Available online www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 215 (2026) 112-123 EISSN 2392-2192

Characterization of Organic Wastes for Biogas Production Suitability

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https://doi.org/10.65770/HUUI6005

ABSTRACT

This study is conducted on three different organic wastes namely, poultry droppings (PD), water hyacinth (WH), and orange mesocarp (OM) to systematically analyze their properties and behaviors to investigate their suitability for anaerobic co-digestion for effective biogas production. Proximate and ultimate investigation methods were employed to analyze the organic wastes, and certain biological and elemental properties were found in differing fractions. The ultimate analytical method was used to investigate the percentage of hydrogen to be 5.28, 4.13 and 4.89, nitrogen as 3.78, 3.52 and 1.36, carbon to be 48.13, 42.93 and 44.19, sulphur to be 0.58, 0.76 and 0.18, and finally, oxygen as 42.23, 48.66, and 49.38 each for poultry droppings, water hyacinth, and orange mesocarp, respectively, as shown in Table 1 below. In the same vein, proximate analysis was used to check the percentage ash content to be 10.73, 9.26 and 6.83, moisture as 7.18, 64.22 and 9.76, volatile solid to be 70.46, 64.89 and 58.14 and finally, fixed carbon to be 15.77, 13.38 and 11.94 each for poultry droppings, water hyacinth and orange mesocarp, respectively. With respect to the elemental properties, carbon/nitrogen ratios for the three organic wastes were as well determined to be 12.7:1, 12.2:1 and 32.5:1 for poultry droppings, water hyacinth, and orange mesocarp, respectively. This study necessarily precedes the anaerobic co-digestion (AcoD) of the three organic wastes mentioned above in order to check the substrate's suitability for the production of biogas.

Keywords: Characterization, Organic wastes, Biogas production, Ultimate analysis, Proximate analysis, Anaerobic co-digestion

(Received 19 March 2026; Accepted 21 April 2026; Date of Publication 17 May 2026)

1. INTRODUCTION

This study predominantly centers on the characterization of three organic wastes, namely poultry droppings, water hyacinth, and orange mesocarp, for the purpose of biogas production through anaerobic digestion (AD) process. Characterization is a process of determining the physicochemical properties of a substance through laboratory screening process (Farhana Fadzil & Amira Othman, 2021). In its nutshell, it is a scientific method of determining the physical, chemical, and biological properties of a substance, and this must precede the AD of organic waste or substance in order to achieve the desired productive result(s) (Silveira et al., 2023). Characterization is also used to determine the suitability and performance of an organic waste or substrate devoid of posing a significant threat on human life or material of the biodigester during the production of biogas (Iweka et al., 2021). It can also be used to determine the composting, AD, and energy recovery potential of an organic substance (Varma et al., 2018). Characterization as a laboratory technology, also exposes the physical properties like moisture content (MC), total solids (TS), volatile solids (VS) and particle size (PS) of a substance or material (Mrosso et al., 2023). It is also used to check chemical properties such as pH value, carbon/ nitrogen (C/N) ratio, alkalinity, acidity, as well as organic material's nutrients like nitrogen, phosphorus, potassium and others (Hidaka et al., 2017). Characterization is also reliably used to determine certain biological properties like the volatile fatty acids (VFA) content, microbial growth potential, biodegradability, lignin content, pathogenic content, volatile organic compounds, toxic compounds amongst others (Morales-Polo et al., 2018). Characterization is of utmost importance in selecting relevant feedstock, optimizing biomethane yield, preventing bioreactor failure, deciding on best co-digestion strategy, and others during AD process (Miah et al., 2016). It is very useful in the selection of co-digestion compatibility materials to reduce toxicity of product and encouragement of maximum yields (Morales-Polo et al., 2018). Characterization is paramount in determining the biomethane potential (BMP) of organic waste (or substrate) with the intent of maximum and optimal biogas production (Murto et al., 2004). It also helps in unveiling whether pretreatment is pertinent on an organic waste or substrate prior to an AD process to achieve eco-friendly and maximum biogas yield (Hansen et al., 2021).

