Bio
digestion:
Alternative use of vegetable matter for obtaining biofuel in the province of Ocaña, Colombia

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Abstract: The Catatumbo region offers a great variety of agricultural products on demand in the urban centers of the department of North Santander. Since in this locality there is no management or use for vegetable material wastes this study focused on the public market, represented by a wholesale and retail trade in agricultural products, the most representative being tomatoes and onions. This research prospects the potential for biogas as an alternative, based on anaerobic digestion for the production of bioethanol from lignocellulosic biomass from vegetable species of the Catatumbo region. An assessment of possible raw materials that exist within the region was carried out, determining operating conditions and estimative production of bioethanol.

1. Introduction
Exhaustion of world-wide fossil fuel reserves and pollution generated by its use, had intensified the need to look for alternative energy sources. One of the main alternative sources for energy is biomass, which is found in vast quantities around the world. It can be transformed into biofuels and other products of aggregated value.

First generation biofuels have the main problem of being obtained from crops, such as sugarcane, corn, wheat, grains, oilseeds, vegetable oils and animal fats [1], that otherwise could have been used for human nutrition, competing with the human food chain. Second generation biofuels are produced mainly from lignocellulosic biomass, this implies a non-competitive relationship with human food sources while employing vegetable waste as raw matter; making it a better alternative.

Livestock and agricultural activity produce organic matter which is designated biomass; this residue could be treated as raw matter for obtaining biogas and other biofuels through biodigesters in a process of anaerobic digestion.

Amongst biofuels is bioethanol, which is produced through alcoholic fermentation, employing microorganisms, using vegetable matter, such as sugarcane, sugar beetroot and corn [1-2]. In the United States of America, bioethanol production plants utilize primarily corn; while in Brazil sugarcane is mainly employed. In Colombia bioethanol is mainly obtained from sugar cane, in sugar mills that operate primarily in the Cauca river’s valley; however, this production has been
monopolized by few economic groups which has not allowed the creation of new jobs in other parts of the country [3-4].

As stated above, the production of bioethanol of first generation competes with the food market since plantation crops, consumable by part of the population, are used as raw matter for the production of biofuels; thus, generating a negative impact from the socioeconomic point of view [5-6].

In the state-of-the-art it is possible to find studies related to the employment of agricultural or municipal wasting in the production of biofuels [7-11]; however, these processes exhibit different challenges that must be overcome to establish processes of economic feasibility.

One of the challenges consists in achieving an efficient elimination of lignin while keeping cellulose and hemicellulose present for hydrolyzation; in this sense, it is technically possible to find different methods for biomass pretreatment, but none of them has reached actual economic viability. Another challenge is related to the optimization of the polysaccharide’s hydrolysis and sugar’s fermentation, since the current processes are not economically viable and of low efficiency [12-16].

A very relevant aspect to highlight is that the quantity of agri-food waste produced is increasing world-wide. In Europe, a third of produced food is wasted, accumulation of the waste generates an environmental problem because of its gradual deterioration, it is also possible to perceive the affectations from an economical point of view, due to the increasing costs of recollection, transportation and final disposal of unused food. On the other hand, agroindustry waste constitutes the most abundant biomass source in the world; its utilization presents great potential since it is a renewable substrate and have no commercial value [17].

In Colombia economical losses, occasioned by perishable products from harvest to commercialization, are affected by diverse factors that vary between regions of the same department, differences of climate, technology of crop systems and handle of the product; and oscillate between 15% and 60% [18-20]. The cause of food waste is related to the behavior of the consumer and the normativity to take priorities in each sector [21].

In many countries, agricultural activities do not carry out suitable disposal of wasting, in fillings or otherwise; unregulated burning of the vegetal matter is perceived as a better economic alternative. Farmers opt for this option because it reduces the volume of matter, clears the zone for future harvests, eliminates pests and releases nutrients [22]; however, this generates harmful effects to the environment because it is considered that biomass burning is responsible for 40% of CO₂, 32% of CO, 20% of particulate material and 50% of polycyclic aromatic hydrocarbons (PAH) global emissions [23].

