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Evaluation and utilization of agro-industrial residues of fruit origin

Evaluaciòn y aprovechamiento de residuos agroindustriales de origen frutal

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Abstract: In this work an exhaustive analysis of the state of the art in the processes of compost, vermicompost and anaerobic co-digestion for the integral use of the wastes under study was carried out, using academic search engines that provide real, verified and objective information. In addition, the synergy of the wastes was carried out by performing the balance of matter of the wastes generated in the production processes of a fruit processing company. For this study, a model considering important parameters was started by means of the MATLAB software GUI. The ratio model (C/N) of the codigestion is composed of two methods that will be filled according to the parameters contained by the user. As for the composting C/N design, it has the same principle as that of codigestion, but its capacity to receive variables is limited. The model (Piles/Bins), also based on the composting method, is a useful tool for the design and capacity of the containers to be used in composting and vermicomposting.

Keywords: composting, vermicomposting, anaerobic co-digestion, state of the art, waste.

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Resumen: En este trabajo se realizó un análisis exhaustivo del estado del arte en los procesos de compost, vermicompost y codigestión anaerobia para el aprovechamiento integral de los residuos en estudio, empleando buscadores académicos que proporción de información real, verificada y objetiva. Además, se llevó a cabo la sinergia de los residuos al realizar el balance de la materia de los residuos generados en los procesos de producción de una empresa procesadora de frutas. Para este estudio, se comenzó un modelo que considera parámetros importantes por medio de la GUI del software MATLAB. El modelo de relación (C/N) de la codigestión se compone de dos métodos que serán llenados acorde a los parámetros que contenga el usuario. En cuanto al diseño de la relación (C/N) del compostaje, tiene el mismo principio que el de la codigestión, pero su capacidad para recibir variables se ve limitada. El modelo (Pilas/Hileras), también basado en el método del compostaje, resulta una herramienta útil para el diseño y la capacidad de los recipientes que se utilizarán en el compostaje y el vermicompostaje.

Palabras clave: compostaje, vermicompostaje, codigestión anaerobia, estado el arte, residuos.

1. Introduction

The increase in production, resource consumption and commerce in general is the reason for the higher generation of solid and liquid waste. It highlights the fact that about 46% of solid waste is of organic type. (Chávez & Rodríguez, 2016). The incorrect management of this waste is the main cause of the creation of more dumps for storage and/or incinerators, in order to comply with its final disposal, especially in factories and agroindustrial plantations, where this waste is burned or disposed of in the open air for its natural deterioration, causing serious environmental pollution. Globally, agro-industrial waste ends up being a difficult problem to control, this is why there are multiple ideas to take advantage of this waste (Vargas & Pérez, 2018). One of the alternatives for the integral use of agroindustrial waste is anaerobic co-digestion, which allows the optimization of resources, avoiding pollution and reducing biogas production costs. We should also consider composting and vermicomposting, which are methodologies that provide key benefits in soil treatment and bioremediation, as well as in crop fertilization.

This study has reviewed the state of the art of the methods proposed for the integral utilization of waste, classifying them according to the methodology applied by the authors. The first method presented is anaerobic co-digestion, followed by composting, and finally vermicomposting.

In addition, a mathematical model has been proposed for the calculation of the carbon/nitrogen ratio of wastes in anaerobic co-digestion and composting processes, using MATLAB mathematical language. This model will allow a more accurate and efficient design of these processes.

State of the art for the utilization of agro-industrial wastes by anaerobic co-digestion.

It consists of the decomposition of organic matter in the absence of oxygen by bacterial action, which gives as a final product a mixture of gases (called "biogas") from which methane is used.CH_4, CO_2, H_2S, H_2) called "biogas", from which methane is the major component of the mixture. (CH_4) which is the major component of the mixture. (Vera, 2017).

Significant waste in the Ecuadorian agroindustrial sector are among others we have coffee, banana, cocoa, rice husk, flowers, palm heart, corn, sugar cane, potatoes and fruits; reason why the management of their waste is of importance for each industry, in this context the development of new techniques allows adding value to these wastes. (Vera, 2017). According to the research places where waste is captured in very high quantity are households, markets and industries, which are common sources for the generation of organic waste.

