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Research article

Design of experiments to evaluate pH and temperature parameters with different inoculums in domestic biodigester

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ABSTRACT

The comprehensive management of organic urban solid waste is a concern due to its direct and indirect impact on the environment. Anaerobic Digestion (AD) has been recognized as an alternative and environmentally friendly technology for waste disposal, converting them into organic fertilizers and renewable energy. This research presents an experiment involving four reactors fed with household organic waste, three inoculated with canine, goat, and rabbit manure, and one without inoculum. The experiment was observed for 30 consecutive days to analyze the pH and temperature parameters involved in the AD process in domestic reactors. Statistical methodology, including one-way analysis of variance for assessing the effect of the type of inoculum, Tukey's simultaneous confidence intervals for mean differences, and 90 % confidence intervals for μ in temperature and manure, was utilized. Additionally, main effects analysis of the factors of average temperature and pH were conducted. The results of the one-factor experiment show that the type of inoculum does not significantly influence the variation in pH, while temperature remains relatively stable throughout the AD process. However, the analysis of main effects indicates that goat manure tends to stabilize the temperature with minimal variation, whereas variation is more heterogeneous in the other experiments.

1. Introduction

Nowadays, the World Bank estimates that waste generation by 2025 will reach 3,400 million tons, with 33 % of this waste being inadequately managed, receiving no treatment, of which 50 % corresponds to organic waste [1]. Different methods reported in the literature such as aerobic composting, landfills, incineration, anaerobic digestion, and others are used for the treatment of organic waste [2]. Anaerobic Digestion (AD) has been recognized as an environmentally friendly technology for converting food waste into renewable energy and organic fertilizers [3].

The AD is the biological decomposition of organic matter where hydrolytic, acetogenic, and methanogenic bacteria work in coordination to convert it into methane and carbon dioxide [4], this process is typically executed in a vessel that provides a uniform environment for microorganisms to grow and maintain equilibrium in biochemical reactions. Therefore, reactors can be designed or

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Table 1
Raw materials in the reactors.

R1	R2	R3	R4	kg
Organic Matter	Organic Matter	Organic Matter	Organic Matter	12
Canine Manure	Goat Manure	Rabbit Manure	Without Manure	9
Rain water	Rain water	Rain water	Rain water	15

manufactured based on the growth requirements of the organisms used for biotransformation and bioconversion into desirable products [5], the obtained result of this process includes biogas and organic compost [6]representing an alternative for the treatment of organic waste and the reduction of greenhouse gas emissions. It is worth noting that the AD process is influenced by various factors. Temperature plays a crucial role as it determines the thermodynamic balance of biochemical reactions, while pH serves as a critical factor and an indicator of system stability. The Carbon-to-Nitrogen (C/N) ratio is another important aspect where Carbon acts as an energy source while Nitrogen aids in cellular structure development. Additionally, Hydraulic Retention Time (HRT) represents the average amount of time the raw material will remain in the reactor, while Inoculum maintains system stability and accelerates the digestion process. Research has shown that utilizing the appropriate inoculum and substrate can enhance biogas production, increase the disintegration rate, thus promoting stable AD. However, these factors require defined control to prevent adverse effects on the involved microorganisms [3,4,7–9]. The incorporation of animal manure in the AD process allows for the implementation of better standard practices in the efficient disposal and effective management of Organic Solid Waste (OSW), thus mitigating greenhouse gas emissions and reducing diseases caused by water and soil pollution [10].

Several studies propose experimenting with AD using unsorted food waste, employing bovine manure as an inoculum [6,11,12]. In Ref. [13] a biodigester with passive heating fueled by waste from a university restaurant plus pig manure with rainwater was designed, while [14] utilized waste from a university cafeteria, chicken manure, and wastewater sludge.

In Africa, experiments were also conducted with unsorted household waste and bovine manure [12,15]. In Nigeria, organic waste from a university cafeteria, chicken manure, and wastewater sludge were used [14]. In Ref. [16] utilized kitchen waste, Tithonia diversifolia leaves, and bovine manure. In India, organic waste from a community hostel, bovine manure, and water were incorporated; in another similar study, cardboard and sludge from wastewater treatments were added [11,17,18]. In Italy [19] experimented with food waste and previously treated animal manure, while in China, waste from a university restaurant was utilized, inoculated with sludge from a wastewater treatment plant [20].