World-wide normativity is increasingly strict, particularly in terms of solid organic waste, Global demand renewable fuels has been increasing too. Due to these factors, during the last years, organic waste valorization has become one of the most important areas of investigation, attracting great attention with the development of potential alternatives to the integration and disposal of solid organic waste. Increasing development of environmental strategies to process solid wastes is an interesting area of increasing importance in our current society, especially with the design of new equipment and accessible tools to the rural community and improving the quality of life [24].

Different criteria are taken into consideration to determine the biofuel potential that can be attained from agricultural residual biomass, including lignocellulosic biomass, amylase biomass, sugared biomass, and energetic biomass amongst others [25-27].

Fermentation (anaerobic respiration) is the conservation of the energy in anaerobic environments. The process of fermentation is basically composed of four phases: the first phase designated hydrolysis, the second phase of acidification (acidogenesis), the third phase of acetates formation (acetogenesis) and the fourth phase of methanization (methanogenesis). In the latter phase proteins, carbohydrates and fat, amino acids, alcohols and fatty acids that are formed in the previous phases are converted into methane, carbon dioxide and ammonia causing the fermentation product (digestate) to become more fluid [28].

In many regions of Colombia, potential of profitability of the vegetal waste with application of anaerobic technologies has not been evaluated. Cadavid [29] determined the potential of fruits and vegetables waste originated in restaurants in the city of Palmira, Cauca Valley, to generate renewable
energy as biogas, with a yield of 364 L CH$_4$/kg Volatile Solids, with an average methane content of 65% in the biogas [29].

In the Table 1 it is shown some cases of anaerobic digestion for different substrates of vegetal matter and the yield in methane liters per volatile solids kilogram.

| Substrate                                      | Reported performance | Reference                           |
|------------------------------------------------|----------------------|-------------------------------------|
| Fruits and vegetables                          | 180 – 732 L CH$_4$/kg VS | Gunaseelan [30]                     |
| Fruits and vegetables - meld                    | 595 L CH$_4$/kg VS   | Sitorus, et al. [31]                |
| Domestic organic residue – separated at source  | 495 L CH$_4$/kg VS   | La Cour Jansen, et al. [32]         |
| Municipal solid residue (food) – different sources | 300-570 L CH$_4$/kg VS | Davidsson, et al. [33]              |
| Municipal solid residue                         | 360 L CH$_4$/kg VS   | Shanmugam & Horan [34]              |
| Food residue                                    | 340 L CH$_4$/kg VS   | Browne, et al. [35]                 |
| Lignocellulosic                                 | 212.5 L CH$_4$/kg VS | Boni, et al. [36]                   |
| Digested vegetable matter residue               | 169.4 L CH$_4$/kg VS | Temesgen & Pappaterra [37]          |

For the design of a biodigester it is indispensable to assure the homogeneity of the mixed elements in the system, and to maintain favorable conditions for microbial development, in order to obtain the expected product. According to Patrón and Rodríguez [39], the most significant criteria for the design of a bioreactor are:

- The tank must be designed to work aseptically for many days, this is to avoid the appearance of contaminants in long-term bioprocess operations.
- It should allow a large contact area between the biotic and abiotic phases of the system, that is to provide a suitable aeration system or anaerobiosis and agitation to supply the metabolic needs of the microorganisms.
- The energy consumption must be the minimum possible.
- It should have inlets for the addition of nutrients and pH control.
- The microbial growth is generally an exothermic process; thus, the bioreactor should facilitate the heat transfer between the medium and the cells, in addition to be able to maintain a stable desired temperature.
- The cells should be uniformly distributed throughout the culture volume.
- Oxygen and other gases supply rate should be sufficient to satisfy the consumption of the system.
- The design should allow to hold a pure culture once the whole system has been sterilized and subsequently inoculated with the desired microorganism to avoid contamination.

