	soluble chemical oxygen demand
TKN	total Kjeldahl nitrogen
TS	total solids
TVS	total volatile solids
VFAs	volatile fatty acids

pathways, which depend essentially on the substrates (carbohydrates, lipid and proteins) (Garcia et al., 2018).

In order to strengthen the potential of MMCs fermentation in terms of VFAs production, it is necessary to pay close attention to process parameters and operational conditions during the experimental setup. In fact, different hydraulic retention time (HRT), organic loading rate (OLR), temperature, and pH, influence the VFAs yield as far as the amount of other fermentation by-products, such as longer chain fatty acids, other carboxylic acids, alcohols, biohydrogen, biomethane, esters, and other intermediates (Mohan et al., 2016). The different pathways seem to have some preferential operative conditions: thermophilic temperatures, controlled pH at neutral values (6.0–7.0) and short HRT between 1 and 10 days, depending on the substrates (Bolzonella et al., 2005). For example, these conditions favour the glycolytic pathway allowing the acetic acid production, inhibiting the methanogens. On the contrary, a pH in the range 7.0–7.5 and higher HRT enable the survival and the activity of microorganisms producing methane from VFAs (Baumann and Westermann, 2016). Several studies emphasized that the two-stage anaerobic digestion (AD) process as the most promising way for VFAs production (Nagao et al., 2012; Jiang et al., 2013; Browne and Murphy, 2014). Hydrolysis and acidogenesis are the first steps of AD: firstly, the complex polymers present in organic matter are reduced into soluble monomers (simple sugars, amino acids, glycerol) along hydrolytic phase and then fermented by MMCs into VFAs, carbon dioxide (CO_2), and hydrogen (H_2) along the acidogenic phase, also known as dark fermentation (DF) (Fig. 1) (Parawira et al., 2004).

This paper reviews the results obtained in several studies dealing with the production of VFAs through acidogenic fermentation of FWs carried out by MMCs, in order to provide a view on the best FWs

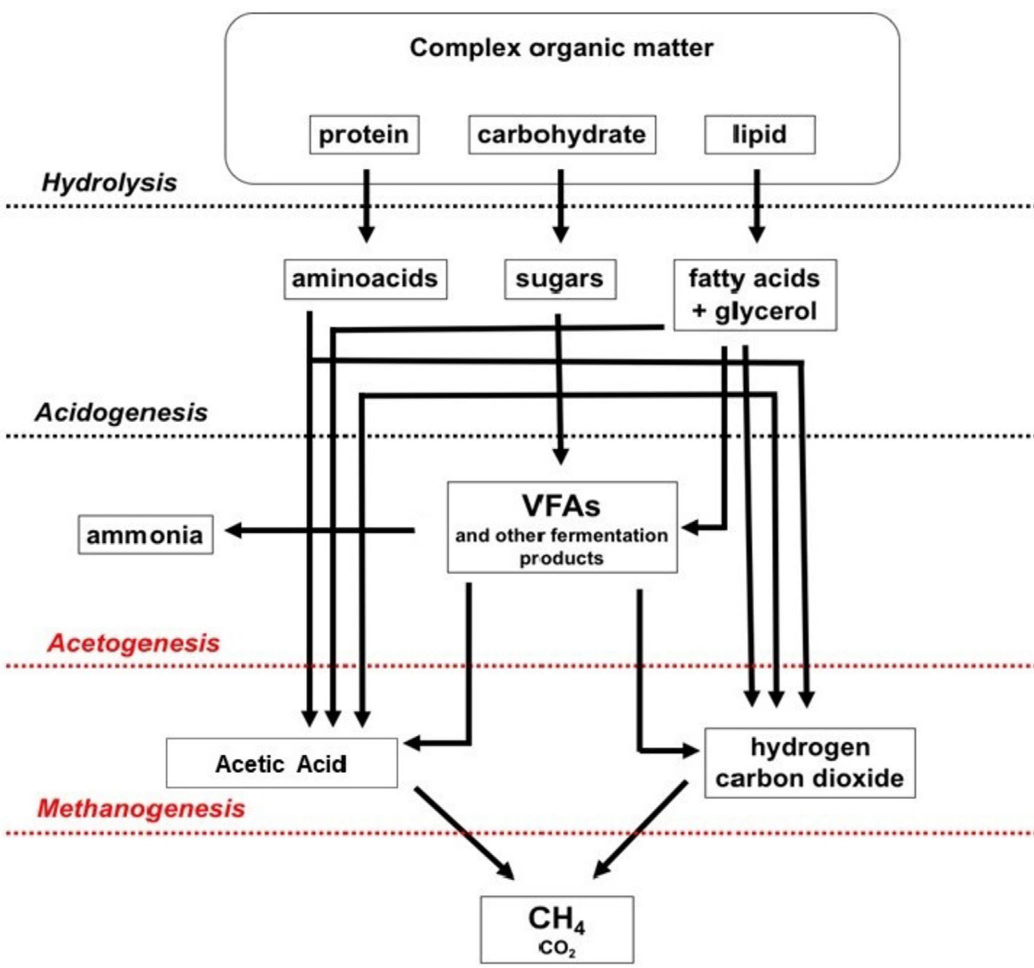

Fig. 1. Process cascade of anaerobic digestion process. Red line indicates the phase separation to obtain VFAs (Adapted from Batstone et al., 2002).