For the analysis of parameters in AD, various studies such as [19] assess differences between samples within each microbial group using a one-way Analysis of Variance (ANOVA) and Duncan's post hoc test for pairwise mean comparison. In Ref. [12] means, standard deviation, relevant grapHs, and application of one-way ANOVA were calculated. In Ref. [13] ANOVA was applied to measure the relationships between mass, methane percentage, and external temperature, along with Tukey's significant difference tests for methane measurement at different stages. In Ref. [21] correlation analysis was conducted between different Hydraulic Retention Times (HRT) tested and the performance of each system in terms of methane production and efficiency. Additionally, means of methane yields and HRT reduction were compared. In Ref. [3] a descriptive analysis of means and standard deviation of their samples was conducted. They also performed correlation analysis between the parameters and methane concentration using a multiple linear regression model.

This research presents a biodigester experimental setup involving three types of inoculums: canine, goat, and rabbit manure, along with one control without inoculum. The objective was to assess the pHysicochemical parameters of pH and temperature in anaerobic digestion (AD) observed in four biodigesters fed with household organic waste. To know the impact of the inoculum type on these parameters, a statistical methodology involving a single-factor experimental design and analysis of main effects of the average °C and pH was applied. The results of the analysis of variance of fixed effects, simultaneous Tukey intervals for mean differences, and 90 % confidence intervals for the population mean μ show that the type of inoculum does not significantly influence pH variation, and the temperature remains relatively stable throughout the AD process. However, principal component analysis of temperature and pH indicates that the goat inoculum tends to stabilize temperature with minimal variation compared to the other experiments, where variation is more heterogeneous.

2. Materials and methods

2.1. Reactors materials

For the construction of the reactors, four 19-L plastic containers were utilized, along with 6 m of gas hose and various fittings including: four pieces each of terminal nipples ½ x 3/8, Galu tee ½, red bushing ½ x ¼, ½-inch threaded nipples, ½-inch flanges, ¾-inch PVC threaded ball valve, ¾-inch threaded nipples, ¾-inch flanges, wheelbarrow chambers, 3/8-inch hose tee; six 2-inch PVC pipes (meters), two 2-inch couplings, two 2-inch caps, 24 clamps, two silicones, two Teflon tapes. For measurement purposes, four DS18B20 submersible temperature sensors, a computer, an Arduino uno, and 120 PH test strips were utilized.

The substrate comprised a mixture of organic household waste (vegetable residues such as lettuce, tomato, onion, tortillas, eggs, chili peppers, pineapple, apple, carrots, parsley, rice, ground beef, and spices) collected from homes over a week. This waste primarily originated from meal preparation and leftovers; and for statistical analysis, Minitab version 20 statistical software was employed.

Once the Organic Matter (OM) was characterized, it was triturated in a home blender for 4 min until reaching a particle size smaller

Fig. 1. Household reactors fed with organic waste.

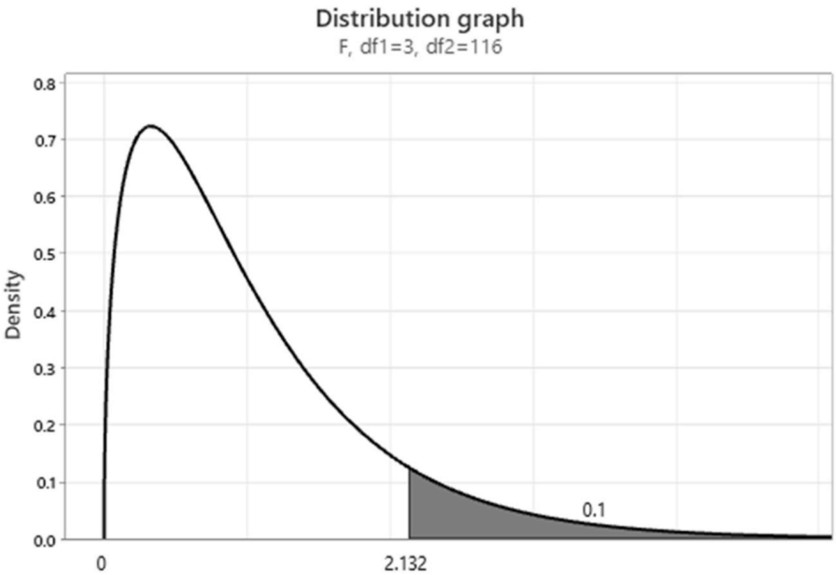

Fig. 2. Distribution grapH F.

than 10 mm. For each of the inoculated reactors, the material was diluted in 9 L of rainwater, three kg of manure, and OM. In contrast, in the uninoculated reactor, only 9 L of rainwater and six kg of OM were added. The reactors were operated at a Hydraulic Retention Time (HRT) of 30 consecutive days, as shown in Table 1.

