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Experimental tests on commercial Sweet Product Residue (SPR) as a suitable feed for anaerobic bioenergy ($H_2 + CH_4$) production

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ABSTRACT

Food stores can find themselves in the position of having to dispose of different types of products, such as snacks, confectionery, prepackaged food, drinks and others, Sweet Product Residue (SPR), which presents a great opportunity to produce energy through Anaerobic Digestion (AD), due to its high sugar, carbohidrate and fat contents. In order to valorise SPR, this paper takes into consideration the all necessary treatments; owing the fact that the refuses are constitute by an organic part and packaging (plastic, paper and their combinations), a pretreatment able to remove the latter is necessary. SPR refuse was initially subjected to novel pretreatment approach: extrusion at 200 atm to remove the packaging, and a Basic Pre-treatment (BP) then tested through a Two-Stage AD (TSAD) process, for H_2 and CH_4 productions. The experimental results were analysed considering three parameters: *Efficiency* (ξ), which takes into account the quantity of the energy produced as hydrogen plus methane that the bioreaction is able to extract; *Efficacy* (η), which takes into account the efficiency of the actual test, compared with that obtained from a reference test carried out with glucose; *Energy Sustainability Index* (*ESI*), which takes into account the total amount of energy produced as H_2 plus CH_4, and the amount of energy consumed to pretreat the refuse. The effectiveness of the extrusion process in removing the packaging was very high: about 80% of the organic part present in the SPR was recovered. The obtained results have pointed out that SPR is suitable for energy valorization process: $\xi = 50\%$, $\eta = 0.67$ and $ESI = 24.4$, without the need of basic pre-treatment.

1. Introduction

Wasted food has increasingly become a hot topic throughout the world, as more and more countries realize its economic and environmental implications. The growing interest in waste management, from the industrial stage to the final consumer, has promoted the development of different directives and policies to address this problem at European and worldwide level (Priefer et al., 2016). Different penalty and incentives schemes play a fundamental role at national level and require technical and economically viable solutions to be implemented (Cossu and Masi, 2013). Valuable resources are squandered on the production of food, much of which ends up directly in landfills. According to the FAO (Food and Agriculture Organization), one third of all the food produced in the world is never consumed, thus 1.3 billion tonnes of food per year is wasted. In Europe alone, about 90 million tonnes of food is wasted annually (Waselikowski, 2014).

Moreover, more than 5000 tonnes of foodstuff, excluding fruit and vegetables, meat and fish, are wasted each year in Rome (Fiorentino, 2002); an average 12 million tonnes of agro-industrial waste is produced each year in Italy (Maio, 2013). However, the most worrying data arrive from the United States, where 14–15% of edible food remains packaged and not consumed, for a total of approximately 6.5 billion dollars of value (Timothy, 2004).

The need for action, such as food allocation and food waste valorisation, is obvious. In this context, the use of food waste as an alternative energy source that is able to reduce the use of fossil sources seems an interesting option and biogas production, via anaerobic digestion (AD), takes on great importance for the degradation of organic refuse. Biogas prevalently contains methane (CH_4), carbon dioxide (CO_2) and Hydrogen (H_2), whose concentrations depend on the pre-treatment that is used (Ruggeri et al., 2013).

The overall objective of the present study is to obtain suitable information to valorise SPR which is a particular type of organic refuse that is unsold taken off the shelves after the expiry date. SPR refuse is made up of snacks, confectionary, packed food, drinks and other products with high carbohydrate, fat and sugar concen-

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trations. SPR refuse is usually covered in a final packaging of paper, plastic and their combinations, which contains the organic part. In order to recover the organic part that has to be fed to AD process, the packaging needs to be eliminated. To this end, several pre-treatments of a different nature can be considered. In this study, an innovative pre-treatment extrusion was tested at 200 atm in order to separate the waste into dry and wet fractions. In addition, a chemical pre-treatment with a 2 N NaOH solution was also tested, in order to evaluate the biodigestibility enhancement of the different organic components of the SPR.

Recently, a Two-Stage AD (TSAD) has been exploited to recover more energy from AD, and to better control the whole process (Sunyoto et al., 2016; Abreu et al., 2016; Lee et al., 2014). The main difference is that the four steps of AD take place in the same volume in one-stage AD, while in the Two-Stage AD (TSAD) process, the first three steps occur in one volume and methanogenesis takes place in another one. In addition, TSAD can be conducted in one or two physically separated reactors, the former in the case of batch runs and the latter in the case of continuous runs, respectively (Ruggeri et al., 2015). TSAD permits more energy to be recovered than in a one stage process (Siddiqui et al., 2011), not only due to the energy produced as hydrogen, but also due to the high methane production. This is because the first stage probably works as a biological pre-treatment, thus making the substrates more easily biodegradable by methanogens, and hence increasing the energy efficiency of the process (Luongo et al., 2015).

