

## Potential supply of lactic acid as a diversification alternative of the sugar agro-industry in Veracruz, Mexico

Oferta potencial del ácido láctico como alternativa de diversificación de la agroindustria azucarera en Veracruz, México

Potencial oferta de ácido láctico como alternativa para diversificação da indústria açucareira em Veracruz, México

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### Socioeconomics

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### Abstract

In Mexico, sugarcane (*Saccharum* spp.) is one of the most notable agrifood crops, due to the economic importance it represents, sucrose and ethanol are systematically produced from it. However, a modernization scheme is currently required through productive diversification, valorizing and taking advantage of the generated co-products. In this scheme, the production of lactic acid is proposed, which generates added value and has potential demand in different industries such as food and pharmaceuticals. Therefore, the objective of this research was to evaluate factors that determine potential supply of lactic acid, if it were produced using bagasse and molasses generated in 18 sugar mills located in four sugarcane regions in Veracruz, Mexico. Statistical methods of panel data analysis were applied by estimating five econometric models, using the factors that can determine such supply. Analysis results indicated that the four sugarcane regions have lactic acid production potential, highlighting the Papaloapan-Gulf (2.6 million t) and Cordoba-Gulf (1.6 million t) regions. Factors that influenced or determined supply were: harvest duration, lactic acid import price, the number of co-products and by-products, the harvested area and the average of schooling level. In conclusion, the sugar agroindustry in Veracruz has the potential to diversify its production through the co-production of lactic acid in the context of a deficit trade balance.

## Resumen

En México la caña de azúcar (*Saccharum* spp.) es uno de los cultivos agroalimentarios más notables, debido a la importancia económica que representa, a partir de la cual se produce sistemáticamente sacarosa y etanol. Sin embargo, actualmente se requiere un esquema de modernización mediante la diversificación productiva, valorizando y aprovechando los coproductos que se generan. En este esquema se propone la producción de ácido láctico, el cual genera valor agregado y tiene demanda potencial en diferentes industrias tales como alimentaria y farmacéutica. Debido a esto, el objetivo del presente trabajo fue evaluar los factores que determinan la oferta potencial del ácido láctico, si fuera producido utilizando el bagazo y melaza que se generan en 18 ingenios azucareros ubicados en cuatro regiones cañeras en Veracruz, México. Se aplicaron métodos estadísticos de análisis de panel de datos mediante la estimación de cinco modelos econométricos, utilizando los factores que pueden determinar dicha oferta. El resultado de los análisis indicó que las cuatro regiones cañeras tienen potencial productivo de ácido láctico resaltando las regiones Papaloapan-Golfo (2,6 millones de t) y Córdoba-Golfo (1,6 millones de t). Los factores que influenciaron o determinaron la oferta fueron: la duración de la zafra, el precio de importación del ácido láctico, número de coproductos y subproductos, la superficie cosechada y el grado promedio de escolaridad. En conclusión la agroindustria azucarera veracruzana tiene potencial para diversificar su producción por medio de la coproducción de ácido láctico en el contexto de una balanza comercial deficitaria.

**Palabras clave:** Modelos econométricos, subproductos de la caña de azúcar, valoración de coproductos.

## Resumo

No México, a cana-de-açúcar (*Saccharum* spp.) é uma das culturas agroalimentares mais notáveis, devido à sua importância econômica, da qual são produzidos sistematicamente sacarose e etanol. No entanto, atualmente é necessário um esquema de modernização por meio da diversificação produtiva, valorizando e aproveitando os coprodutos gerados. Neste esquema, propõe-se a produção de ácido láctico, que gera valor agregado e tem potencial de demanda em diferentes indústrias, como alimentícia e farmacêutica. Devido a isso, o objetivo deste estudo foi o de avaliar os fatores que determinam o potencial de oferta de ácido láctico, se for produzido com bagaço e melaço gerado em 18 usinas de açúcar localizadas em quatro regiões canavieiras em Veracruz, México. Foram aplicados métodos estatísticos de análise em painel de dados estimando cinco modelos econométricos, utilizando os fatores que podem determinar a referida oferta. Os resultados das análises indicaram que as quatro regiões canavieiras apresentam potencial produtivo de ácido láctico, com destaque para as regiões Papaloapan-Golfo (2,6 milhões de t) e Córdoba-Golfo (1,6 milhão de t). Os fatores que influenciaram ou determinaram a oferta foram: a duração da safra, o preço de importação do ácido láctico, o número de coprodutos e subprodutos, a área colhida e a escolaridade média. Em conclusão, a indústria açucareira de Veracruz tem potencial para diversificar sua produção através da coprodução de ácido láctico no contexto de uma balança comercial deficitária.