While the fermentation process is important, the prototype of the process is also important; Since there is a wide variety of biodigesters, it is possible to do a categorization taking into consideration different criteria, such as operation continuity; volume, quantity, configuration and orientation of process vessels; and the system of biomass mobilization [40].

Based on these antecedents, there is a great opportunity of investigation for the university; as one of the main academic centers in the region, it should take part in the development of knowledge in the area of biofuels. In this research project, it is pretended to carry out an assessment of the potential for the production of second-generation bioethanol from lignocellulosic matter through alcoholic fermentation, employing vegetable matter from the region of Ocaña as raw matter.

2. Materials and methods
The methodology was developed within a quantitative paradigm with a non-experimental descriptive approach; the main tool for gathering information was the survey. The first step, in the field phase,
was to quantify the yearly production of agri-food waste in the Central Market Square of Ocaña. A survey was carried out to census the totality of traders, dividing the population in two sectors, wholesalers and retailers. 25 Wholesalers were identified in a sector called “las bodegas”; while for the retailers it was found that they were distributed as follows: 38 in the square of “Cuadra del burro”, 4 in the establishment “Cuento con Vos”, 39 in carts situated in the surrounding streets, 25 in the gathering center “Plaza de Mercado” and 7 in a square called “Centro Mercado”. For a total of 138 traders between retailers and wholesalers. Once the locations and numbers of traders were identified, the surveys were applied to the entire population, in order to determine the products handled by each trader, the tonnage by year of each product and the produced waste by product tonnage by year. Lastly, the categorization and computing of the products and the waste generated, in relation to the profitability of the vegetal material for the obtention of biofuel.

3. Results and discussion

The total quantity of vegetable waste produced by agricultural trading companies in the public market of Ocaña, North Santander, is 6160.34 tons. For retailers, the most representative waste is from potatoes; while for the wholesalers it’s from onions, as it can be seen in Table 2.

| Table 2. Quantity of waste produced by small wholesale. |
|-------------------------------------------------------|
| Tons of waste generated by retailers per the year      |
| Sum         | 3472.655 | 205.3406 |
| Average     | 93.85    | 5.54     |
| Max         | 680.63   | 81.275   |
| Min         | 0.65     | 0.0098   |

| Tons of waste generated by wholesalers per the year   |
|-------------------------------------------------------|
| Sum         | 26830.00 | 5955.50 |
| Average     | 3832.86  | 850.79  |
| Max         | 17024.00 | 4228.00 |
| Min         | 6.00     | 0.40    |

According with bio-methanization studies, from the onion residue [41] and analysis of production of biogas done by the Chilean government [42] the quantity of biogas that can be obtained, from the residue of potatoes and onions originated in the public market of Ocaña, is estimated at 2.301x10³m³ per year.

To this purpose, it is proposed to integrate a process to obtain biogas and bioethanol from these vegetable waste, in a configuration that allows for its exploitation as it is shown in the following scheme (Figure 1):

![Figure 1. Flow diagram of the process for obtaining bioethanol, biogas and fertilizer.](image)

In the process to obtain bioethanol, organic material is processed by enzymatic hydrolysis for posterior fermentation, liquid residue is distilled to obtain bioethanol as a product. It is important to
state that, ethanol is a product of interest in the automotive industry, its use improves the combustion process of engines, producing an increase in the torque and thermal efficiency [43].

4. Conclusion
An assessment of the potential for the production of bioethanol and biogas from lignocellulosic material from agri-food waste in Ocaña was carried out. This allowed for an evaluation of possible raw materials in the region, as well as the proposal of a process for obtaining bioethanol and biogas exploiting vegetable waste. The vegetable waste generated in the public market of Ocaña per year, has the potential to produce 2.301x10^3 m^3 of biogas, amount that could make an important contribution to reduce the energy demand of the municipality. In these process, part of the methane produced could be integrated as an energy source to reduce operation costs in the biogas and bioethanol obtention.

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