The anaerobic co-digestion process is carried out in a biological reactor, where a biodegradable organic substrate is fed and an inoculum is loaded into it, which is responsible for providing the mixture with an ecological micro-system of microorganisms that in various stages end up producing methane, Most of the authors investigated use animal manure as inoculum for starting the anaerobic process, since they report that it improves the biodigestion process due to the presence of microbial activity, while authors such as Mosos used anaerobic sludge from a reactor as inoculum. (Mosos Martínez, Cadavid Rodríguez, & Agudelo H, 2012).as well as Hernández inoculated the substrate with anaerobic sludge from a laboratory-scale anaerobic digester. (Hernández Juárez Alberto, 2015)

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July, presented a study on the evaluation of anaerobic co-digestion of municipal sewage sludge with food waste, widely used due to its technical and economic advantages by optimizing its use (July, 2016). In 2017 in Mexico Sanchez and Vizcon studied the anaerobic co-digestion of organic waste as an energetic, environmental and human health contribution. (Sánchez & Vizcón, 2017). Peralta and Serrano in their undergraduate thesis presented an investigation on the anaerobic co-digestion of raw food waste generated in cafeterias of university institutions. (Peralta & Serrano, 2019)..

Álvarez, presented a study on the co-digestion of waste for its biomethanization, using crushed orange waste from citrus plants in the province of Castellón, Spain. (Álvarez-Arregui, 2012).. In 2018, Rodriguez and Hernandez studied the effect the co-digestion of citrus waste with different types of manure they indicate that citrus waste contains considerable values of soluble to insoluble carbohydrates that can be digested to biogas, however, it is a real challenge due to the presence of the antimicrobial compound d-limonene of which all citrus waste consists. (Rodriguez & Hernandez, 2018).

State of the art of agro-industrial waste utilization by composting

One of the studies on the use of agro-industrial wastes is that of Cotacallapa, Vilca and Coaguila, which argues that the management of pomace residues, a solid residue obtained from the extraction of grape juice in the wine industry, represents a real problem due to its high pollutant load; however, it is rich in functional elements, ethanol and compost and therefore they propose the use of these residues as a source of bioactive elements to obtain compost. (Cotacallapa, 2020).

Vargas, employs composting as an alternative for the use of organic waste in the supply plants in the municipality of Acacias, Colombia. (Vargas Pineda, 2019). In 2016 Campos, Brenes and Jimenez presented a study about the technical evaluation of two composting methods for the treatment of household biodegradable solid waste and its use in home gardens, the substrates for composting were inoculated with mountain microorganisms and takakura type substrate, separately the mixtures were rice granaza and charcoal. (Rooel Campos, 2016).

Solid waste management is a situation of social awareness and strategy planning, according to Iñiguez, in his research on the separation of household waste for the preparation of compost and its analysis in the production of cucumbers. (Iñiguez, 2011). On the other hand, researchers Ballesteros, Hernandez conducted a study where they evaluated the microbial growth in compost piles of organic waste and biosolids after aeration. (Ballesteros & Hernandez, 2018).

López, in her degree work, investigated the use of non-hazardous industrial waste through the composting process and its application to the cultivation of corn and beans (López, 2010). (López, 2010).

State of the art of agro-industrial waste utilization by vermicomposting

This section presents the compilation of research on the use of waste using the vermicomposting method, a technology that contributes to organic waste management and consists of the decomposing habit of some species of earthworms that are responsible for stabilizing and transforming organic waste into a nutrient-rich element similar to humus by physical action involving aeration, mixing and grinding of waste (Villegas & Laines, 2017). Muniyandi, conducted a study about vermiconversion of biowaste with high to low C/N ratio into value added vermicomposting. (Muniyandi & Natchimuthu, 2019). On the other hand, Sifolo, investigated the use of vermicomposting as a pathway to rural food security. (Silofo, 2021).

In 2012, Mamani evaluated the behavior of the red earthworm (Eisenia spp.) in vermicomposting systems of organic waste. (Mamani-Mamani, 2012). While in Soobhany's study, a preliminary evaluation of the load of pathogenic bacteria in organic compost from municipal solid waste and vermicompost was conducted. (Soobhany, 2018).

