Use of underutilized residues from Theobroma cacao to obtain biogas

Armijo Hidalgo, Johanna[1]; Vera Sánchez Jordy[2]; Jácome Pilco Carlos[3]

[1] Universidad Estatal de Bolivar, Faculty of Agricultural and Environmental Sciences, Agroindustry Career, Guaranda, Ecuador.

[2] Universidad Estatal de Bolívar, Faculty of Agricultural and Environmental Sciences, Agroindustry Career, Guaranda, Ecuador.

[3] Universidad Estatal de Bolivar, Faculty of Agricultural and Environmental Sciences, Agroindustry Career, Guaranda, Ecuador.

joharmijo@mailes.ueb.edu.ec, jordvera@mailes.ueb.edu.ec, cjacome@ueb.edu.ec

Abstract

This article will analyze the main residues used from the industrialization of cocoa among these the mucilage, placenta and cascará for obtaining biogas, through the use of rigid biodigesters of Chinese dome, identifying the production of methane from water displacement through a bibliographic study, to enhance the production of biogas from waste from agricultural activities in the production of industrialized cocoa, to optimize methane in the drying of a cocoa farm, since the gas serves as combustion or co-management. In this way, the study makes clear the imprudence of importing or extracting fossil fuels, especially in rural areas. As a result, it can be said that biogas comes from an anaerobic generation of methane, carbon dioxide and sulfuric acid.

Keywords: Gas resources, fermentation, Biomass energy.

DOI Number: 10.14704/nq.2022.20.9.NQ440122 **Neuro Quantology 2022; 20(9):1083-1089**

Resumen: El presente artículo analiza los principales residuos utilizados de la industrialización del cacao entre estos el mucilago, placenta y cascará para la obtención de biogás, mediante el uso de biodigestores rígidos de cúpula china, identificando la producción de metano de desplazamiento de agua a través de un estudio bibliográfico, con la finalidad de potenciar la producción de biogás de los residuos provenientes de actividades agrícolas en la producción de caco industrializado, para optimizar el metano en el secado del cacao de finca, ya que el gas sirve como combustión o cogestión. De esta forma, se comienza a comprender la imprudencia de importar o extraer combustibles fósiles, sobre todo de la zona rural de nuestro país. Como resultado, se puede decir, que el biogás proviene de una generación anaeróbica de metano, anhídrido carbónico, ácido sulfúrico.

Palabras clave: Recursos de gas, fermentación, Energía de la biomasa.

1 Introduction

In recent years, the attention of biomass as a substitute for fossil fuels has steadily increased. In addition to the normal burning process, which is most suitable for wood residues, some types of heat and biological processes are considered attractive for energy generation (Caposciutti *et al*., 2020).

In anaerobic processes, microorganisms produce much less energy than aerobic microorganisms and, to meet their energy needs, they metabolize more sugar and thus process more sugar and larger amounts of metabolites. These microorganisms produce methane in the last step of the anaerobic digestion process. Biogas-producing bacteria are completely anaerobic organisms and, therefore, can only survive in the total absence of oxygen in the atmosphere, in addition to energy consumption and in the form of stable final waste, with a high rate of destruction of pathogenic microorganisms, qualifies for use as a soil conditioner. The application of heat can break down complex organic wastes into simpler, biodegradable components. This process mainly affects the hydrolysis stage, accelerating it, reducing the volume of sludge and increasing biogas production (Kougias & Angelidaki, 2018).

The Bioenergy Atlas of Ecuador is the primary source of information on the number of cocoa crop residues, estimated at 2,015,353 t/year for 2014. These residues correspond to cocoa shells representing 14.32 % (by weight) of the total residues of this crop, equivalent to 288,580 t/year. (Sigüencia Avila *et al*., 2020). One ton of drying tool can provide 12 kg of nitrogen, 2.5 kg of phosphorus (P2O5), 42 kg of potassium (K2O), 4.2 kg of calcium (high) and 4.2 kg of magnesium (MGO) (Carvajal *et al*., 2018).

Similarly, cocoa has mucus residues (Baba or Cocoa Mucílago) obtained as a product of a fermentation process carried out in the production of good quality cocoa, which includes sponge cells, with rich sugar cells (from 10% to 13%), citric acid (from 1% to 2%), spikes (from 2% to 3%) and salt (at approximately 8%, 3% and 10%) (Gutiérrez, 2020). Biogas production is a sustainable process that is set up to produce simultaneous renewable energy and organic waste management (Carvajal *et al*., 2018).

