Biogas potential of residues generated by the tomato processing industry under different substrate and inoculum conditions.

M. Martínez*, L. Driller*, R. Chamy*,**, Wolfgang Schuch*, M. Nogueira***, P. Fraser***

*Fraunhofer Chile Research, Av. Mariano Sanchez Fontecilla 310, Santiago de Chile. Phone: +56 (22) 378 1659 | Email: maria.martinez@fraunhofer.cl | www.fraunhofer.cl.

** Núcleo de Biotecnología de Curauma (NBC), Pontificia Universidad de Valparaiso (PUCV). ***School of Biological Sciences, Royal Holloway University of London (RHUL)

INTRODUCTION

A major problem faced by the tomato growing and processing industry is the accumulation, handling and disposal of processing wastes. Currently, tomato residues are either used as fertilizer or disposed at landfills with its inherent carbon footprint and commercial costs. A promising treatment of tomato production waste is the production of biogas via anaerobic digestion (AD). During the AD process, approximately 50-70% of the chemical energy conserved in the tomato organic matter can be converted into methane gas, allowing up to 99% of the total weight of plant material to be digested. The experiential work has been carried out within the framework of the FP7 project: "High Value Plant Products – From DISCOvery to final product" . The aim of the work carried out is to add value to the tomato production process by using its waste materials for energy production and recovering water and nutrients that can be further used as fertilizer. In particular, methane production from tomato waste is a complex, multi-step process that involves multiple syntrophic interactions. Due to the difficult to degrade lignocellulosic matrix present in the plant tissue, BMP tests had been used as a tool to measure the bio-methane potential, as well as to determine bio-kinetic constants. In order to maximize the methane production and the efficiency of the digestion process, operational conditions had been optimized and different tomato plant residues had been evaluated.

MATERIALS & METHODS

Two different tomato plant materials were considered at this stage of the FP7 project: (1) plant material from a novel transgenic tomato line (ZWRI) developed by RHUL, and (2) natural tomato plant material (NTP) from Chile as control, both consisting mainly in leaves and stems. Tomato plant residues were chopped and adjusted to 94% of water content before its addition to the reactors as shown in Fig. 01. Different inoculums had been tested and characterized. Finally, two inoculums were identified regarding their suitability for tomato plant degradation: The first was a sludge from a wastewater treatment plant (raw WWTP), and the second was a preadapted sludge for "easy-to-degrade" sugars (EDS), that is commonly used for anaerobic tests under standardized laboratory conditions.

A complete characterization of physicochemical properties of tomato residues and inoculum was performed under APHA (2012) and AOAC (2012) guidelines, including Volatile Solids (VS) and Total Solids (TS), Carbon (C), Nitrogen (N) and Fibers (cellulose, hemicellulose and lignin).

Figure 01. Tomato plant residues (1) ZWRI and (2) NTP after processing and water adjustment.

Bio-methane potential (BMP) was based in ABAI Task Group (2006) procedures for batch assays. BMP of tomato plants, expressed as the methane produced per amount of organic matter (Nm^3 CH_4·gVS^{-1}d^{-1}) were performed at laboratory scale (0.1 L), operating at mesophilic conditions (36 ±2°C), using different substrate concentrations (1.0, 3.0 and 5.0% TS w/v), while reaction medium was the indicated by Field (1987). Inoculum were added to the medium at 1.5 g VS·L^{-1}, with a Specific Methanogenic Activity (SMA) of 0.38-0.43 g COD-CH_4·gVS^{-1}d^{-1}. Methane production and its content in the biogas were measured by GC-TCD, VFA was measured by HPLC-UV and NH4-N by spectrophotometry, while CH_4 volume was measured by liquid displacement of a NaOH 1N solution.

RESULTS & DISCUSSION

Tomato plant residues characterization is described in Table 01 (st. dev. 7-18%), in which can be observed an important content of fibers and a low C/N ratio (<10), which can lead in an ammonium inhibition if concentration is above 1.0-2.0 ppm during the anaerobic degradation.