In this study, three organic wastes namely poultry droppings (PD), orange mesocarp (OM), and water hyacinth (WH) were characterized using Proximate and ultimate analyses. The proximate analysis is used to determine the fundamental compositional fraction of these organic wastes (Janajreh et al., 2020). The proximate analysis determines MC, TS, VS, ash content (AC), and fixed carbon (FC) by oven-drying the organic wastes at 105^0C (or other exalted temperature) depending the substance and your presumed outcome. The proximate analysis is also important in evaluating organic substance's quality and assessing the energy potential of the organic materials involved. It aids in optimizing the design of biogas digester to achieve relevant reliability and optimal lifespan of material (Mondelli et al., 2022).

The Ultimate analysis is basically used to determine the elemental composition of PD, OM, and WH in this study. It helps in identifying certain elements present in the above-mentioned organic wastes that affect the combustion behavior and nutrient balance of the organic wastes. Basically, the ultimate analysis checks the carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S) and nutrients like the phosphorus, calcium, and potassium (Morales-Polo et al., 2018). This analysis is also capable of detecting certain traceable elements that can inhibits combustion and calorific value of biomethane like hydrogen sulphide (H_2S), heavy metals, and others. Carbon and hydrogen are the actual energy-producing elements which play major role in the formation of methane and as well, contributing to energy content, while oxygen reduces its calorific value (Paglini et al., 2022).

Nitrogen content in the organic waste or substrate encourages microbial growth but inhibits ammonia in a biogas digester system when it is in excess. Sulphur present in the organic substances leads to formation of H_2S which is corrosive to metallic components of the biogas digester and also toxic to environment and harmful to human beings (Zhu et al., 2021). Ultimate analysis is also useful in the determination of C/N ratio for biogas production stability, and estimation of theoretical methane potential, assessing pollutant emission as well as supporting biogas digester energy system design (Zhang et al., 2007).

Characterization is also prominent in aiding waste to energy (WtE) design in energy process studies (Azevedo et al., 2021). It has the capability of determining combustion characteristics, energy content, and environmental impact of biomethane, fuel, or organic material (Al-Ghouti et al., 2021). In the same vein, characterization plays a paramount role determining the calorific value of organic fraction of municipal solid waste (OFMSW), biodegradability of organic waste or substance, and can also determine whether a residue is incinerated as an alternative means of energy recovery, mostly through the use gravimetric method (Ulloa-Murillo et al., 2022). Organic or synthetic materials have been conventionally analyzed through laboratory procedure to disclose their biodegradability ratio and chemical composition with the objective of achieving an eco-friendly and optimal energy recovery rate (ERR) (Duan et al., 2022). Over biogas production activities, the process of characterization of substances also plays an indispensable role in nanotechnology, as it is applied in checking properties of nanoparticles applicable in energy induction, energy recovery, as well as energy generation technologies (Naganthran et al., 2022).

2. MATERIALS AND METHODS

Samples of organic wastes, namely poultry droppings, orange mesocarp (collected and blended with an electric blender), and water hyacinth, were obtained from different locations in Rivers State of Nigeria. The methods applied in characterization is further shown below.

2.1. Organic Wastes For Characterization

The organic wastes used in this study are poultry droppings, grinded orange mesocarp, and water hyacinth.

2.1.1. Poultry Droppings (PD): The poultry droppings were obtained from Chika & Chisa Aquaculture & Equipment Limited, located at No. 250 Sandfield Road, Rumuokparali / Rumualogu, off SDA junction, Choba, Port Harcourt, Rivers State of Nigeria. It was collected and weighed into a mass of 5 kg for laboratory screening (characterization).

2.1.2. Orange Mesocarp (OM): The orange mesocarp, as one of the organic wastes, is gotten from an orange seller at Eleme junction axis of Eastwest Road, Port Harcourt, Nigeria. They were collected, hand-treated by removing the skins, and weighed to mass of 5 kg, grinded using an electric blender to impart easy fermentation and biodegradability. The species of orange selected in this case is the normal Nigerian sweet orange (Citrus sinensis) belonging to Rutaceae family.

2.1.3. Water Hyacinth (WH): The water hyacinth is obtained from the surface of a fresh river water water referred to as Maamuidee, located at Khana local Government Area of Rivers State, Nigeria.