Agricultural residues correspond to lignocellulose biomass and lipids, although difficult to hydrolyze, can be divided into monosaccharides and simpler esters through physical, chemical and/or biological processes. Therefore, the use of agricultural residues increased thanks to surveys conducted in developed countries, so that waste no longer became a potential raw material, which increases their ability to use it. On the other hand, they cause an important environmental problem by eliminating possible (Mejías et al., 2016).

Bermudez et al. emphasized that fermentation of cocoa shells with Pleurotus strata allowed a remaining substrate with high nutritional value to be used in animal diets or as organic fertilizer (Carvajal *et al*., 2018). During biodegradation, biochemical reactions are carried out by different families of microorganisms and occur in 4 stages. The first step is hydrolysis, in which acid-producing bacteria break down complex molecules of the organic matter to produce fatty acids and alcohols. During the second period, acetate bacteria produce acetate and hydrogen. The third group of bacteria, known as homoacetogens, is responsible for converting a wide range of organic compounds into acetic acid. In the final stage, methanogenic bacteria can digest the acetic acid and convert it into methane and carbon dioxide, which are the main bases of biogas. (Ávila *et al*., 2018).

The energy value of biomass provides the amount of energy it contains and can be released when it undergoes energy conversion. A large part of the rural population in developing countries depends on biomass for energy. Therefore, this work aims to study the use of the residues used in the industrialization of cocoa among these the mucilage, placenta and husk to obtain biogas.

2 Methodology

The type of approach of the research is qualitative since it intends to investigate through the technique of documentary analysis in indexed journals all the relevant information for the article so that academic search engines will allow finding the articles that best fit the topic.

For achieving the objective of the study, a bibliographic study of how a Chinese dome biodigester is made is carried out. This model has as its main characteristic to work with variable pressure. "It is a closed, hermetic and impermeable container (called reactor) inside which the organic material to be fermented is deposited in a certain dilution of water to be decomposed by microorganisms, producing, on the one hand, methane gas and on the other hand organic fertilizers rich in nitrogen, phosphorus and potassium" (Reyes & Cortés, 2017).

3 Results

Design and construction

For its design and construction, the first step is the baseline survey, sampling and characteristics of the cocoa residue, the load is quantified, the site is located, the plans are drawn up in AutoCAD, and the environmental impact is evaluated. It is built with a single structure with concrete, brick or block materials, these materials are used for the high pressure that can reach in its internal part and its variation.

The materials needed are cement, electro-welded mesh, enclosing mesh, blocks or bricks, fine sand, ballast, 1/8 iron, wooden board, 0.5 mm triplex, white tie wire, tire tubes, 2 inch nails, 2 ½ inch nails, 3-inch nails, 8-inch PVC pipe. 6-in. PVC pipe, ½-in. pipe, ½-in. PVC plug, 6-in. PVC plug, ½-in.

stopcock, ball valve, ½-in. tee, ½-in. tee, ½-in. elbows, 12-in. neplo, 2-in. to ½-in. reducer, 2-in. union 2-in. wrench, 10.5-plastic M, pipe glue, Teflon M, gas hose M, clamp, plastic bottle" (Carvajal *et al*., 2018).

Once the material is ready, the site where the construction will begin is selected; it should be firm, with no bodies of water and it should be a place with little vegetation. The land is cleaned and prepared in a radius of 5 meters around, the selected site is marked with a circumference built of iron, then the construction of the inlet and outlet box is marked, it must be separated with a "distance of 0.83 and 0.52 that separates them from the biodigester, the hole must have a diameter of 2.54m and the trench where the inlet and outlet pipe will be placed will have a height of 60cm and 80cm from the base of the biodigester" (Montenegro *et al*., 2016).

For the construction of the biodigester base, a thin layer of granite is spread and the soil is compacted. Once the cement mixture is ready, it is deposited on the fine stone and compacted with the base. In the construction of the digestion chamber of the biodigester, "the electro-welded mesh and rods are placed to provide greater resistance and safety to the tank, then the formwork and placement of inlet pipes (organic waste plus water), biol outlets and sludge outlet, then the casting was done". A mixture of cement, gravel and sand is used to prevent the walls from splitting, and then the walls are plastered. (Carvajal *et al*., 2018).