Importance of modeling for integrated waste utilization

Anaerobic co-digestion is a structured method for the integral utilization of different types of waste containing organic material. In order to have an approximate result of the theoretical methane yield, it is necessary to calculate different process parameters. The proposed model presents the measurement of a parameter that will allow to know if the use of the cosubstrate to be used is viable or not (Diaz, 2018). In composting, the stabilization and maturity of the compost is analyzed by means of a parameter such as the C/N ratio. This variable indicates the ideality that two substrates have to form a cosubstrate rich in carbon and nitrogen. The ratio stipulated for the creation of compost is between 25-30 (Bernal, 2009). A value higher than 30 means that the composting

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process is slow and its nitrogen content will be low (Heredia, 2008). (Heredia, 2008).. An excess of nitrogen could react and transform into an inorganic element and be lost in the process by different means. (Bernal, 2009).

The importance of windrow modeling lies in calculating the capacity of waste that could be accumulated in a container or site for vermicomposting and the ability to have a rough estimate of the number of windrows as empirical data. These methods are specifically for the beginning of a project, for other procedures more parameters are needed.

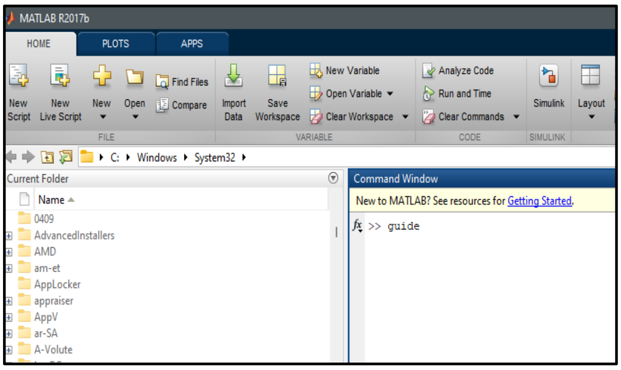
Materials and methods

The mathematical model used is Matlab® from Mathworks, a program specially designed to solve scientific models and engineering problems using its different toolboxes created for each specific case. The product that stands out is Simulink, which simulates different designs from simple to complex dynamic systems. The latest version of Matlab is R2022a. The version used in this model is R2017b.

Matlab Guide

Matlab has many different aspects of creation for visualization, analysis and adjustment of data that can be represented in a graphical interface. One of the ways to enter the graphical interface design is through the "guide" command in the Windows Command as shown in Figure 1.

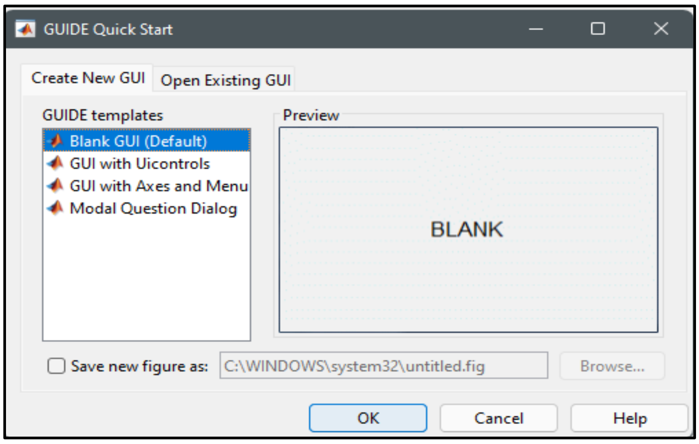
Figure 1. MATLAB guide login.



Source: (Bone Lemos & Lopez Villalta, 2021)

Subsequently, the graphical interface construction options can be accessed as shown in Figure 2.