Table 01. Tomato plant residues characterisation.

SUBSTRATE	TS (% wet basis)	VS (% dry basis)	pH	C/N	Cellu-lose (%)	Hemi-cell. (%)	Lignin (%)
ZWRI (RHUL)	5.4	89	5.5	7.2	11.7	7.4	2.2
NTP (Chile)	6.1	89	5.4	7.5	13.2	8.2	1.9

So far, best results have been obtained at total solid concentrations of 1.0% for both ZWRI and NTP, showing maximum methane productions of 220 and 168 mL CH_4·gVS^{-1}, respectively, in accordance to those reported previously for different tomato residues by several authors.

Methane production ranged from an average of 45 to 220 mL CH_4·gVS^{-1} as shown in Fig. 02, and in an inverse relation to the initial TS concentration

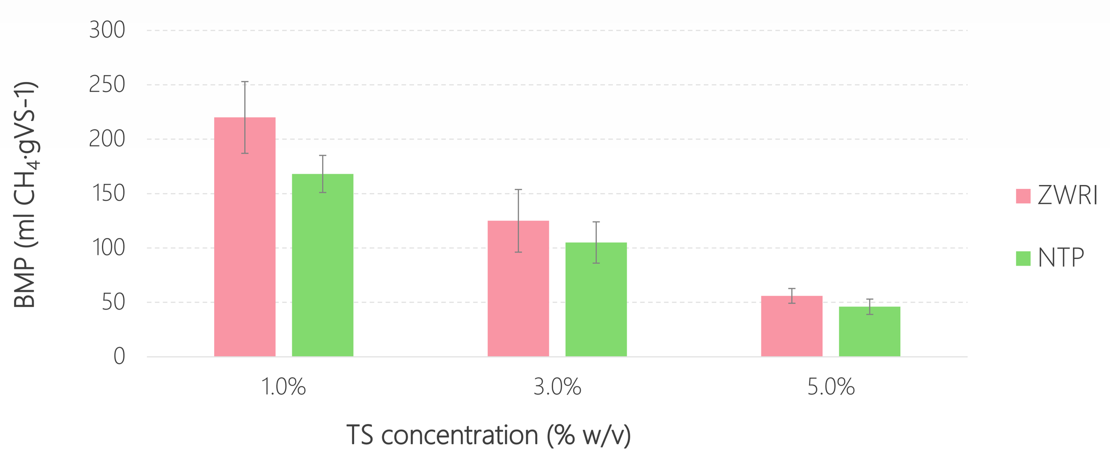

Figure 02. Bio-methane potential (BMP) for ZWRI and NTP at 1.0, 3.0 and 5.0% TS, using raw WWTP as inoculum.

Methane production started within the first week and decreased between day 15 to 20, achieving 80-90% of the total methane accumulated as show in Fig. 03. After this period, methane production ceased almost completely after day 20 to 30 of the process. Maximum methane rates were achieved in the first 10 days, with values of 32, 19 and 6 mL CH_4·day^{-1} for ZWRI at 1.0, 3.0 and 5.0% of TS, respectively. Slightly lower rates (approx. 10-15% lower) were achieved for NTP biomass, with a similar methane production.