Construction of the loading box is done with blocks or bricks, it is plastered internally and externally to avoid any difficulty, then it is placed in the center of the box the 8-in. pipe with a height of 40 cm. Construction of the biol outlet box is made in the same way "it was made at a distance of 52 cm to the digestion chamber and at a height of 10 cm less the level of the discharge pipe so the outlet pipe" (Genesis Water Tech, 2019).

Construction and installation of the cleaning box, the 6" pipe is installed, building a hermetically reinforced concrete box, cast in iron with measures of 0.3m on all sides with the objective of greater firmness. Construction of the dome of the biodigester, "After one day of plastering the tank, the participants proceeded to the construction of the dome, as in the tank participants used electro-welded mesh, iron rods and made the formwork from inside the tank" (Vargas & Pérez, 2018).

Construction of the gas exhaust valve will help that the pressure does not damage the biodigester; a manometer is coupled to one of the ends next to one of the stopcocks to regulate the output of biogas; the tube is submerged 8cm in the water. Construction of the water trap "A TEE is coupled and in its lower part a half-inch PVC tube of 15 cm in length and a stopcock is installed" (Montenegro Orozco *et al*., 2016). 1085

Construction of the hydrogen sulfide filter, using 2 joints and neplo pipe horizontally, installing the pipe with its adaptations by placing glass sponges at the ends, and filling it with iron shavings. Construction of gasometer, a gasometer is installed near the kitchen once all the parts of the biodigester have been built, making it easier to cook (Montenegro Orozco *et al*., 2016).

Bioreactor technology

The installation of piping that will lead to the biogas "In one of the pipes that is in the dome, a 900 elbow was coupled to it, a 1 m pipe was installed, a universal followed by a 1.5 m pipe, then the water trap was coupled, then a 2.5 m pipe, plus a TEE" (Barrera *et al*., 2020).

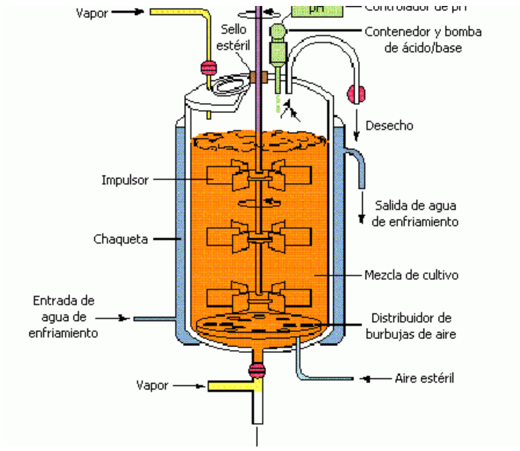

Figure 1. Bioreactor operation and application.

Sequential bioreactor technology is the perfect alternative to traditional activated sludge technology. It is based on the use of a single reactor operating in an intermittent sequential way. The SBR series bioreactor system consists of at least four cyclic processes: filling, aeration, hypoxia, settling and degassing, wastewater and sludge. This technology can withstand changes in loads and flows and produce a stable suspension as a product, sometimes the most suitable technology for the industry. (GWT, 2019).

Advantages:

- High-quality effluent contains fewer solids, thanks to the constant and tight settling allowed by the system, which has a direct impact on the reduction of other quality control standards for wastewater.
- Increased resistance to thermal changes, as it allows control of raw water loading cycles, setting standards for how, when and how to implement them.

Disadvantages:

- These are the systems that require the greatest investment in ventilation systems and the greatest demand for punctual energy, due to the intermittent supply of energy to the plant.
- It is very important to measure well and safely the ventilation system.

Biogas is a gas composed mainly of methane (CH4) and carbon dioxide (CO^2), in different proportions depending on the composition of the organic matter that composes it. The main sources of biogas are livestock and agricultural wastes (Energia , 2017) as well as waste produced by industries that are used for biogas production.

Table 1. Biogas Composition

Components	Concentration
Methane (CH4)	50-75%
Water (H2O)	25-45%
Carbon Dioxide (CO2)	2-7%

Source: Own elaboration.

Advantages and disadvantages of obtaining biogas

Biogas is a renewable energy source produced from various gases resulting from the decomposition of organic matter in the absence of oxygen. Biogas facilitates the production of electricity and heat while respecting the environment and is one of the most efficient alternatives to fossil fuels. This type of renewable energy has the potential to reduce greenhouse gases, oil dependence and pollution (Valencia *et al.*, 2022).