**Palavras-chave:** Modelos econométricos, subprodutos da cana-de-açúcar, avaliação de coprodutos.

## Introduction

In Mexico, the sugarcane (*Saccharum* spp.) is very important economically, given that it currently ranks sixth in the world in sugarcane production, with a volume of 51.3 million tons of raw cane milled in the last cycle; according to the Secretariat of Agricultural, Rural and Fishing Development (SEDARPA, 2019), Veracruz ranks first in production at the national level and according to the National Committee for the Sustainable Development of Sugarcane (CONADESUCA, 2021), 18 of the 51 national sugar mills are located in this entity. However, the co-products and by-products generated in the sugarcane agroindustry (boiler ash, straw and bud, combustion gases, vinasse, cachaza, molasses and bagasse among others) are not valued, since industrial activity is limited to the production of sucrose and ethanol, giving an opportunity to the productive diversification of this agroindustry (Aguilar-Rivera *et al.*, 2017).

The productive innovation adopted in the sugar agroindustry (biorefinery concept) by countries such as Australia (Bell, 2017), Brazil (Albarelli *et al.*, 2018) and Thailand (Silalertruksa *et al.*, 2017) has made it possible to provide added value to the co-products and by-products generated, this strategy improves the marketing conditions, quality and variety of the products, increasing their value at each stage of their production and is important because that implies jobs generation and sustainable processes developing by investments (Llanes-Gil-López *et al.*, 2017). Value-added products that can be produced are biofuels such as biohydrogen, ethanol, carbon fibers, cellulose, animal feed, paper, detergents, lubricating oils, paints, electricity, lactic acid and bioplastics, among others (Aguilar-Rivera, 2017).

Lactic acid is a little explored option that has a wide range of applications in the food, cosmetics, chemical industry and as a precursor molecule that can produce biodegradable biopolymers such as polylactic acid (Llanes-Gil-López *et al.*, 2017).

The above provides an alternative to the pollution generated by petroleum-derived plastics since according to the Ministry of Environment and Natural Resources (SEMARNAT, 2018) approximately 300 million tons of plastic waste are produced annually and, in the Mexican context, according to Greenpeace (2019), more than seven million tons of plastic are produced in Mexico, 48% is used for packaging production which are mostly discarded and Veracruz is the fourth state that generates the most urban solid waste in the country (SEMARNAT, 2020). This problem accentuates the need to offer biodegradable products generated from productive diversification.

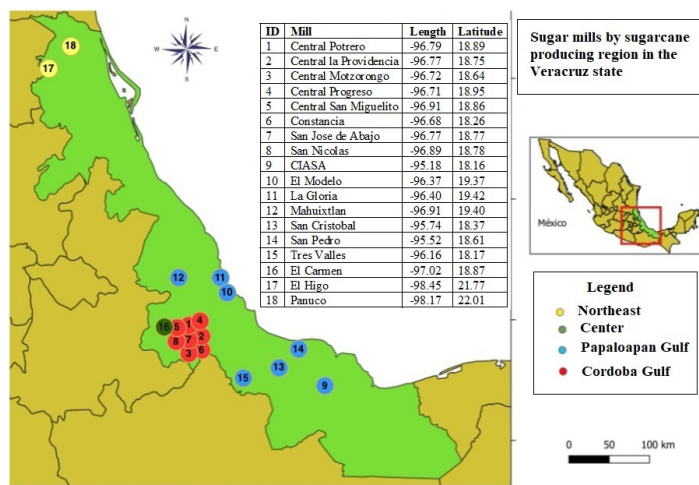
The production of lactic acid from molasses and bagasse produced in the sugar agroindustry could be a convenient diversification alternative in Mexico. Therefore, the objective of this study was to evaluate factors that determine the potential supply of lactic acid if it were produced using bagasse and molasses generated in 18 sugar mills located in four sugarcane regions in Veracruz, Mexico.

