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Bioenergy potential from agroindustrial wastes of the state of Veracruz

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Abstract: The use of fossil fuels is losing versus the use renewable energy sources such as biomass and biogas, due to the environmental impacts that they generate. In Mexico, Veracruz has an area of 7.24 x 106 hectares, representing 3.7% of the national area, being the main provider of agroindustrial products due to its diversity of ecosystems. The objective of this paper is to evaluate the bioenergy potential of organic solid waste generated from the main agroindustrial products of the state of Veracruz. To carry out this research, ten main crops of Veracruz were selected through a literature review, determining the percentage of waste generation and heating value of each of them. With the previous data, the tons of agroindustrial waste and the bioenergy potential were estimated. Finally, the total bioenergy potential of agroindustrial wastes was calculated. As part of the results, Veracruz produces approximately 25.5 x 106 tons of agroindustrial products made up of sugarcane, orange, lemon, pineapple, coffee, banana, grapefruit, watermelon, rice and pear. Derived from the ago-industrial activity, 6.97 x 106 tons of waste are generated annually, being the sugarcane waste the most with 75% equivalent to 5.28 x 106 tons, followed by citrus around 0.98 x 106 tons. Likewise, and as a consequence of agroindustrial waste, Veracruz has a bioenergy potential close to 130.00 PJ per year, which would place it as the largest supplier of renewable energy from biomass.

Keywords: Bioenergy potential; agroindustrial waste; biomass; biogas; heating value

Introduction

Historically, the main sources of energy have come from non-renewable resources such as hydrocarbons, a fact that has generated serious environmental problems due to increased greenhouse gas (GHG) emissions. Because of this, the collective efforts of nations to reduce GHG emissions and promote the sustainability of the energy sector through the use of renewable energy sources such as hydropower, wind power and solar power, biomass and biogas have increased globally (SENER, 2018). This means that hydrocarbons are losing positions to alternative energies (CESOP, 2019), highlighting biofuels such as biomass and biogas. Biomass is characterized by having a variable carbon content and its heating value depends on the type of biomass and the moisture content (INEL, 2018).

Whereas, biogas is mainly composed of methane, which is an alternative of the natural gas, its heating value is approximately 6.5-7.0 kWh/m^3 at standard pressure and temperature when the methane composition is 55-70% (Vega De Kuyper and Ramírez Morales, 2014). In developing countries, the use of biomass and biogas is playing an increasingly important role, for example, in Mexico the National Energy Balance 2017 mentions that biomass is conformed by 31.8% of sugarcane bagasse and 68.2% of firewood, contributing 367.18 PJ per year; while biogas is a product derived from the anaerobic digestion of organic solid waste and wastewater contributing 2.52 PJ per year (SENER, 2018).

Agroindustrial wastes are considered as biomass with high potential for the generation of energy. At the same time, there is a need to solve the environmental problems and impacts caused by the agroindustrial wastes and their poor management and disposal, since they emit bad odors, volatile organic compounds, leachate contamination and GHG. The most relevant agroindustrial waste utilization processes can be classified into three categories: 1) direct combustion processes, which refer to the direct burning of biomass in furnaces or boilers, 2) thermochemical processes, which indicate the chemical transformation of biomass by application of heat, which produces gaseous, liquid and solid compounds depending on the technology used, and 3) biochemical processes, which employ biochemical reactions, generally using microorganisms as providers of these transformations (Vega de Kuyper and Ramírez Morales, 2014).

The state of Veracruz is the main supplier of agroindustrial products in Mexico, due to its diversity of ecosystems, ranking first place in the production of sugarcane, oranges, pineapple and grapefruit; second place in the production of lemons and cherry coffee; third place in bananas and pears produced; and finally, fourth place in watermelon and palay rice produced (SIAP, 2018). Veracruz has an area of 7. 24 x 106 hectares, which represents 3.7% of the total area of Mexico, its agricultural activity is carried out on 1. 5 x 106 hectares, of which about 1.4 x 106 are harvested (INIFAP, 2017). From the agroindustrial activity, large amounts of organic waste are generated that can be used as biomass through thermo-chemical and biological processes, which would increase the national energy contribution in terms of renewable energy sources, being Veracruz the main producer.

Some researchers have oriented their works to the use of agroindustrial waste as an energy source. Vargas and Pérez (2018), presented a literature review of different alternatives for the use of agroindustrial waste to improve the quality of the environment, where biomass and biogas are highlighted. On the other hand, Ortiz Laurel et al. (2016) obtained 57 x 103 PJ of available energy from usable biomass from 25 sugar mills. Likewise, Montenegro et. al (2016) estimated an average biogas potential of 10 PJ/year, where the waste with the highest contribution was generated by agricultural activities, through anaerobic digestion. Similarly, González et al. (2015), showed that banana residue is a raw material with high methane production potential, obtaining 63.89 mLCH4/gCOD. Finally, Ramírez (2012), reached 2.7 L of biogas/kg of mixture of manure and rice husk, with 48.9% methane, through anaerobic codigestion process.

Therefore, the objective of this research is to evaluate the bioenergy potential of organic solid waste generated from the main agroindustrial products of the state of Veracruz.