These three organic wastes were taken in separate clean containers to Austino Research & Analysis Laboratory located at No. 2 University of Port Harcourt Teaching Hospital (UPTH) Road, Alakahia Junction, Opposite Alakahia Motor Park, Behind Jovit Restaurant, Alakahia Port Harcourt, Rivers State of Nigeria, for Proximate and Ultimate Analyses (or characterization). The procedure of laboratory analysis or characterization and the corresponding results are shown below in Plate 1 and also replicated in Table 1 and 2.

2.1.4. Laboratory Equipment: The following laboratory equipment were used in the laboratory to carry out the laboratory analysis vis-à-vis characterization: analytical weighing balance, hot plate, Kjeldahal's apparatus, burret, conical flask, ceramic crucible, oven, desiccator, and thermometer.

2.2. Methodology

During the determination of physical composition, proximate analysis was applied on the organic wastes and they were oven-dried at the temperature of 105^0C for about 35 minutes and later left to cool to atmospheric temperature when determining the moisture content while gravimetric calculation process was used to check the TS content. During the determination of VS as well as ash content in the organic wastes, the samples were ignited in the furnace at an exalted temperature of about 550^0C. In the same vein, ultimate analysis was used to determine their elemental composition. C, H, N, and S were determined by using individual elemental analyzers, while Kjeldahal's apparatus was used to check the fixed carbon while the pH value was checked using the pH meter. Using gravimetric method to calculate the MC, TS, and VS is shown below.

2.2.1. Determination of Moisture Content (MC): Moisture content can simply explained as the quantity of water contained in an organic waste or sample, and it is usually expressed as a percentage. In this study, empty crucibles (containers) were first of all washed and dried up in an oven normally, weighed, and their masses recorded. 5g of the wet sample is put inside the cleaned and dried crucible and then weighed uncovered. The uncovered ceramic crucible containing the samples were placed in an electronic hot air oven and allowed to be strongly heated for one hour, which was maintained at a temperature of 105^0C. After the heating, the crucibles containing the samples were taken out with a pair of tongs. The crucibles were then covered and allowed to be cooled in a desiccator for about 20 minutes, and then reweighed.

$$\%\ \text{Moisture content, MC} = \frac{(w_2 - w_1) - (w_3 - w_1)}{(w_2 - w_1)} \times 100 \quad (1)$$

Where, w_1 = Weight of empty crucible

w_2 = Weight of sample + crucible (before heating)

w_3 = Weight of sample + crucible (after heating)

w_4 = Weight of remains after TS was burnt in furnace at 550^0C + crucible

2.2.2. % Total Solid, TS: Total solid is the quantity of solid matter present in a sample of organic waste. It is simply everything that is not liquid in the entire organic sample, and it is expressed in percentage.

$$\% \text{ Total Solid, TS} = \frac{w_3 - w_1}{w_2 - w_1} \times 100 \quad (2)$$

Also,

$$TS = VS + Ash \quad (3)$$

2.2.3. Ash Content Determination: Ash is the remnant obtained when TS is burnt in a furnace at an elevated temperature of 550^{0}C. 1 gram of each powdered, air-dried sample was taken in covered ceramic crucibles and strongly heated at 550^{o}C, until all carbonaceous contents burn away and ash remains. After heating, it was then cooled in a desiccator for 15 minutes and then weighed. The ash in the crucible was brushed out and the empty crucible weighed. In this test (determination of ash content) everything except the ash is burned, so that the final weight is the ash.

$$\% \text{ Ash} = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \quad (4)$$

2.2.4. Determination of Volatile Matter Content: Volatile solid or matter is the organic fraction of total solids in an organic substance that totally burns off when heated to an elevated temperature of 550^{0}C. On this note, 5g of the powdered air-dried sample weighed and also placed in ceramic crucible covered with well fitted lid and heated to 850^{0}C for 30 minutes in the absence of air. After heating, the crucible was removed and cooled in air and then in a desiccator which was weighed in a similar manner.

$$\textbf{\% Volatile matter} = \frac{w_3 - w_4}{w_3 - w_1} \times 100 \quad (5)$$

2.2.5. Fixed Carbon Determination: Fixed carbon is simply the solid and combustible material remaining after the determination of moisture, volatile matter, and ash content. It has a higher calorific value and portrays the capability of sustaining heat when it is been burnt in a material. A material or substance with higher FC content can burn slowly, and the heat lasts longer, while when a substance with lower FC is burnt, the heat becomes more volatile and burns faster and also extinguishes fastly. FC is simply using the following formula:

% Fixed carbon = 100 – (%Moisture + %Volatile matter + %Ash) (6)

2.3. Physicochemical Properties of the Organic Wastes

Table 1. Elemental properties of the organic wastes from Ultimate Analysis.