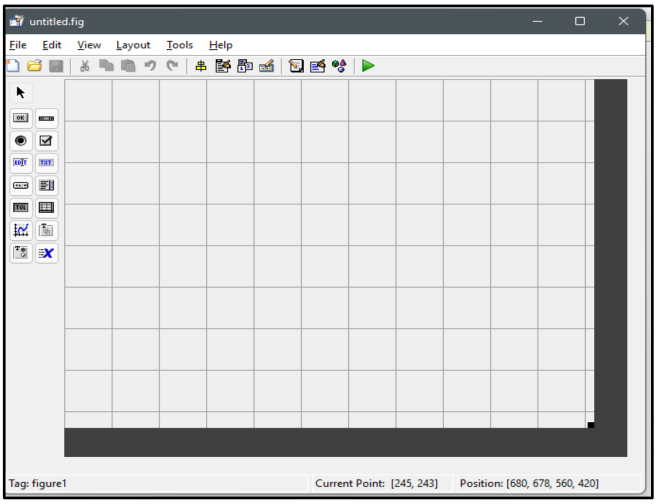
Figure 2. Chart for the creation of the MATLAB graphical interface.



Source: (Bone Lemos & Lopez Villalta, 2021)

Selecting Blank GUI displays the form where the interface to solve the mathematical model projected in Figure 3 is developed.

Figure 3. MATLAB graphical interface.



Source: (Bone Lemos & Lopez Villalta, 2021)

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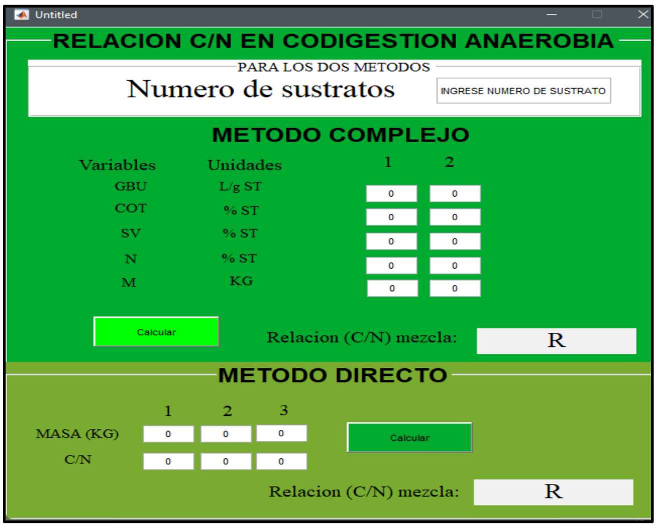
Design of the "carbon/nitrogen ratio in anaerobic co-digestion" model.

Figure 4. Interface of the model "carbon/nitrogen ratio in Codigestion".



Source: (Bone Lemos & Lopez Villalta, 2021)

Figure 4 shows the interface created to calculate the ratio (C/N) of the mixture in two methods: the complex method and the direct method. In the complex method there are variables that will be used according to the data contained by the user, i.e., it is not necessary to fill in all the boxes to obtain the final value. The direct method is used when the user has the values of the initial masses and ratios (C/N). For both methods, the representative box is used at the top with the legend "Number of substrates" where the data for each one will be placed.

3. Result

Complex Method

Input parameters

Cumulative biogas production (GBU)

Parameter used in the GUIDE model that determines the accumulated biogas production. Its units are (L/g ST).

Total organic carbon (TOC)

Parameter used in the GUIDE model to determine the amount of total organic carbon in the substrate. Its units are (%ST).

Organic matter (SV)

Parameter used in the GUIDE model to determine the amount of organic matter in the substrate. Its units are (%ST).

Organic nitrogen (N)

Parameter used in the GUIDE model to determine the amount of total organic nitrogen in the substrate. Its units are (%ST).

Substrate mass (M)

Parameter used in the GUIDE model to determine the amount of mass of the substrate. It is an essential part of the calculation, so its quantity will determine the proportion assigned to it in the C/N of the mixture. Its units are (Kg).

Output parameters

Anaerobic biodegradable organic carbon (BOCan)

One of the output parameters not described in the complex method interface, but it is a determinant value for the mathematical model. This parameter is calculated by experimental analysis using Gbu's method as described in Equation 1.

Equation 1. Gbu's method for calculating COBan.

$$COBan = Gbu * \frac{1\ mol}{22.4\ L} * \frac{12\ g\ C}{1\ mol\ biogas} * 100$$

Source: (Diaz, 2018)

If the COBan cannot be determined for any reason, Equation 2 will be used.

Equation 2. COT method for calculating COBan.

$$COBan = 0.57\% * COT$$

Source: (Puyuelo, Ponsá, Gea, & Sanchez, 2011)

To calculate TOC, the Haug relationship described in Equation 3 is used.