The main advantages and disadvantages of biogas are presented below.

Advantages

- Renewable
- Ecological
- Reduces the amount of waste in landfills
- Reliable source of energy
- Reduces dependence on fossil fuels.

Disadvantages

- It is not possible to produce biogas in any location
- Production is affected by weather
- Energy with impurities
- Large quantities of soil are needed

Biofertilizers

Biofertilizers are organic fertilizers that provide plants with the nutrients they need for growth while improving soil quality and helping to achieve a natural and optimal microbiological environment that benefits sustainable and sustainable production for human use (Franco, 2022).

The use of biofertilizers are essential for organic farming because they help to improve agricultural production and obtain large harvests without harming the environment at any time and following the principles of total respect for the soil, nature, nature and sustainable development (Lira *et al.*, 2018).

The function of biofertilizers includes bacteria or fungi whose properties allow plants to obtain nutrients to improve their performance. They do this naturally, providing them with useful elements, especially nitrogen and phosphorus. The microorganisms that produce it convert atmospheric nitrogen into organic nitrogen and supply it to plants. This process occurs naturally, as the elements are extracted from the soil itself and, after mass production, are returned to the plant and the soil itself. This completes a cycle that contains no artificial or harmful products (Xavier *et al.*, 2021).

A bioreactor is a vessel or system with controlled environmental conditions favorable for the growth of cultured microorganisms, such as temperature, pH, oxidation, gas concentration (O2/CO2), pressure and agitation, among others. The bioreactor is distinguished by its components and accessories manufactured with advanced technology and is divided into three parts: Vessel, Control Module and Auxiliary Sensors (Manzoni *et al*., 2021).

4 Discussion

For agro-industrial assessment and inca approach, the generation of agricultural by-products or residues is currently a global problem, as in most cases, it is neither treated nor disposed of. New technologies are interesting solutions to reduce heat losses, it has been widely applied in existing plants to produce biomethane or biomass as an energy source (Singh & Verma, 2021).

The agri-food industry has the potential to drive global economic, social and environmental development (Vargas & Pérez, 2018). Rapid population growth increases production and demand for products and energy, which leads to increased air pollution and waste. It is usually transported to a landfill or dump. However, the landfill method of solid waste management is still insufficient to be considered the best sustainable and feasible management option. Anaerobic digestion of organic waste consists of using the potential energy of the waste to convert it into biogas. Capsule, placenta and cocoa gum wastes are an excellent and viable alternative, as they currently have no added value, are mass-produced and are not adequately managed (Tapia *et al*., 2021).

Hydrolysis is a necessary first step for the anaerobic decomposition of complex organic matter. Therefore, it is hydrolysis that provides the organic substrate for anaerobic digestion. Through "anaerobic fermentation, a process by which organic matter is catabolized and decomposed in the absence of oxygen by anaerobic microorganisms (bacteria), most of the compounds that undergo this process are derived from alcohol, making the fermentation methanogenic (Vele *et al*., 2021).

$$C_aN_bP_cK_d + H_2O \rightarrow C_eH_f + CO_2 + P_gO_h + K_iO_j + N_2C_6H_{12}O_6 \rightarrow CO_2 + CH_4$$

For the reactions, temperature ranges can be used "in which anaerobic microorganisms can work for an optimal biogas residue: psychrophilic (below 25°C), mesophilic (between 25 and 45°C) and thermophilic (between 45 and 65°C)". Furthermore, soluble compounds, consisting mainly of sugars, polysaccharides, alcohols, amino acids and fatty acids, are fermented by acid-forming microorganisms primarily to produce short-chain fatty acids, carbon dioxide and hydrogen (Soha *et al*., 2021).

Anaerobic digestion of waste, and therefore, the associated biogas generation, consists of a set of redox reactions mediated by particularly complex enzymes possessed by microorganisms, organisms capable of degrading these substrates. This process involves the decomposition of organic matter by microorganisms. This decomposition occurs in four successive stages: hydrolysis, acid-genesis, acetone generation and methanogenesis, which operate through biochemical reactions (Arteaga Cortez *et al*., 2019).