Materials and Methods

Main agroindustrial products of Veracruz

To carry out this research, the state of Veracruz was selected as a case study, since it is the main supplier of agroindustrial products in Mexico. Approximately 1.5x106 hectares are dedicated to agriculture, which is equivalent to 20.7% of its total area. Besides, ten main Veracruz's crops, which stand out nationally in terms of production were selected, which are presented in Table 1.

Table 1. Production data of the main crops in Veracruz (SIAP, 2018).

Product	Tones
Sugarcane	21.12×10^6
Orange	2.33×10^6
Lemon	0.66×10^6
Pineapple	0.61×10^6
Grapefruit	0.24×10^6
Banana	0.21×10^6
Cherry coffee	0.19×10^6
Watermelon	0.11×10^6
Rice palay	0.03×10^6
Pear	0.002×10^6

Agroindustrial waste generation

The current demand for agri-food products leads to a sustained growth in industrial activity and therefore in the generation of large amounts of waste, which can be used for different purposes including the generation of bioenergy (Vargas and Pérez, 2018). This fact can bring economic benefits for those who generate them, if the residues are used properly. However, most agroindustries do not have clear strategies for their use. Through an exhaustive literature review, Table 2 shows the approximate percentages of agroindustrial waste generated by product.

From the data reported in Tables 1 and 2, and using Equation 1, the tons of agroindustrial waste (TAW) for each product were obtained.

$$TAW = \sum_{i}^{n} \frac{P_{(i)}\ x\ \%W_{(i)}}{100} \quad \textbf{(1)}$$

Where:
$P_{(i)}$ represents the tons of producto.
$\%W_{(i)}$ is the percentage of agroindustrial waste generated from each product.

Table 2. Percentage of agroindustrial waste generated by product in Veracruz.

Product	% agroindustrial waste	Reference
Sugarcane	25.0	Kazmi *et al.* (2016)
Orange	27.0	SIAP (2018)
Lemon	36.0	FEN (2018)
Pineapple	65.0	Sánchez *et al.* (2015)
Grapefruit	50.0	Wilkins *et al.* (2007)
Banana	40.0	Oberoi *et al.* (2011)
Cherry coffee	92.4	Suárez (2012)
Watermelon	35.0	USDA (2004)
Rice palay	25.0	Llanos *et al.* (2016)
Pear	12.0	FEN (2018)

Data collection of the Heating Value (HV)

Heating value is defined as the amount of energy released as heat in one kilogram, or in one cubic meter of fuel when completely burned in a constant pressure environment of 101 kPa and 25 °C. In other words, the heating value is the absolute value of enthalpy (Arroyo and Guzmán, 2016). For the purposes of this research, the HV expresses the amount of usable energy that has the biomass from each agroindustrial waste.

Thus, HVs were obtained through a literature review focused on the utilization of agroindustrial waste by biological and thermochemical processes. Table 3 shows the HVs on dry basis from each agroindustrial waste.

Table 3. Heating value from each agroindustrial waste generated in the state of Veracruz.

Product	HV (MJ/kg)	Reference
Sugarcane	19.40	McKendry (2002)
Orange	15.82	Ayala *et al.* (2017)
Lemon	17.84	Universidad Politécnica de Cartagena (2017)
Pineapple	14.27	Saha *et al.* (2016)
Grapefruit	17.60	Ozturk *et al.* (2006)
Banana	16.58	Saha *et al.* (2016)
Cherry coffee	17.90	Toschi *et al.* (2014)
Watermelon	13.85	SENER (2018)
Rice palay	15.70	De Oliveira *et al.* (2017)
Pear	18.40	Riva *et al.* (2014)

Theoretical Bioenergety Potential (BPT)

Theoretical bioenergy potential shows a total annual estimate of biomass energy from agroindustrial waste. The value of BPT varies according to the amount of waste produced annually (Avcioglu et al., 2019). Therefore, to determine this value, Equation 2 is used, through the results obtained from Equation 1 and the data collection mentioned in Table 3:

$$BP_T = \sum_{i}^{n} TAW_{(i)}\ x\ HV_{(i)}\ x\ 1x10^{-6} \quad \textbf{(2)}$$

Donde:
$TAW_{(i)}$ represents the tons of agroindustrial waste from product.
$HV_{(i)}$ is the heating value from each agroindustrial waste.
$1x10^{-6}$ is the conversion factor from MJ/kg to PJ/T of agroindustrial residue.

Results and Discussion

Agroindustrial waste generated

Sugarcane is one of the crops with the lowest percentage of agroindustrial waste generation compared to other products such as lemon, pineapple, grapefruit, banana, coffee, cherry and watermelon. Sugarcane has the highest production with 21.12 x 106 tons and according to Equation 1, it generates 5.28 x 106 tons of waste, which also position the sugarcane as the largest waste generator, accounting for 76.0% of total waste. Other important crops are citrus, consisting of oranges, lemons and grapefruit, which together generate 0.98 x 106 tons, representing 14.0% of total waste. Soft products with high sugar content, such as pineapple, banana, watermelon and pear, accounting for about 0.52 x 106 tons, which corresponds to 7.0% of total waste. Finally, for this analysis, cherry coffee contributes 3.0% of total waste, while rice palay generates less than 0.1%.