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Equation 3. Haug's method.

$$COT = \frac{SV}{1.8}$$

Source: (Haug, 1993).

Ratio (C/N) mixture in complex method

It is the main output parameter that will be calculated when the user places all the values in the parameters. Its units are dimensionless.

Direct Method

Input parameters

Initial C/N of substrate

Parameter used in the GUIDE model to know the initial C/N of the substrate. This parameter will allow defining the C/N of the mixture directly without the need for any additional calculation.

Substrate mass (M)

Parameter used in the GUIDE model to determine the amount of mass of the substrate. It is an essential part of the calculation, so its quantity will determine the proportion assigned to it in the C/N of the mixture. Its units are (Kg).

Output parameters

Ratio (C/N) mixture in direct method

For the C/N value of the mixture, each variable was given a value in the MATLAB GUIDE graphical interface and calculated using Equation 4:

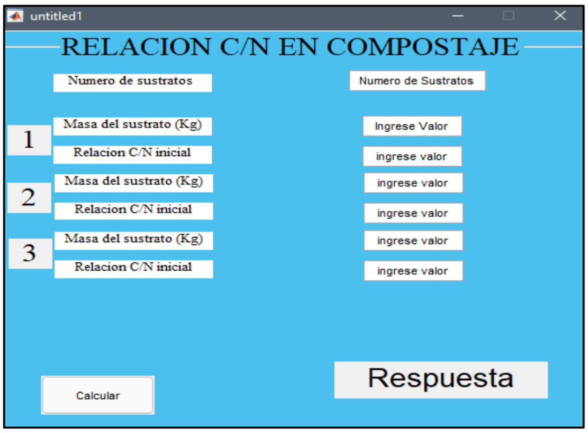
Equation 4. Equation C/N ratio of the mixture.

$$\left(\frac{C}{N}\right)_{mezcla} = \sum_{i=1}^{n} pi * \left(\frac{C}{N}\right)$$

Source: (Diaz, 2018)

Design of the "carbon/nitrogen ratio in composting" model.

Figure 5. Interface of the model "C/N ratio in composting".



Source: (Bone Lemos & Lopez Villalta, 2021)

Description of the model

Figure 5. shows the interface that will have the variables that will be determined in order to generate a value in the script. The structure of this model is based on boxes that will allow placing the values that will be used to calculate the C/N ratio of the mixture based on the variables obtained.

Design parameters

Input parameters

Initial C/N ratio of the substrate

Parameter used in the GUIDE model to know the initial C/N of the substrate. This parameter will allow defining the C/N of the mixture directly without the need for any additional calculation.

Substrate mass (M)

Parameter used in the GUIDE model to determine the amount of mass of the substrate. It is an essential part of the calculation, so its quantity will determine the proportion that will be assigned to it in the C/N of the mixture. Its units are (Kg).

Output parameters

C/N ratio composting mixture

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For the C/N value of the mixture, a value was entered for each of the variables in the MATLAB GUIDE graphical interface. The model used is based on finding the ratio of each mass followed by the multiplication of each with their respective initial C/N ratio giving a final value.

Design of the "piles/stacks" model.

Figure 6. Interface of the "Stacks/Stack" model.

Source: (Bone Lemos & Lopez Villalta, 2021)

Description of the model

The model presented in Figure 6. is presented in an interface that is divided into three parts, which are elementary for the design of piles and windrows that are formed to take advantage of waste in general. In each of the separate tables, the programming is carried out with its mathematical methods obtained from bibliographic sources.

Calculation of pile volume

For the first part of the model, the volume of a pile with a truncated pyramid geometry with rectangular base was considered in the calculation. The model presents the "METRIC DATA" where the values necessary for the final calculation will be entered; the value of the variables are entered in the boxes with the legend "Edit Text". In the second part the "VOLUME OF THE PILE" is presented, which will show the response of the model proposed in the script.

Input parameters

Height

This parameter must be written in the interface with its direct value in meters (m).

Larger base area

For the input of this parameter, the area of the major trapezoid must be directly calculated. The value to be entered must be in meters squared (m2).

