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BIOTRANSFORMATION OF THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTES TO BIOETHANOL

BIOTRANSFORMACIÓN DE LA FRACCIÓN ORGÁNICA DE LOS RESIDUOS SÓLIDOS URBANOS A BIOETANOL

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Abstract

Poor management of municipal solids wastes is leading to pollution of the oceans, causing flooding, transmitting diseases, and affecting flora and fauna worldwide. Of municipal solids wastes, 52% represent organic fraction, which, due to their carbohydrate content are likely to be used for the generation of bioethanol by liquid or solid fermentation. For this, various process configurations have been developed, which include studies of strain selection, substrate pre-treatment, and type of bioreactor. With this, bioethanol production yields from 30 to 100 g/L were obtained from different organic wastes. However, it is necessary to optimize operating conditions to ensure a profitable process at the industrial level.

Keywords: Bioethanol, solid-state fermentation, submerged fermentation, organic wastes, biotransformation.

Resumen

La mala gestión de los residuos sólidos urbanos está produciendo la contaminación de los océanos, causando inundaciones, transmitiendo enfermedades y afectando a la flora y fauna a nivel mundial. De los residuos sólidos urbanos, el 52% representan los residuos orgánicos; los cuales, por su contenido de carbohidratos sus susceptibles de utilizarse para la generación de bioetanol por fermentación líquida o sólida. Para ello, diversas configuraciones de proceso han

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sido desarrolladas; las cuales, incluyen estudios de selección de cepa, pretratamiento del sustrato y tipo de biorreactor. Con ello, se han obtenido rendimientos de producción de 30 a 100 g/L de bioetanol a partir de diferentes residuos orgánicos. Sin embargo, es necesario optimizar condiciones de operación para garantizar un proceso rentable a nivel industrial.

Palabras clave: Bioetanol, fermentación en estado sólido, fermentación líquida, residuos orgánicos, biotrasformación.

1. Introduction

Worldwide, activities related to technological, industrial, and economic development have a significant impact on the volume and composition of waste generated in cities. The increase in the volume of urban solid waste (USW) generation and its inadequate disposal results in negative impacts on human health and the environment. [1]. For this reason, various strategies have been developed for the recycling of certain fractions of USW. Within USW, there is a fraction made up of organic waste from the production, processing, and consumption of food [2-4]. In certain parts of the world, the final disposal of the organic fraction of urban solid waste (OWF) is carried out by conventional dumping in landfills and open-air dumps [5]. In these systems, OWF is degraded through the putrefaction process (uncontrolled anaerobic degradation); in which organic matter is transformed by microorganisms into simpler compounds, which lead to the formation of CO_2, CH_4 [6] and leachates, causing contamination to soil, water, and atmosphere. Due to the potentially harmful effects of these techniques, efforts have been developed to generate sustainable strategies for the final disposal of OWF, such as composting, anaerobic digestion, and alcoholic fermentation. The alcoholic fermentation used for bioethanol production has gained importance as a disposal strategy of the OWF because it is a relatively simple process, there is high diversity of fermentative microorganisms and, the final product (ethanol) reduces the production of greenhouse gas emissions [6,7]. Therefore, this review will address general aspects and advances in the bioethanol production process from OWF.

2. Bioethanol production process

Bioethanol production arises from the growing demand for energy compounds capable of replacing fossil fuels. The diversity, abundance, and cost of raw materials that can be bio-transformed into bioethanol, have given it the characteristic of being one of the most produced worldwide. Bioethanol production is carried out through alcoholic fermentation, which is biotransformation of carbohydrates to ethanol and CO_2. The process conditions include oxygen absence, fermentable carbohydrates, and the microorganism capable of bio-transforming carbohydrates to ethanol.

For this process, several microorganisms were evaluated (Table 1); among them, the *Saccharomyces cerevisiae* yeast stands out, due to its high biotransformation yields. Normally, the microorganisms used in bioethanol production are capable of fermenting monosaccharides (hexoses and pentoses) and disaccharides (sucrose). However, to guarantee the adequate development of the microorganism and its production of ethanol is necessary the availability of macronutrients (N, P, K, S) and micronutrients (Fe, Mg, Mn, Zn, etc). Therefore, to determine the design and process conditions that allow the OWF to be used for bioethanol production, a characterization study of its composition is required, which will be addressed in the next section.

3. Organic waste fraction composition

OWF content food waste comes from processing plants, kitchens (domestic and commercial), and restaurants. Its composition contains up to 69% of total sugars, 24% of lipids, 21.8% of proteins, and 5.9% of ashes [14]. Therefore, the requirements of carbon source, macronutrients, and micronutrients necessary for alcoholic fermentation are satisfied. However, most sugars in the OWF are polysaccharides such as starch and cellulose. Those sugars are present from 24.0 to 46.1% and from 1.6 to 16.9%, respectively [2-4]. Therefore, considering that starch and cellulose are not fermentable sugars (by the action of yeasts), it is important to implement a pretreatment (physical, chemical, biological, or enzymatic) that allows these polysaccharides to be broken down into fermentable sugars and thus, increase ethanol production.

Table 1. Microorganisms used for ethanol production.