2.2. *Methodology*

To know the effect of the inoculum type on anaerobic digestion (AD), experimentation was conducted in four reactors over 30 consecutive days, as shown in Fig. 1 and Fig. 2.

The statistical methodology of one-factor fixed-effects analysis of variance was applied [22,23] in the PH factors, morning °C and evening °C, Tables 2, 4 and 6, simultaneous Tukey intervals for mean differences, confidence intervals for μ morning and evening ° per type of inoculum, equation (2), and analysis of main effects of two factors in Table 8, equations (2)–(4).

2.2.1. *Unifactorial fixed effects analysis of variance*

To compare treatments or levels of a single factor. The response observed in each of the treatments is a random variable. The data would appear as in Tables 2–7, with an entry y_{ij} with an entry j-th observation of treatment i, and n observations for treatment i [23].

Table 2
Typical data for an unifactorial experiment of pH factor.

Treatment	Observations																														Totals	Average
PH_R1	5	6	7	5	5	6	6	7	7	7	7	8	8	7	8	8	8	8	8	8	8	8	8	9	9	8	8	8	9	8	222	7.40
PH_R2	6	8	6	6	6	8	8	8	7	8	7	8	8	7	7	8	7	7	8	7	8	8	8	8	7	9	9	7	8	8	225	7.50
PH_R3	7	6	6	6	6	7	8	8	6	7	8	8	8	6	8	8	8	7	6	8	8	7	8	8	8	8	8	8	8	8	221	7.37
PH_R4	6	8	5	7	5	6	7	8	7	8	9	8	8	7	7	8	7	8	8	8	6	7	8	8	8	9	8	8	8	8	223	7.43

Table 3
Unifactorial fixed effects analysis of variance for PH.

a) Hypothesis formulation

$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$
$H_1: Not\ all\ means\ are\ equal$

$\mu_1: Mean\ PH\_R1\ with\ canine\ inoculum$
$\mu_2: Mean\ PH\_R2\ with\ caprine\ inoculum$
$\mu_3: Mean\ PH\_R3\ with\ rabbit\ inoculum$
$\mu_4: Mean\ PH\_R4\ without\ inoculum$

b) Significance Level α=0.1

c) Calculate the critical value F = $F_{0.05,4-1,120-4}$=2.132, figure 2.

d) Calculate F_0, **by unifactorial fixed effects** ANOVA

Source of Variation	**Squares Sum**	**Degrees of Freedom**	**Squares mean**	**F_0**	**Valor de P**
Between treatments	$SS_{Treatments}$=0.292	a-1=3	$MS_{Treatments}$=0.09722	0.11	0.957
Error (In treatments)	SS_E=107.033	N-k=116	MS_E=0.92270		
Total	SS_T=107.325	N-1= 119			

$SS_{Treatments}$: Sum of Squares Treatments

$$SS_{\text{Treatments}} = \sum_{i-1}^{a} \frac{y.^2}{n} - \frac{y..^2}{N}$$

SS_T: Square total sum

$$ss_T = \sum_{i-1}^{a}\sum_{j-1}^{n} y_{ij}^2 - \frac{y..^2}{N}$$

SS_E: Error square sum

$$ss_E = ss_T - ss_{\text{Treatments}}$$

a-1: Treatments minus one

N: Total number of treatments observations

$MS_{treatments}$: Mean Square due to Treatments

MS_E: Mean Square due to Error

2.2.2. Simultaneous Tukey intervals at 90% confidence for the difference of means

To complement the unifactorial fixed effects analysis of variance, the Tukey test was applied which declares a pair of means Y ̅_(i.)-Y ̅_(j.) significantly different, if the interval does not include zero, equation (1), Table 8.