Samples	H (%)	N (%)	C (%)	S (%)	O (%)
Poultry dropping	5.28	3.78	48.13	0.58	42.23
Water hyacinth	4.13	3.52	42.93	0.76	48.66
Orange mesocarp	4.89	1.36	44.19	0.18	49.38

Table 2. Determination of certain useful properties of the organic wastes from Proximate Analysis.

Samples	**Ash content (%)**	**Moisture content (%)**	**Volatile solid (%)**	**Fixed carbon (%)**
Poultry dropping	10.73	7.18	70.46	15.77
Water hyacinth	9.26	64.22	64.89	13.38
Orange mesocarp	6.83	9.76	58.14	11.94

Table 3. Carbon/Nitrogen ratio content of the organic wastes.

Parameter	**Poultry droppings**	**Water hyacinth**	**Orange mesocarp**
Carbon : Nitrogen	12.7 : 1	12.2 : 1	32.5 : 1

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Certificate of Analysis

NAME OF CLIENT:	Mr. Justice Emmanuel
NO. OF SAMPLE (S):	3
SAMPLE TYPE:	Solid waste
ANALYSIS REQUIRED:	Proximate & Ultimate Analysis
REPORTING DATE:	19/07/2024

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Plate 1. The procedure of laboratory analysis and results.

3. RESULTS AND DISCUSSION

The characterization (which involves the Ultimate and Proximate Analyses) of organic wastes: PD, WH, and OM were taken in separate containers to Austino Research & Analysis Laboratory located at No. 2 University of Port Harcourt Teaching Hospital (UPTH) Road, Alakahia, Junction, Opposite Alakahia Motor Park, Behind Jovit Restaurant, Alakahia Port Harcourt, Rivers State of Nigeria.

Table 1 above shows the elemental properties (such as hydrogen, nitrogen, carbon, sulphur, and oxygen) available in the organic wastes, namely poultry droppings, water hyacinth, and orange mesocarp, through the investigation of ultimate analysis. Table 2 above indicates the ash, moisture, volatile matter, and fixed carbon contents of the three organic wastes mentioned above.