## Materials and methods

An evaluative research with a longitudinal evolutionary design was carried out to estimate the supply of lactic acid and weight the incidence of the factors that intervene in it, records were taken of the production of sugarcane by-products of the sugar mills of Veracruz for a period of 10 years (2010-2020). Likewise, social, productive and macroeconomic data from documentary sources were taken.

### Study area

The research was carried out considering four sugarcane regions of the state of Veracruz that groups 18 sugar mills (figure 1); Córdoba-Golfo region: Central El Potrero, Central La Providencia, Central Motzorongo, Central Progreso, Central San Miguelito, Constancia, San José de Abajo and San Nicolás located between parallels 17° 48'19" 8' N and meridians 96° 1'97" 2' W; Papaloapan-Golfo region: CIASA, Modelo, La Gloria, Mahuixtlán, San Cristóbal, San Pedro and Tres Valles located between parallels 17° 42'19" 46' N and meridians 94° 52'96" 57' W; Central region: El Carmen located between parallels 18° 8'19" 29' N and Meridians 96° 43'99" 24' W and Northeast region: El Higo and Pánuco located between parallels 21° 31'23" 8' N and Meridians 97° 59'99" 31' W.



**Figure 1. Sugar mills by sugarcane region in the state of Veracruz.**  
Source: Own elaboration.

### Data

To analyze regions potential, a graph was constructed from a database of production, by-products and co-products generated in the sugar mills, taking into account period from 2010-2011 to 2019-2020, according to CONADESUCA (2021). The potential supply of lactic acid was analyzed by projecting its production with bagasse and molasses considering theoretical yields reported by Alves de Oliveira *et al.* (2019), for lactic acid produced from bagasse and by Anaya-Reza and López-Arenas (2018), for lactic acid produced from molasses in order to project the possible diversification through value addition of the four sugarcane regions in the studied period.

Likewise, information was collected on the export and import volumes of lactic acid in Mexico through the tariff information system via the internet (SIAVI, 2020), and the trade balance of lactic acid was analyzed.

### Variables selection

It were selected context socioeconomic and productive variables (average level of schooling of the population, real sugarcane price, harvested area and sugarcane yield) of municipalities where the sugar mills are located, in order to evaluate factors that determine the supply of lactic acid, using official information from the National Institute of Statistics and Geography (INEGI, 2020) and the Agrifood and Fisheries Information Service (SIAP, 2020). The average schooling level is a socioeconomic variable of interest that is related to production, according to Licea (2019), there is a direct relationship between education and salary; rural populations with higher level of schooling choose to develop non-agricultural activities and migrate to other states in order to increase family income, which has an impact on

the production of agricultural activities. In turn, according to reported by Montesillo-Cedillo (2017), variables such as price, planted area and yield are directly related to the product supply.

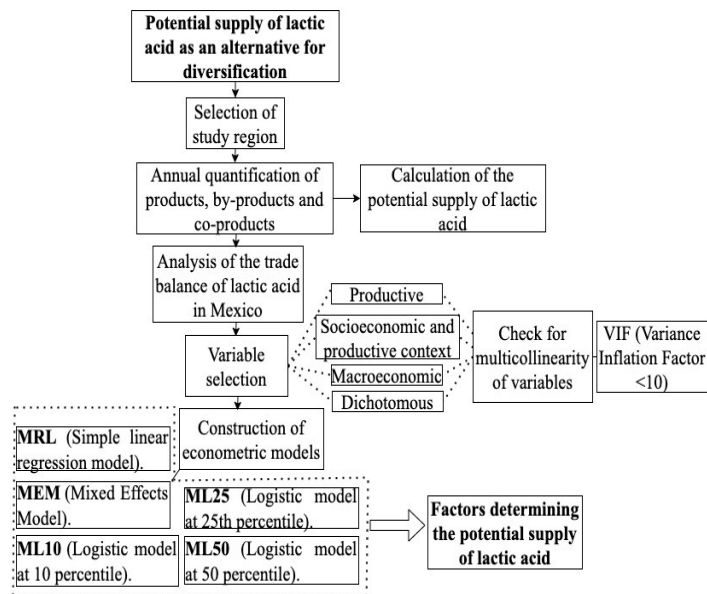
In turn, productive variables were selected (harvest days, number of products, co-products and by-products and time trend for the sugar agroindustry in the study region according to CONADESUCA, (2021). These types of variables are related to product diversification (Aguilar-Rivera 2017).