According to Equation 1, from the main crops of the state of Veracruz, approximately 6.97 x 106 tons of agroindustrial waste can be generated as shown in Table 4. Making a comparison, Alvarado-Lassman et al. (2016) report that 41.0 x 106 tons of municipal solid waste are generated in Mexico and 22.0 x 106 tons correspond to organic solid waste, so Veracruz contributes about 32.0% of organic solid waste according to the analysis presented in this study. On the other hand, in Latin America it is estimated that 127 x 106 tons of food waste are disposed annually (FAO, 2016), so Veracruz would be contributing 5.5%

Table 4. Tons of waste generated in Veracruz.

Product	Production (Tons)	% agroindustrial waste	TAW
Sugarcane	21.12×10^6	25.0	5.28×10^6
Orange	2.33×10^6	27.0	0.63×10^6
Lemon	0.66×10^6	36.0	0.23×10^6
Pineapple	0.61×10^6	65.0	0.40×10^6
Grapefruit	0.24×10^6	50.0	0.12×10^6
Banana	0.21×10^6	40.0	0.08×10^6
Cherry coffee	0.19×10^6	92.4	0.18×10^6
Watermelon	0.11×10^6	35.0	0.04×10^6
Rice palay	0.03×10^6	25.0	0.007×10^6
Pear	0.002×10^6	12.0	0.0002×10^6
Tons of total agroindustrial waste			6.97×10^6

All this makes that Veracruz position as a waste generator with a high utilization potential for different purposes, including the generation of bioenergy, soil improvers, recycling, among others.

Obtaining the Theoretical Bioenergy Potential

From Equation 2, the Theorical Bioenergy Potential of each residue was estimated, as well as the total BP_T. The lowest specific HV corresponds to watermelon with 13.85 MJ/kg, while the highest is for sugarcane with 19.40 MJ/kg, which means that watermelon has a higher moisture content than sugarcane, being the average HV of all residues is 16.74 MJ/kg. As expected, sugarcane residue had the highest BP_T with 102.00 PJ, as shown in Table 5. This data is comparable with the reported in the National Energy Balance (2017), since it indicates that from biomass from sugarcane bagasse 115.00 PJ per year are produced in Mexico, so Veracruz can contribute 88.7%, being a state with highest sugar activity. Likewise, citrus fruits (oranges, lemons and grapefruit) have 16.32 PJ, being the solid fraction the one with the highest energy contribution, since Rosas-Mendoza et al. (2019) concluded that about 0.06 PJ per year can be obtained in Mexico from anaerobic digestion of effluents from the citrus industry, considering the inhibition effects due to D-limonene.

Biomass from pineapple, cherry coffee and banana had a combined energy contribution of 10.20 PJ, being residues with bioenergy potential lower than citrus fruits. Watermelon, rice palay and pear residues had the lowest bioenergy potential with about 0.67 PJ, with watermelon having a higher BPT than pear, despite having a lower HV. Finally, the main agroindustrial waste in Veracruz has a total BPT of 130.00 PJ, as shown in Table 5. This would position to Veracruz as the largest supplier state of renewable energy from biomass, contributing 36%, as 362.00 PJ were generated in Mexico in 2017 from biomass such as firewood and sugarcane bagasse (SENER, 2018). In countries such as Turkey, BPT equivalent to 90.00 PJ from horticultural crops have been reported (Avcioglu et al., 2019).

Table 5. Theoretical bioenergy potential from agroindustrial wastes in Veracruz.

Product	TAW	HV (MJ/kg)	BP_T (PJ)
Sugarcane	5.28×10^6	19.40	102.00
Orange	0.63×10^6	15.82	9.96
Lemon	0.23×10^6	17.84	4.23
Pineapple	0.40×10^6	14.27	5.61
Grapefruit	0.12×10^6	17.60	2.13
Banana	0.08×10^6	16.58	1.37
Cherry coffee	0.18×10^6	17.90	3.22
Watermelon	0.04×10^6	13.85	0.55
Rice palay	0.007×10^6	15.70	0.11
Pear	0.0002×10^6	18.40	0.0045
Total theoretical bioenergy potential			130.00

Conclusions

The state of Veracruz is the largest supplier of agroindustrial products with around 25.5 x 106 tons per year, according to the ten crops studied, from which 6.97 x 106 tons of waste are discarded, corresponding to 27.33% on average. The total bioenergy potential from agroindustrial solid waste in Veracruz corresponds to 130.00 PJ per year, which depends on the amount of crop produced, the percentage of waste generated and the specific heating value. Thus, Veracruz would be able to contribute 36% of the energy produced by renewable sources such as biomass, compared to the 362. 00 PJ reported in the National Energy Balance, which is equivalent to 5.4% of fossil fuels.

As part of the future work, a supply chain will be designed for the generation of bioenergy from the same waste through system dynamics, considering different factors such as planted area, harvested area, crop production, waste generation, waste treatment method, among others.

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