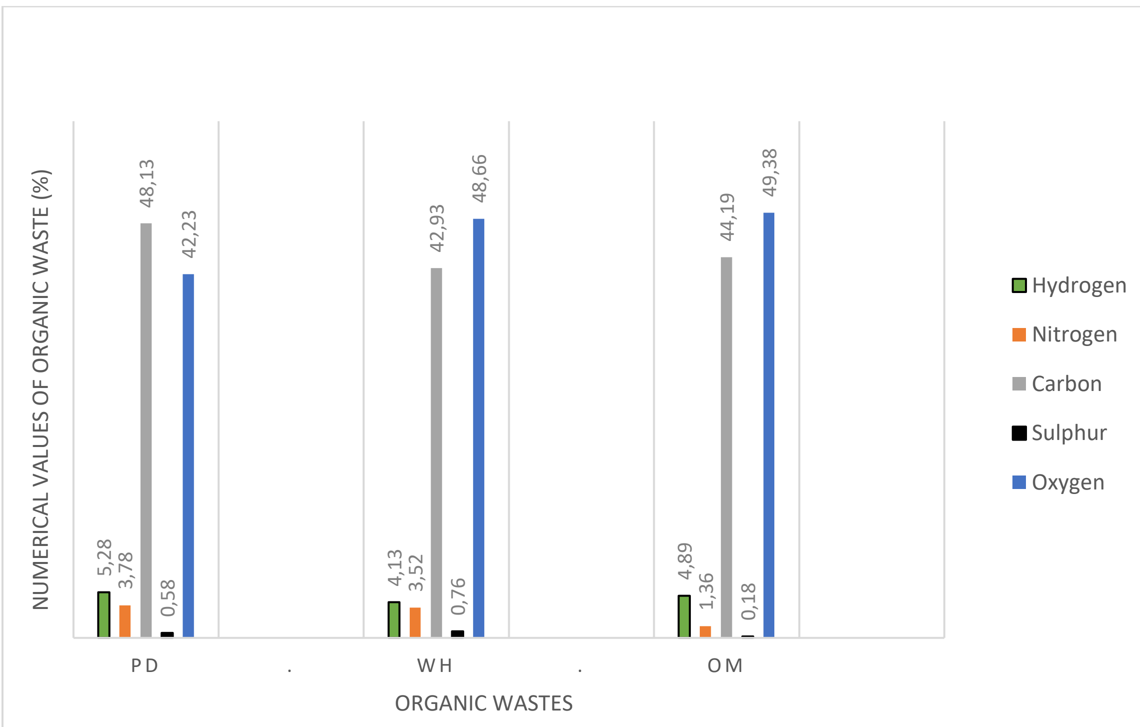

Figure 1. Graphical representation of elemental properties of the organic wastes.

Figure 1 above is a graphical representation of the percentage elemental content of the various organic wastes used in this study. Basically, poultry droppings contains 5.28 percent of hydrogen, 3.78 percent of nitrogen, 48.13 percent of carbon, 0.58 percent of sulphur, and 42.23 percent of oxygen. Water hyacinth contains 4.13 percent of hydrogen, 3.52 percent of nitrogen, 42.93 percent of carbon, 0.76 percent of sulphur, and 48.66 percent of oxygen, while the orange mesocarp contains 4.89 percent of hydrogen, 1.36 percent of nitrogen, 44.19 percent of carbon and finally 49.38 percent of oxygen. The determination of these factors is imperative as it used to find out the extent an organic waste can be toxic to the environment, or material-friendly and/ or raw biogas packed. It indispensably shows the extent and method of upgrading that is imminent to achieve best result.

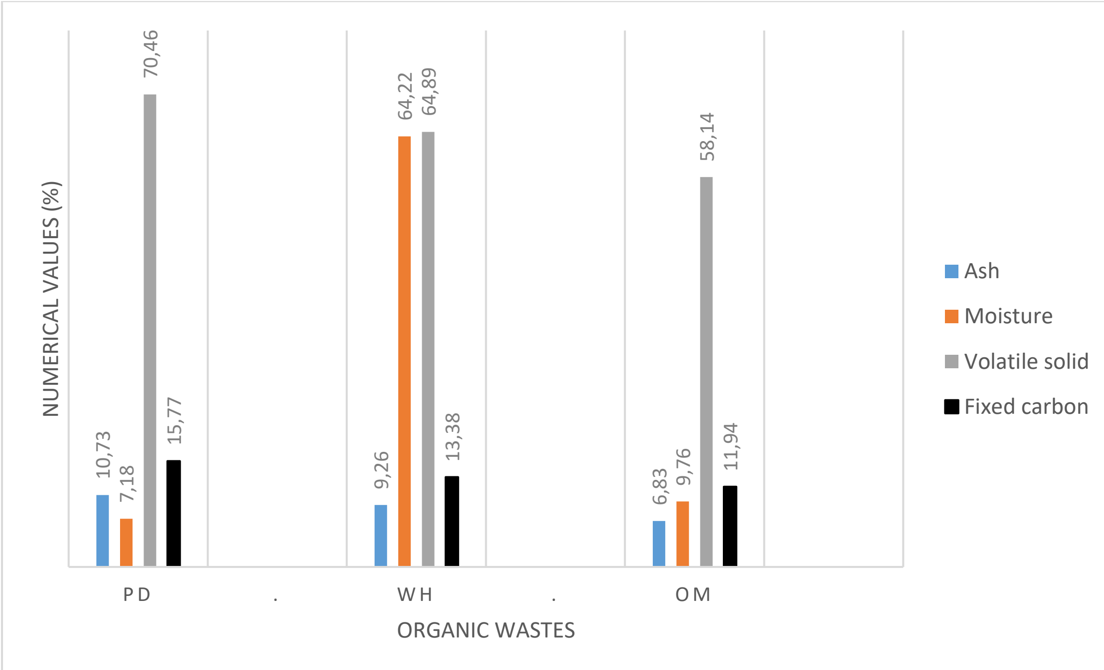

Figure 2. Availability of basic biogas influencing properties of the organic wastes.