Microorganisms	Substrate	Ethanol production yield (g /kg dry matter)	Reference
Schw. castelli CBS2863	Starch with sugarcane bagasse	89.30	[8]
S. cerevisiae	Kitchen waste	154.50	[2]
S. cerevisiae	OWF	126.20	[9]
S. cerevisiae CECT1329	Lemon peel	254.84	[10]
Z. mobilis PTCC 1718	Carob fruit	60.91	[11]
S. cerevisiae	Food waste	290.00	[12]
S. cerevisiae	Rice husk	135.00	[13]

4. Pretratments for the brakdown of polysaccharides

Bioprocesses that use biomass as a substrate regularly require strategies to solubilize and/or separate one or more compounds contained in it. The foregoing allows for improving the rates and yields of substrate consumption and the production of metabolites [15]. The selection of the pretreatment method must consider the adequacy of the substrate with little or no production of inhibitors and with a cost that does not affect the feasibility of the process [16]. As mentioned in the previous section, most of the OWF components are lignocellulosic residues, in which various physical (pyrolysis, mechanical grinding, steam explosion), chemical (CO_2 explosion, explosion of fibers with ammonia solution, acid hydrolysis, alkaline hydrolysis, hydrolysis by organic compounds) and biological (by microbial action or by enzymes) to hydrolyze polysaccharides [17]. Within them, steam explosion and CO_2 explosion are considered profitable [17]; however, these pretreatments partially hydrolyze the polysaccharides and cause the generation of microbial inhibitors (acetic acid, furfural, and hydroxymethylfurfural). Compared to steam and CO_2 explosion processes, biological processes have advantages in the degradation of hemicellulose and lignin with a low energy requirement; however, they have low rates of sugar hydrolysis.

On the other hand, to increase the speed and yields of polysaccharide hydrolysis, treatments with acids have been used, which are more efficient hydrolysis processes than biological and enzymatic ones [17]. However, acid hydrolysis generates toxic compounds (such as furfural) [18] that significantly affect the microbial activity and, therefore, the volumetric and specific bioethanol productivity. Due to the above, some authors [9, 19] propose the hydrolysis of the polysaccharides contained in the organic wastes by thermal pretreatment with a low residence time (2-15 min) and followed by a steam explosion, which contributes to breaking the structural fibers of the waste, reducing the microbial load and, thereby, improving fermentation yields. However, in most of the process designs aimed at the bioethanol production from the OWF, the use of filamentous fungi has been implemented in the substrate pretreatment stage [12, 20].

5. Advances in the production of bioethanol from the organic wastes

Determining the fermentation conditions that allow obtaining high yields of bioconversion of carbohydrates to bioethanol from OWF has been a topic of interest in recent years. To design viable processes for the production of bioethanol, studies have been carried out on the selection of the microorganism, the pretreatment of the substrate, type of bioreactor, among others, which have been incorporated for evaluation into comprehensive processes. In most, the solid fraction is suspended in an aqueous medium for its thermal or enzymatic pretreatment and separated for the fermentation of carbohydrates in liquid state. [2- 4, 9, 12, 20].

Tang et al. [9] developed a process to produce bioethanol from kitchen waste. The authors obtained a high glucose recovery (85.5%) from saccharification with Nagase N-40 glucoamylase (at 60 °C and agitated at 150 rpm per 2 h). The saccharification liquid was used directly for bioethanol production by fermentation (without the addition of nutrients), obtaining up to 30.9 g/L of bioethanol (154.5 g of ethanol/kg dry matter (DM)) using a strain genetically modified strain of *Saccharomyces cerevisiae* (KF-7). Uçkun-Kiran and Liu [12] carried out hydrolysis with *Aspergillus awamori* enzymes, obtaining up to 127 g/L of glucose. Alcoholic fermentation was carried out by *S. cerevisiae* in Erlenmeyer flasks (250 mL), reaching a bioethanol production of 58 g/L (290 g/kg DM). Both works demonstrated that enzymatic hydrolysis is effective for the saccharification of food residues and the subsequent bioethanol production.

On the other hand, bioethanol production processes have been developed in a solid medium. Saucedo-Castañeda et al. [8] used a thermal treatment (121 °C per 30 min) for starch hydrolysis. Subsequently, using packed columns (1 L), the substrate was fermented by the action of *Schwaniomyces castelli*, reaching a maximum ethanol production of 89.3 g/kg DM. Mazaheri et al. [11] used a mixture of carob and wheat bran as a substrate for ethanol production using *Z. mobilis* in a 0.5 L column fermenter. The substrate was thermally pretreated (121 °C for 15 min), and fermentation was carried out at 28 °C with intermittent aeration (0.1 L/min for 15 min every hour). At the end of the fermentation, maximum ethanol production of 60.9 g/kg DM was obtained. Canabarro et al. [13] modified inoculum concentration and substrate (rice bran) moisture content for ethanol production in Erlenmeyer flasks. Adding an inoculum of 10% and a moisture content of 65%, they reached an ethanol production of 138.7 g/kg DM. Under the established conditions, they operated a packed bed bioreactor with a capacity of 1L (10 times greater than the flasks) with which they acquired a similar yield of ethanol production (135±10.8 g/kg DM) to that obtained in Erlenmeyer flasks.

6. Conclusion

The management of organic wastes is a world concern issue, which has generated studies aimed at its use and valuation. For its composition, one of those alternatives can be its bioconversion to bioethanol. For this, fermentation in liquid and solid state represent two appropriate process configurations with high bioconversion yields.

However, aspects such as strain selection, pretreatment, cultivation system, and the type of bioreactor must still be studied and particularized to establish feasible processes at the industrial level.

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