By means of collected data from the tariff information system by internet (SIAVI, 2020), macroeconomic variables were selected (import price of lactic acid in Mexico and imports volume). According to reported by Benítez-Ramírez *et al.* (2010) and Rebollar-Rebollar *et al.*, (2019) these types of variables directly influence product supply. Likewise, dichotomous type variables were created for the region with the highest production.

The selected variables were checked for multicollinearity by estimating the variance inflation factor (VIF), according to Kothari (2015) and Salmerón-Gómez *et al.* (2020) variables with a variance inflation factor (VIF) greater than 10 present a significant degree of collinearity.

### Data analysis

Data analysis was performed using Stata® ver 12.0 statistical software (Girón 2017; Iglesias and Fernández, 2022) to build simple linear regression econometric models (LRM), mixed effects (MEM), logistic at 10th percentile (LM10), logistic at 25th percentile (LM25) and logistic at 50th percentile (LM50), which were used to evaluate factors that determine the potential supply of lactic acid through an analysis. Finally, the Akaike information criterion (AIC) was used since it reflects the conformity of the model with the observed data and the Bayesian information criterion (BIC) because is the probable (selected) model that best fits the data; these criteria are widely used in the comparison and optimal selection of models choosing as adjusted model, i.e. in balance goodness of fit and parsimony, the one with minimum values of AIC and BIC (Cavanaugh and Neath, 2019). Figure 2, shows the procedure of the research which summarizes all the methodology previously explained.



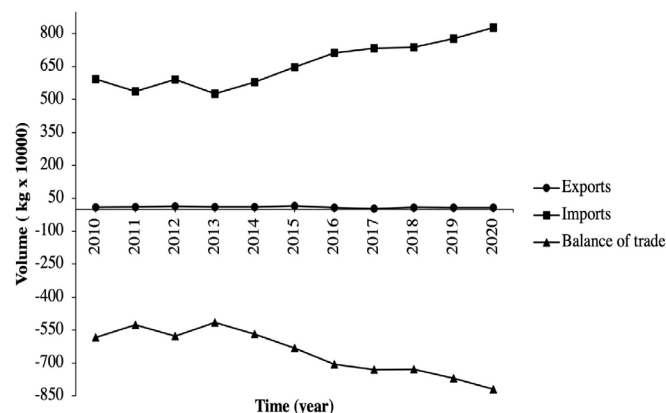
**Figure 2. Research procedure for evaluating factors that determine the potential supply of lactic acid.**

Source: Own elaboration.

## Results and discussion

The inventory of products, by-products and co-products of the sugar agroindustry in the region indicated that the most generated products are bagasse (1287.63 thousand t), cachaza (524.37 thousand t), sucrose (469.1 thousand t), molasses (179.67 thousand t) and ethanol (460.49 thousand L). With the inventory analysis (figure 3) and valorization information, it was decided to perform an analysis with econometric models with bagasse and molasses data as reported by Alves de Oliveira *et al.* (2019) and Anaya-Reza and Lopez-Arenas (2018). The trend of bagasse and molasses generation (production cycle 2010-2011 to 2019-2020), and the projection of lactic acid production volumes if they were produced from these co-products can be observed in Figure 3. The theoretical volumes of lactic acid were calculated in reference to the yields reported by Alves de Oliveira *et al.* (2019) for bagasse and Anaya-Reza and Lopez-Arenas (2018) for molasses.

As can be seen in figure 3, the Papaloapan-Golfo and Córdoba-Golfo sugarcane regions show a greater potential for lactic acid production from bagasse and molasses co-products, with a linear trend that projects a possible increase in production volumes over time, demonstrating that mills belonging to these regions can consider diversification through sustainable production of lactic acid, in addition to the products they traditionally produce.



**Figure 4. History of international trade of the lactic acid product in Mexico, period 2010-2020.**

Source: Prepared by the authors with data from SIAVI (2020).

According to the Observatory of Economic Complexity (OEC, 2020), Mexico exported around \$872,000 USD in lactic acid, its salts and esters in 2020, which placed it as the 24th exporter in the world, its main destination was Egypt (\$349,000 USD), the United States (\$304,000 USD) and Singapore (\$63,400). It was also the 11th importer (\$17,800,000 USD) of lactic acid in the world, indicating that it is a product in demand in Mexico, showing a window of opportunity to supply the domestic requirement of the product with lactic acid produced from sugar cane by-products and co-products.