The use of biomass with its high moisture content reduces combustion efficiency since the heat released is used for water evaporation and not for the chemical reduction of the material. Anaerobic digestion has been established as a viable alternative in the rural sector, considering that both livestock and agricultural waste can be used as raw material for the generation of renewable energy, being able to be used to cover the energy needs of the farm itself or to sell it in the electricity market (Tursi, 2019).

5 Conclusions

It is concluded that the production of biogas in agriculture generates several benefits such as obtaining energy, as well as a source of liquids that can be used in crop irrigation and the solid part can be used as fertilizer. The organic residues produced by industrialization have great potential in their chemical variation, which establishes several options to reuse them and obtain the raw material for the benefit of different processes such as the use of biogas.

Cocoa residues produce combustible gases that can be used as an energy alternative, obtaining synthesis gas as biogas that can be used to generate electricity or a combustion system.

The method to be used to extract biogas from organic cocoa waste is the Chinese dome biodigester, which is optimal for the farmer because it is easy to build and without a high cost or labor, this option allows obtaining large volumes of agricultural waste with high fiber content.

Conflict of Interest

Authors must declare that there are no conflicts of interest of any nature or declare the type of conflict of interest that the author(s) maintain with the present research.

References

Arteaga Cortez, V. M., Quevedo Nolasco, A., Valle Paniagua, D. H. del, Castro Popoca, M., Bravo Vinaja, Á., & Ramírez Zierold, J. A. (2019). Estado del arte: Una revisión actual a los mecanismos que realizan los humedales artificiales para la remoción de nitrógeno y fósforo. *Tecnología y ciencias del agua*, *10*(5), 319-343. https://doi.org/10.24850/j-tyca-2019-05-12

Ávila Hernández, M., Campos Rodríguez, R., Brenes Peralta, L., & Jiménes Morales, M. F. (2018). Generación de biogás a partir del aprovechamiento de residuos sólidos biodegradables en el Tecnológico de Costa Rica, sede Cartago. *Revista Tecnología en Marcha*, *31*(2), 159-170.

Barrera Cardoso, E., Odales Bernal, L., Carabeo Pérez, A., Alba Reyes, Y., & Orestes, F. (2020). Recopilación de aspectos teóricos sobre las tecnologías de producción de biogás a escala rural. *Tecnología Química*, *40*(2), 303-321.

Caposciutti, G., Baccioli, A., Ferrari, L., & Desideri, U. (2020). Biogas from anaerobic digestion: Power generation or biomethane production? *Energies*, *13*(3), 743.

Carvajal Jara, C. A., Tafur Escanta, P. M., Villavicencio Poveda, Á. H., & Gutiérrez Gualotuña, E. R. (2018). Caracterización del poder calorífico de la biomasa residual de cacao CCN51 mediante procesos de gasificación anaeróbico y termoquímico. *Científica*, *22*(2), 113-123.

Franco Polo, R. (2022). “Biofertilizantes” una revisión sistemática de la literatura científica en los últimos 10 años. *HIGH TECH-ENGINEERING JOURNAL*, *2*(1), 90-97.

Genesis Water Tech. (2019, junio 7). Pros y contras: Tecnología de biorreactor de lecho móvil. *Genesis Water Technologies*. https://es.genesiswatertech.com/entrada-en-el-blog/Pros-y-contras-de-un-biorreactor-de-lecho-m%C3%B3vil/

Genesis Water Technologies. (2019, junio 7). Pros y contras de un biorreactor de lecho móvil. *Genesis Water Technologies*. https://es.genesiswatertech.com/entrada-en-el-blog/Pros-y-contras-de-un-biorreactor-de-lecho-m%C3%B3vil/

Gutiérrez Espantoso, R. A. (2020). *Obtención de biogás y abono líquido mediante la descomposición anaeróbica de residuos de la fermentación del mucílago de cacao en Pucallpa-Perú* [Tesis, Universidad Científica del Sur]. https://repositorio.cientifica.edu.pe/handle/20.500.12805/1311

Kougias, P. G., & Angelidaki, I. (2018). Biogas and its opportunities—A review. *Frontiers of Environmental Science & Engineering*, *12*(3), 14. https://doi.org/10.1007/s11783-018-1037-8

Lira Saldivar, R. H., Méndez Argüello, B., Santos Villarreal, G. D. los, Vera Reyes, I., Lira Saldivar, R. H., Méndez Argüello, B., Santos Villarreal, G. D. los, & Vera Reyes, I. (2018). Potencial de la nanotecnología en la agricultura. *Acta universitaria*, *28*(2), 9-24. https://doi.org/10.15174/au.2018.1575