Figure 2 is a display of basic biogas yield influencing properties in percentage. These factors have vital effect on the extent an organic waste can be biodegradable and can produce or yield biogas during anaerobic digestion process. These properties basically affect the duration an organic waste can remain useful in the bioreactor, and they are ash, moisture, volatile solid, and fixed carbon. In an anaerobic digestion system, sample or organic waste with higher volatile solid characterizes a longer hydraulic retention time (HRT) thus, correspondingly, portrays longer useful fermentation and production period.

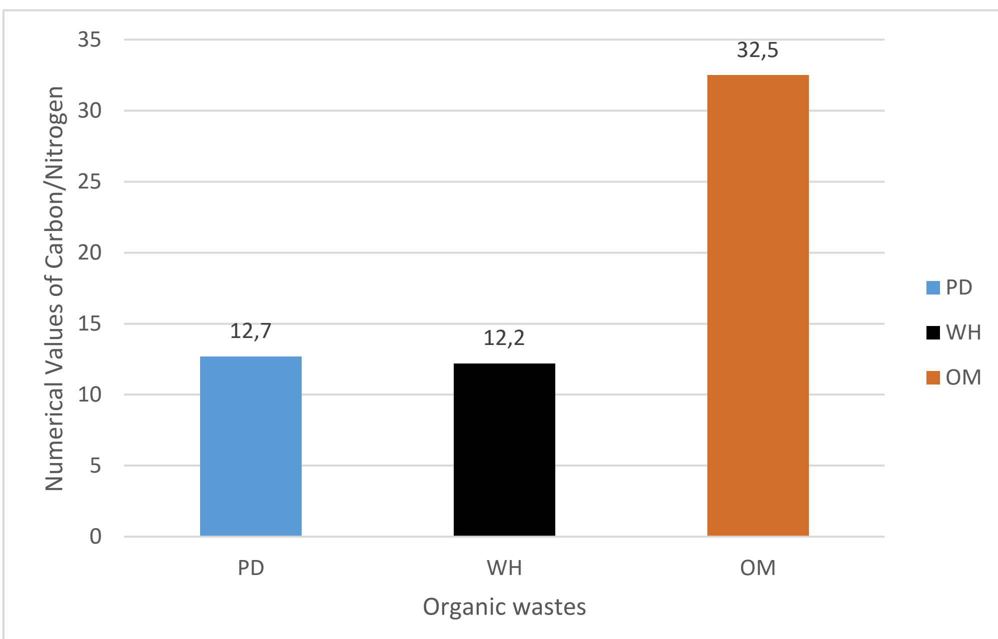

Figure 3. Graphical representation of Carbon/Nitrogen ratio of the three organic wastes.

Figure 3 above is a graphical representation of carbon/nitrogen ratio of each organic waste: poultry droppings, water hyacinth, and orange mesocarp used in this study. Carbon/nitrogen ratio is a paramount factor that encourages stable biogas production during anaerobic digestion process. Carbon is a viable energy source, while nitrogen is a good recipe for fermentation and microbial growth of the organic waste. Considering this, carbon/nitrogen ratio strikes a good balance and stands at a center stage to composting science and biogas production yield of a particular organic waste or substrate.

4. CONCLUSION

The results emanating from the laboratory investigation of the three organic wastes were plotted on bar diagrams to display the extent they behave or available in the different organic wastes. However, this investigation is paramountly important to precede any anaerobic digestion, biotechnological activity, or study to disclose the biological and elemental properties of the organic substances. Laboratory investigation also helps in educating us about the effect of certain organic waste on the environment, which would involve different ecosystems, human beings, and engineering materials.

Characterization of organic substances or materials has the capacity of directing us on how to use microorganisms to convert raw biological matters or materials into required output or product. It is indispensable to ensure characterization precede waste water treatment, biogas production from anaerobic digestion, solid waste management, bioremediation, or cleaning of polluted soil or water, and many others.

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