### Factors determining the potential supply of lactic acid

The analysis of variables using econometric models was carried out with the objective of evaluating the factors that determine the potential supply of lactic acid in Veracruz. As shown in Table 1, following the criteria for selection of the model that best fits the observed data according to Cavanaugh and Neath (2019), the MEM model shows the best fit because it has the lowest AIC and BIC, and according to Rafiq and Kazmi (2017) it is defined as follows:

$$Y = X\beta + Z u + \epsilon$$

Where:  $Y$  is the vector of known observations, with mean  $E(y) = X\beta$ ;

$\beta$  is the unknown vector of fixed effects

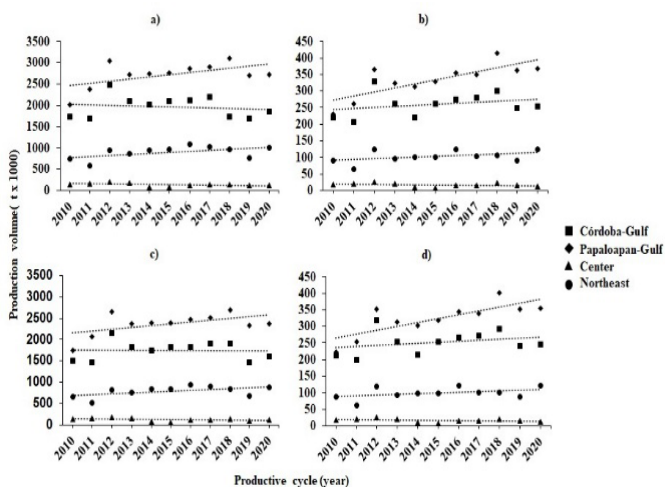
$u$  is the unknown vector of random effects, with mean  $E(u) = 0$  and variance-covariance matrix  $\text{var}(u) = G$ ;

$\epsilon$  is the unknown vector of random errors, with mean  $E(\epsilon) = 0$  and variance  $\text{var}(\epsilon) = R$ ;

$X$  and  $Z$  are known design matrices relating observations  $y$  to  $\beta$  and  $u$  respectively.

Rafiq and Kazmi in (2017) indicated that MEMs integrate fixed effects and random effects and describe the relationship between the response variable and the independent variable(s). Similarly, Gilbert *et al.* (2013), used a MEM concluding that agricultural exports have mixed effects on economic growth in Cameroon.

In this research, models studied to determine the factors that define the potential supply of lactic acid in Veracruz show that the factor *Days of harvest* is highly statistically significant at 1% in the MEM model with the highest adjustment, as well as in the LRM, LM10 and LM50 models, indicating that the greater the number of days of harvest, the greater the probability of producing lactic acid. Due to the availability of sugarcane and by-products (bagasse and molasses) derived from the industrial process is greater as the number of harvest days increases.



**Figure 3. Potential production of lactic acid from co-products of the sugar agroindustry in the sugarcane regions of Veracruz, 2010-2011 to 2019-2020 cycles.** a) Bagasse, b) Molasses, c) Theoretical volume of lactic acid from bagasse and d) Theoretical volume of lactic acid from molasses.

Source: Prepared by the authors with data from CONADESUCA (2020).

### International lactic acid trade in Mexico

In addition, the international trade situation of lactic acid in Mexico faces a trade balance deficit, since purchases of this product abroad exceed sales abroad, as can be seen in figure 4. The results show the opportunity for diversification by promoting production in the domestic market and decreasing dependence on imports from abroad.

On the other hand, the factor Price of lactic acid imports in Mexico turned out to be highly statistically significant in the MEM model and in the LRM and LM10 models but it showed a lower level of statistical significance at 5% and 10%, respectively, those results allowed to selected MEM as the model used for the analysis.

Results suggests that the higher import price of lactic acid increases in Mexico, the higer probability of producing lactic acid domestically increases, which could reduce the volume of imports of this co-product. This result agrees to reported by Benítez-Ramírez *et al.* (2010), who analyzed the supply and demand of beef carcasses in Mexico, using a predictive model.

