Turning urban biowaste in bioethanol in pilot scale

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Keywords: Cellulose, enzymatic hydrolysis, ethanol yield, food waste, saccharification, starch.
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Introduction

The amount of food waste generated by households, restaurants, cafés, and other food-related businesses in urban areas poses a significant environmental and economic issue, contributing to greenhouse gas emissions and enormous amounts of landfill waste. The European Union estimates that food waste in its member states accounts for around 88 million tons per year, while Greece holds the first place with 1.5 million tons of food waste annually. Efforts to reduce food waste are ongoing in Europe, with the EU targeting a 50% reduction by 2030, and several countries, including Greece, enacting laws to combat the issue. Despite these efforts, reducing the urban food waste stream remains a critical challenge, and ongoing efforts are focused on valorising the food waste stream thus d minimizing its associated impacts.

Materials and Methods

Fresh source-separated food waste was utilized in this study as received, from the Municipality of Vari-Voula-Vouliagmeni, Attica, Greece. It was received at the Unit of Environmental Science and Technology (UEST), National Technical University of Athens where it underwent milling and homogenisation by a shredding machine (Bowl Cutter LFC-18V2). The moisture content of the raw material was about 82%. The average composition of the feedstock was estimated in % w/w dry basis as: cellulose 9.35 ± 1.13, hemicellulose 8.51 ± 1.92, starch 4.46 ± 2.78, fats and oils 20.99 ± 7.66, acid soluble lignin 1.04 ± 0.22, acid insoluble residue 9.66 ± 2.14, water soluble solids 39.28 ± 6.44, volatile solids 91.47 ± 1.53.

All chemicals used were of analytical grade. Spirizyme XL which is an amylolytic formulation and non-commercial NS87014 which is a cellulolytic enzyme were provided by Novozymes (Denmark). The activity of Spirizyme XL was measured equal to 2337 U/mL (Xiao et al., 2006). Similarly, the activity of NS87014 was measured equal to 333 FPU/ mL (Ghose, 1987). S. cerevisiae was utilized as fermentation yeast.

Following the NREL laboratory analytical procedures, structural carbohydrates and lignin were determined in the biomass of raw and treated substrate (Sluiter et al., 2012). For the determination of sugars and ethanol in the liquid fraction, samples were analyzed by HPLC. All analyses were performed in duplicate.

Experimental procedure

The pilot scale experiments were performed in a bioconversion pilot plant within the premises of UEST, which consists of two horizontally agitated rotating vessels (200L each) made of stainless steel. These reactors may work independently under different operating conditions. Their temperature is controlled by water recirculation within their double walls. A distillation pilot unit is used to recover the produced ethanol at 70^{o}C with the aid of low vacuum. The pilot plant operation is controlled via a Programmable Logic Controller. During the saccharification and fermentation processes, with a view to better monitor the process, samples were collected at an hourly basis and were characterized in terms of ethanol and glucose. 11 trials were performed. The efficiency of fermentation, for every trial, was assessed by the ethanol yield, Y_{EtOH} (g/g theoretical ethanol) which was set as the optimization parameter for the bioprocess (Table 1).

Results

The ethanol yields, the ethanol concentration along with the achieved solid loading are presented in Table 1. The results appeared to be very encouraging with a mean ethanol yield of 0.74 ± 0.07, comparable to other studies that refer to dry food waste as feedstock (Tsafara, et al., 2022) (Matsakas, Kekos, Loizidou, & Christakopoulos, 2014). Additionally, almost 134L of ethanol could be produced per tonne of dried biowaste. Taking into consideration the characteristics of the feedstock used and the derived stillage, the degradation efficiencies were calculated; the degradation of solids was around 64% and the breakdown of polysaccharides was 80.69 ± 16.27% for starch and 79.41 ± 10.37% for cellulose. Thus, the performance of the continuous pilot plant operation with the wet feedstock could be considered satisfactory.

Table 1. Ethanol Concentration and yield during the pilot trials.

Trials	1	2	3	4	5	6	7	8	9	10	11
Loading (%w/w)	11.41	11.97	10.36	16.74	13.86	12.09	15.51	16.46	15.61	14.49	15.04
Ethanol Concentration (g/L)	9.00	12.00	15.00	20.00	20.00	11.00	15.00	16.00	29.00	18.00	25.50
Y_{EtOH} (g/g)	0.62	0.79	0.68	0.70	0.69	0.71	0.75	0.70	0.85	0.76	0.89

Regarding energy consumption, the analysis was conducted for the three main stages of the process: shredding, simultaneous saccharification and fermentation process and final recovery of produced ethanol via distillation. The mean total energy consumption of the optimized process treating wet source-separated biowaste is 2.17kWh per kg of dried feedstock and this consumption could be fractionated as follows: 8.64% for shredding, 48.19% for bioconversion and 43.17% for distillation.

Conclusions

In conclusion, the use of wet shredded biowaste for the production of bioethanol seems promising due to the elevated ethanol yields and carbohydrates degradation as well as the low energy consumption.

Acknowledgements

The authors acknowledge funding through Horizon 2020 WaysTUP! (Grant agreement No 818308) project for supporting this work.

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