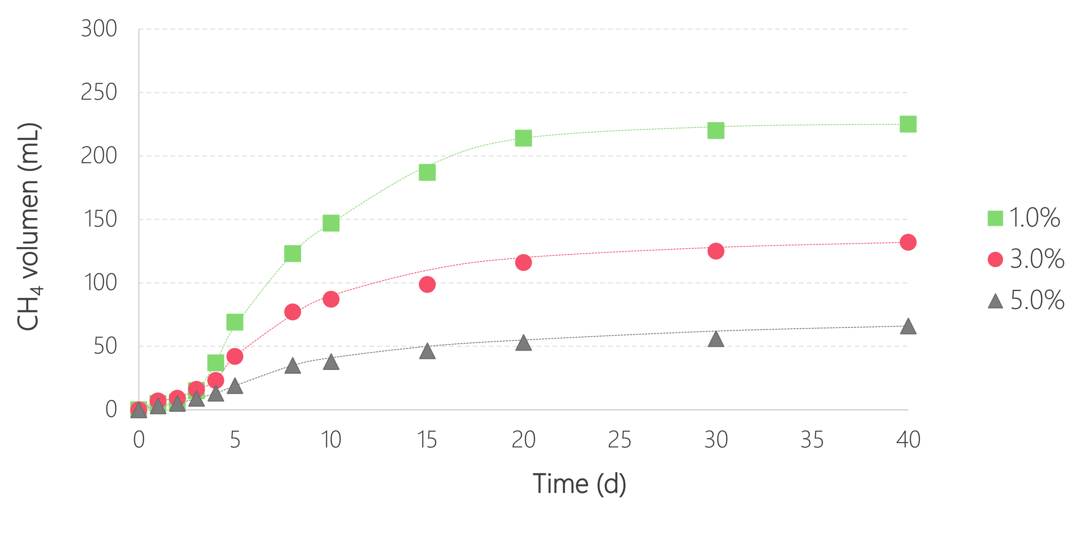

Figure 03. Methane accumulated volume ZWRI at 1.0, 3.0 and 5.0% TS and using raw WWTP sludge.

Experiments using raw WWTP inoculum showed 40-50% higher MP results than using the preadapted inoculum for "easy-to-degrade" sugars (EDS) as shown in Fig. 04. The use of preadapted inoculums is a common approach to standardize methanogenic potential assays. Therefore, to obtain the real BMP of lignocellulosic biomass, it is important to use an inoculum that is capable to hydrolyse complex sugars such as cellulose, hemicellulose and lignin, as seen in this work.

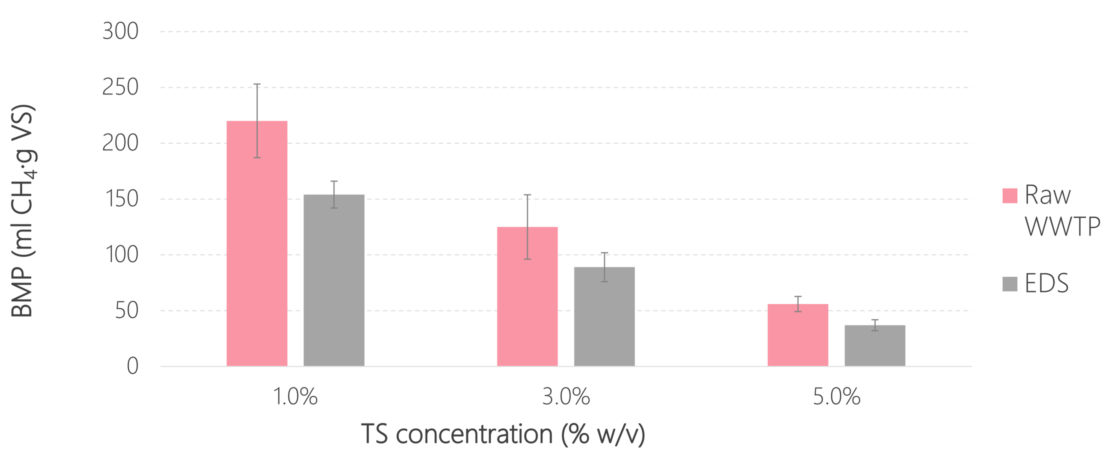

Figure 04. Bio-methane potential (BMP) for ZWRI at 1.0, 3.0 and 5.0% TS using raw WTTP and EDS as inocula.