The results of the TSAD tests were evaluated in terms of efficiency and efficacy, compared with glucose, and an energy sustainability analysis via the energy sustainability index (*ESI*) of the whole process: pre-treatments plus bioreaction, in order to evaluate the possibility of candidate SPR as a suitable feed for AD.

2. Materials and methods

2.1. SPR feedstock preparation

The organic waste used in this study is SPR, constituted by confectionery (chocolate, wafer, biscuit, etc.) residue removed from the market after the expiry date. The SPR was pre-treated by means of extrusion, as described in Section 2.2.1, to remove the packaging. The organic part of SPR is particularly rich in carbohydrates, sugars and fats (Table 1), and presents a high content of energy (*LHV* = 18,648 ± 60 kJ/kg; Table 2).

The tested refuse was collected from a supermarket at the end of the week for 6 weeks, in different seasons, in order to have representative samples of overall SPR. The tested SPR sample was prepared each week according to the waste produced at the end of the week, in terms of quality and quantity, considering the expiry date reported by the supermarket manager, the six sample were mixed together and used for the tests after a subdivision in quarter for three times.

Preliminary samples (10) from the last quarter were prepared, after removing the packaging by hand, and they were successively analysed. Both the packaging and the organic part were weighed in order to evaluate their ratio, and this value was used to evaluate the efficiency of the extruder in removing the packaging. Table 1 shows the composition of the organic part of the SPR obtained in the following manner: considering the composition declared by the producer and reported on the product according to law, and the percentages of the individual products present in the collected SPR. Furthermore, another type of refuse was used to confer lignocellulosic structures to the feedstock; to this end, Coffee Seed Skin (CSS) was used. The CSS refuse was provided by the Lavazza Company (Italy) in pellet form (approximately 0.5 cm diameter and 1–2 cm long). Prior to their use, the pellets were crushed into powder using a kitchen blade mixer; the final concentration was chosen in order to have a suspension that would be able to easily pump by a centrifugal pump. The composition of the CSS has already been reported (Luongo et al., 2015).

The details of the pre-treatment with the extruder are described in the following section; no additive was added to any of the tests as a micronutrient and/or supplement compound, and only tap water was used.

Table 2
Main properties of the liquid produced (SPR_{ex}) by means of extrusion.

Property	SPR_{ex}
Density [kg/L]	1.1332 ± 0.1631
pH	4.19 ± 0.14
Total Suspended Solids (*TSS*) [g/L]	261.83 ± 5.95
Total Volatile Solids (*TVS*) [g/L]	256.29 ± 0.33
Low Heat Value (*LHV*) [kJ/kg]	18,648 ± 60

2.2. SPR pre-treatment methods

A pre-treatment is generally a way of enhancing biogas production, as it increases the biodegradability of several AD feedstocks, such as domestic sludge, solid waste, and most agricultural wastes with high lignin, cellulose and hemi-cellulose contents. Biogas production depends to a great extent on the biodegradability of the substrate, and the hydrolysis rate is generally accepted as a controlling step (El-Mashad, 2003). Thermal, chemical, biological and mechanical processes, as well as combinations of these, have been studied as possible pre-treatments to destroy the lignocellulosic structures, which are resistant to microbial attack. A pre-treatment is able to improve the overall digestion process efficiency and the degradation degree, thus reducing the anaerobic digester retention time and increasing the methane production rate (Hanjie, 2010). In this study, two types of pre-treatments, that is, of a physical and a chemical type, were tested on SPR to improve the energy production of the AD process.

2.2.1. Physical pre-treatment

A physical pre-treatment that has been extensively tested on SPR, after an encouraging preliminary test already been reported (Ruggeri et al. 2013), is extrusion. Table 3 reports the technical characteristics of the used extruder pilot plant. The extrusion was conducted at the "GAIA" waste treatment plant in the province of Asti, Italy. The SPR underwent an extrusion process at 200 atm of pressure in a VM2000F extruder furnished by VM Press, Italy (Fig. 1b). Depending on the type of waste, the extruder permits from approximately 50–90% of organic wet fraction to be recovered. The extrusion pre-treatment was carried out to separate the SPR into a dry fraction (wrappers, packaging) (Fig. 1c) and a wet one (organic matter dispersed in water, Fig. 1d). The SPR was mixed in a 1:1 ratio with tap water (Fig. 1a) before being sent to the extruder. About 5 tonnes of SPR, collected as reported above,

Table 1
Composition of the organic parts of SPR.

Parameters	Proteins	Carbohydrates	Sugars	Fat	Saturated Fat	Dietary Fiber	Sodium
[% *w*/*w*]	5.22%	45.08%	15.74%	21.90%	10.46%	1.54%	0.06%