Manzoni Maroneze, M., Montenegro Herrera, C. A., & Martínez Jiménez, A. (2021). Perspectivas sobre los sistemas de cultivo de microalgas: Una revisión crítica Insights into microalgae culture systems: A critical review. *BioTecnología*, *25*(5). https://smbb.mx/wp-content/uploads/2021/12/Manzoni-Maroneze-et-al.-2021.pdf

Mejías Brizuela, N., Orozco Guillén, E., & Galáan Hernández, N. (2016). Aprovechamiento de los residuos agroindustriales y su contribución al desarrollo sostenible de México. *Revista de Ciencias Ambientales y Recursos Naturales*, *2*(6), 27-41.

Montenegro Orozco, K. T., Rojas Carpio, A. S., Cabeza Rojas, I., & Hernández Pardo, M. A. (2016). Potencial do biogás dos residuos agro-industriais gerados no departamento de Cundinamarca. *Revista ION*, *29*(2), 23-37.

https://doi.org/10.18273/revion.v29n2-2016002

Reyes, G. E., & Cortés, J. D. (2017). Intensidad en el uso de fertilizantes en América Latina y el Caribe (2006-2012). *Bioagro*, *29*(1), 45-52.

Sigüencia Avila, J. M., Delgado Noboa, J. W., Posso Rivera, F. R., & Sánchez Quezada, J. P. (2020). Estimación del potencial de producción de bioetanol para los residuos de la corteza del cacao en Ecuador. *Ciencia & Tecnología Agropecuaria*, *21*(3), 1-20. https://doi.org/10.21930/rcta.vol21_num3_art:1429

Singh, P. P., & Verma, M. (2021). Recent Advances in Alternative Sources of Energy. *Energy: Crises, Challenges and Solutions*, *10*(2), 55-71.

Soha, T., Papp, L., Csontos, C., & Munkácsy, B. (2021). The importance of high crop residue demand on biogas plant site selection, scaling and feedstock allocation – A regional scale concept in a Hungarian study area. *Renewable and Sustainable Energy Reviews*, *141*, 110822. https://doi.org/10.1016/j.rser.2021.110822

Tapia, E., Madrigal, B., & Herrera, E. (2021). Revisión: Biotecnología aplicada a la viticultura. *RIA. Revista de investigaciones agropecuarias*, *47*(3), 305-314.

Tursi, A. (2019). A review on biomass: Importance, chemistry, classification, and conversion. *Biofuel Research Journal*, *6*(2), 962-979. https://doi.org/10.18331/BRJ2019.6.2.3

Valencia Bautista, E. L., Angulo Guerrero, R. J., Farfán Bone, J. M., Verá Lozano, C. J., Arboleda Cheres, I. A., & Orobio Arboleda, T. J. (2022). Una revisión del suministro de energía renovable y las tecnologías de eficiencia energética. *Polo del Conocimiento*, *7*(4). https://polodelconocimiento.com/ojs/index.php/es/article/view/3934

Vargas Corredor, Y. A., & Peréz Pérez, L. I. (2018). Aprovechamiento de residuos agroindustriales en el mejoramiento de la calidad del ambiente. *Revista Facultad de Ciencias Básicas*, *14*(1), 59-72. https://doi.org/10.18359/rfcb.3108

Vele Salto, A. M., Abril González, M. F., Zalamea Piedra, T. S., Pinos Vélez, V. P., Vele Salto, A. M., Abril González, M. F., Zalamea Piedra, T. S., & Pinos Vélez, V. P. (2021). Mini revisión: Aplicación de líquidos iónicos en hidrólisis ácida de material lignocelulósico para la obtención de azúcares. *Ciencia en Desarrollo*, *12*(1), 55-67. https://doi.org/10.19053/01217488.v12.n1.2021.12477

Xavier Junior, O. S., da Rosa Ferraz Jardim, A. M., Bastos de Souza, L. S., Alves de Souza, C. A., da Cruz Neto, J. F., Araújo Júnior, G. do N., Cordeiro Leite, R. M., & Freire da Silva, T. G. (2021). Utilização de biofertilizantes alternativos no cultivo de palma forrageira: Uma revisão. *Research, Society and Development*, *10*(6), e46110616024-e46110616024.