**Table 1. Econometric models of factors that determine the potential supply of lactic acid in Veracruz.**

Variable	VIF	LRM		MEM		LM10		LM25		LM50	
		Coefficient	P-values	Coefficient	P-values	Coefficient	P-values	Coefficient	P-values	Coefficient	P-values
Days of harvest (Day)	1.28	1.004***	P<0.01	1.003***	P<0.01	14.83***	P<0.01	70.37	NS	36.12***	P<0.01
Number of co-products and by-products	1.53	0.0202	NS	0.0204	NS	4.508**	P<0.05	9109	NS	1655	NS
Average grade of schooling (Years)	1.33	0.053	NS	0.0531	NS	0.836*	P<0.1	11.99	NS	7.159**	P<0.05
Average rural cane price (Mexican pesos)	2.00	0.0879	NS	0.0878	NS	-1361	NS	-6132	NS	-4699	NS
Volume of lactic acid imports (t x 1,000,000)	6.60	-0.103	NS	-0.103	NS	4164	NS	-1188	NS	3021	NS
Papaloapan Region (0 or 1)	1.25	0.345	NS	0.344	NS	3302	NS	18.48	NS	3328	NS
Harvested area (ha)	1.41	0.0182	NS	0.0191	NS	5.052**	P<0.05	-3047	NS	1147	NS
Price of lactic acid imports (Mexican pesos)	3.44	0.340**	p<0.05	0.341***	P<0.01	17.82*	P<0.1	0	NS	0	NS
Cane yield (t.ha <sup>-1</sup> )	1.49	0.124	NS	0.119	NS	-3561	NS	-15.75	NS	3490	NS
Constant	N/A	-4.153**	p<0.05	-4139	NS	-333.6**	P<0.05	-345.9	NS	-264.9*	P<0.1
Number of observations	N/A	160		160		160		160		160	
Information criteria Akaike (AIC)	N/A	216.49		-167.2		88.22		65.3		79.45	
Information criteria Bayesian (BIC)	N/A	250.32		-127.2		125.1		99.13		113.3	

\*\*\*: Significant at 1% and P-value=P<0.01, \*\*: Significant at 5% and P<0.05, \*: Significant at 10% (Gilbert *et al.* 2013) and P<0.1; LRM=Simple linear regression model; MEM=Mixed effects model; LM10=Logistic model at 10th percentile; LM25=Logistic model at 25th percentile; LM50=Logistic model at 50th percentile; NS=Not significant; VIF=Variance inflation factor; N/A=Not applicable.

In the same way, Rebollar-Rebollar *et al.* (2019), found similar results, when determining the effect of imports on the main economic and technological variables supply of chicken meat, concluding that the higher the import price, the higher the volume of chicken meat in Mexico.

Additionally, the factors Number of co-products and by-products, harvested area and Average grade of schooling, presented a lower level of statistical significance in LM10 at 5%, 5% and 10% respectively, suggesting that the greater the number of co-products and by-products produced in a mill, the greater the probability of diversifying its production, and the greater the harvested area, the greater the probability of producing lactic acid due to the availability of sugar cane.

Finally, the higher schooling level average of the population where the mills under study are located, the higher probability of producing lactic acid coproduct, similar results to those reported by Aguilar-Rivera (2017), who considered environmental factors such as harvested area, technological factors (installed and milling capacity of sugar mills) and socioeconomic factors such as level of schooling

determined that the Huasteca sugarcane region has an average diversification index of 99.78% (high).

## Conclusions

The analysis of productive diversification of the sugar agroindustry in Veracruz showed that the four regions analyzed have potential for diversification, with the Papaloapan-Gulf (2.6 million tons) and Córdoba-Gulf (1.6 million tons) regions standing out. In addition, bagasse and molasses were identified as the most suitable co-products for the production of lactic acid, with which the productive diversification of the State's sugar agroindustry can be activated, considering the deficit trade balance situation that Mexico faces for this product.

Harvest days and the import price of lactic acid were the main factors that determined supply; other factors, such as the number of co-products and by-products, harvested area and average level of schooling were also determinants of supply in other models studied, but with a lower level of statistical significance.

According to the results, it is suggested to carry out tests of lactic acid production using bagasse and molasses as carbon sources, considering its potential for an alternative system of diversification of the sugar agroindustry in Veracruz, Mexico.

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