Minor base area

To enter this parameter, the area of the minor trapezoid must be directly calculated. The value to be entered must be in meters squared (m2).

Output parameters

Stack volume

The volume of the pile will be calculated by means of Equation 5:

Equation 5. Equation Volume of pyramid trunk.

$$V = \frac{h}{3}(M + m + \sqrt{M * m})$$

Source: (Diaz, 2018)

The result of the equation must be expressed in meters cubed (m3).

Calculation of the recommended volumetric ratio

In frame of the interface of Figure 6. the volumetric ratio is calculated and will be related to the recommended ratio (3/1). This parameter will allow to know if the composting piles will be correctly supplied in volume units. The main legend "FLOW DATA" represents the input parameters to be inserted for the calculation. The values will be entered in the "Edit Text" box. In the lower part you will find the recommended volumetric ratio and the calculated volumetric ratio, where the user will make the comparison.

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Input parameters.

Mass 1

In this parameter should be placed the value of the first mass that will be part of the compost pile and which will have a higher proportion, its units will be written in kilograms (Kg).

Mass 2

In this parameter should be placed the value of the second mass that will be part of the compost pile and which will have a smaller proportion, its units will be written in kilograms (Kg).

Density 1

In this parameter the value of the density of the first mass entered must be entered, its units will be written in kilograms over cubic meters (Kg/m3).

Density 2

In this parameter the value of the density of the second mass entered must be entered, its units will be written in kilograms over cubic meters (Kg/m3).

Output parameters

Calculated volumetric ratio

The calculated volumetric ratio is described as text in the interface followed by values separated by a center dash. This calculation is a division between value 1 and value 2.

Value 1

This output parameter is the representation of the difference between mass 1 and density 1, its value will be given in cubic meters (m3).

Value 2

This output parameter is the representation of the difference between mass 2 and density 2, its value will be given in cubic meters (m3).

Calculation of total volume of waste

In this last part of the model interface the calculation of the total volume of waste will be performed, the values of the previous model will be taken and related to the parameters of this interface. The interface will have a legend

"THEORETICAL DATA" that describes the values that will have to be used to calculate the total volume of waste. These values are entered in the "Edit Text" boxes. In the "TOTAL WASTE VOLUME" box the answer is presented.

Input parameters

Total Mass

It is entered by the user according to the value of the masses that will be obtained as an example, in the calculation is independent of any variable of the interface, and must be entered in kilograms (Kg).

Average density

It is entered according to the densities of the masses placed in the calculation is independent of the densities of the previous model. It is entered in kilograms over cubic meters (Kg/m3).

Number of batteries

The number of piles to be entered will be at the user's discretion, but the experimental area in which it will be used must be considered. This value is dimensionless.

Output parameters.

Total volume of waste

It is calculated by the difference between the value of the total mass calculated from the model "Calculation of total volume of waste" and divided by the input parameter "Average density", thus obtaining the volume of waste in that pile and to project it to multiple piles it is calculated by multiplying the number of piles. The value will be given in cubic meters (m3).

4. Conclusions

The research carried out has as a result the contribution in the construction of the state of the art in the evaluation of agro-industrial wastes for their integral benefit, making use of academic search engines an estimated 50 works classified in scientific articles were found, Among the most relevant research works cited, seven use anaerobic co-digestion, six use composting and four use vermicomposting as alternatives for the use of waste. Thus, the results are

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a reference to opt for an alternative to be used by fruit processing industries in the use of their waste and minimize the negative impact on the environment, thus contributing to the development of the industry in Ecuador. In relation to the models proposed in this research work and developed in the MATLAB GUIDE, they are a fundamental tool in the calculation of important parameters that allow the beginning of the methods proposed in the state of the art. The design of the model ratio (C/N) of the codigestion is composed of two methods which will be filled according to the parameters contained in the user; in the design of the composting ratio (C/N) it has the same principle as the codigestion, but its capacity to receive variables is limited; and finally, the model (Piles/Bins) also based on the composting method, is a useful tool in the design and capacity of the containers that will be used in composting and vermicomposting. With these models we intend to initiate a theoretical process of systematization of parameters that will allow us to obtain multiple solutions to the problems posed.

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