As shown in Fig. 05, VFA and NH_4-N concentration remained below inhibitory concentrations, VFA consisting mostly in acetic and propionic acid (>90%), while pH values were within the recommended range for all conditions tested. Therefore, pretreatment of the raw material is required to fully degraded the organic material. Higher AGV values and lower pH values were obtained for the samples at TS 1.0 and 3.0% due to a higher hydrolytic and acetogenic activity during the biomass degradation, than at TS 5.0%. Moreover, substrate concentrations of TS 1.0% and 3.0% showed higher methane concentrations in the biogas at the end of the experience than the substrates

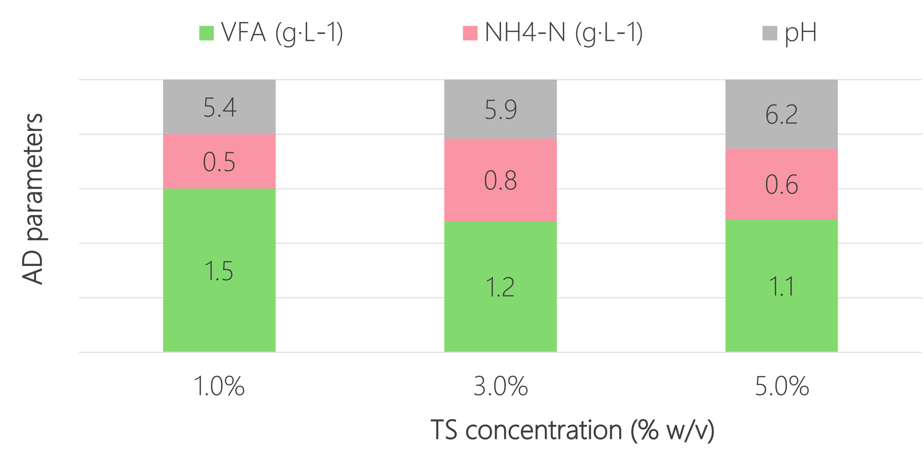

Figure 05. VFA, NH4-N and pH for ZWRI at 1.0, 3.0 and 5.0% TS, using raw WWTP as inoculum.

So far, results are in correspondence with published literature for this type of material. Typical AD process parameter values (VFA, NH_4-N and pH) had been obtained. Nevertheless, current CH_4 production rates and concentrations in the biogas, are still below the recommended range for an industrial application (400-600 Nm3 CH_4·gVS^{-1}d^{-1} and 50-75% CH_4 in the biogas), requiring further operational improvements to obtain an economic and sustainable biogas process.

Even though a significant increase of methane production had been observed by using raw WWTP inoculum, results are still achieving only 40-50% of the theoretical methane production, calculated using the solids content of the biomass. Therefore, results are indicating the necessity of inoculum enrichment and/or adaption, in particular towards the hydrolysis of complex sugars. Next steps include the development of an appropriate pretreatment process, inoculum improvement and process scale-up.

CONCLUSION

So far, best conditions for lignocellulosic biomass degradation in a mesophilic anaerobic process appear to be a low substrate ratio of 1.0% w/v) and the use of the raw WWTP inoculum, which shows superior degradation rates for complex sugars. Therefore, standardized procedures to measure BMP of lignocellulosic biomass need to be addressed in order to avoid underestimation of the methane production.

REFERENCES

Anaerobic Biodegradation, Activity and Inhibition (ABAI) Task Group Meeting 9th to 10th October 2006, Prague.

AOAC, 2012. Official Methods of Analysis of AOAC INTERNATIONAL, 19th Ed.

APHA, 2012. Standard Methods for the Examination of Water and Wastewater, 22th Ed.

Field J., Sierra R., Lettinga G. (1987). Ensayos anaerobios. Wagenigen Agricultural University. Holland.

ACKNOWLEDGEMENTS

This project has received funding from the European Union' s Seventh Framework Programme for research, technological development and demonstration under grant agreement No 613513.

Fraunhofer CHILE

Fraunhofer Chile Research- Center for Systems Biotechnology