$$\left(\underline{Y_i}-\underline{Y_j}\right)\text{-HSD} \le \mu_i\text{-}\mu_j \le \left(\underline{Y_i}-\underline{Y_j}\right) + \text{HSD} \tag{1}$$

where:

$$HSD = q_\alpha; I, N - I\sqrt{\frac{\widehat{S}_R^2}{n}}, \widehat{S}_R^2 = \sqrt{\frac{MSE}{n}}$$

I: Pairs of means; N: Total of data; $\widehat{S}_R^2$: Estimation of variance; *n*: Mean sample size; $N - I$: Number of degrees of freedom associated with $\widehat{S}_R^2$; $\underline{Y}_{i.}$: Grand mean; $\underline{Y}_{j.}$: Least significant mean; α: Significance Level; y $q = \frac{Y_{max} - Y_{min}}{\sqrt{\frac{MSE}{n}}}$.

2.2.2.1. 90 % confidence interval for μ for morning °C by type of inoculum, Fig. 3. $\underline{X}$: Observed sample mean.

Z = ±1.645 standard deviations, Fig. 3.

α: Margin of error.

Table 4
Typical data for an unifactorial effects experiment of the morning °C factor.

Treatment	Observations																														Totals	Average
°C M_R1	23	22	22	21	21	23	21	22	22	22	20	23	22	22	21	21	21	22	26	24	21	22	23	21	20	20	22	21	21	22	651.86	23.28
°C M_R2	23	22	21	21	20	22	21	21	22	22	21	23	21	22	21	22	22	22	25	24	21	22	23	21	20	21	22	21	21	22	652.45	23.30
°C M_R3	22	21	21	21	20	23	21	22	23	22	22	23	21	21	20	22	21	21	27	25	21	22	23	21	21	20	21	21	21	22	652.77	23.31
°C M_R4	23	23	22	21	20	23	21	21	22	22	21	23	22	22	21	22	22	22	25	25	22	22	24	22	20	21	22	21	22	23	659.68	23.56

Table 5
Unifactorial fixed effects analysis of variance for °C morning.

e) Hypothesis formulation

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$
$$H_1: Not\ all\ means\ are\ equal$$
$$\mu_1: Mean\ °C\ M\_R1\ with\ canine\ inoculum$$
$$\mu_2: Mean\ °C\ M\_R2\ with\ caprine\ inoculum$$
$$\mu_3: Mean\ °C\ M\_R3\ with\ rabbit\ inoculum$$
$$\mu_4: Mean\ °C\ M\_R4\ without\ inoculum$$

f) Significance level α=0.1

g) Calculate the critical value F = $F_{0.05,4-1,120-4}$=2.132

h) Calculate F_0, **by unifactorial fixed effects** ANOVA

Source of Variation	**Squares Sum**	**Degrees of Freedom**	**Squares mean**	**F₀**	**Valor de P**
Between treatments	$SS_{Treatments}$=1.354	a-1=3	$MS_{Treatments}$=0.4513	0.32	0.810
Error (In treatments)	SS_E=162.613	N-k=116	MS_E=1.4018		
Total	SS_T=163.967	N-1= 119			

S: Sample standard deviation.
n = 30 observations.
μ: Population mean parameter.

2.2.2.2. *90 % confidence interval for μ for evening °C by type of inoculum*

$$23.34 - 1.645\left(\frac{1.004}{\sqrt{30}}\right) \le \mu \le 23.35 + 1.645\left(\frac{1.004}{\sqrt{30}}\right) = 23.055 \le \mu \le 23.367°C \text{ CI canine inoculum}$$

$$23.21 - 1.645\left(\frac{0.824}{\sqrt{30}}\right) \le \mu \le 23.35 + 1.645\left(\frac{0.824}{\sqrt{30}}\right) = 22.922 \le \mu \le 23.503°C \text{ CI goat inoculum}$$

$$23.09 - 1.645\left(\frac{0.997}{\sqrt{30}}\right) \le \mu \le 23.09 + 1.645\left(\frac{0.997}{\sqrt{30}}\right) = 22.802 \le \mu \le 23.384°C \text{ CI rabbit inoculum}$$

$$23.54 - 1.645\left(\frac{1.005}{\sqrt{30}}\right) \le \mu \le 23.54 + 1.645\left(\frac{1.005}{\sqrt{30}}\right) = 23.249 \le \mu \le 23.830°C \text{ CI not inoculum}$$

2.2.3. *Main effects analysis*

In factorial design, it is important to conduct the analysis of main effects by comparing the effect among the levels of a factor A (Average °C) averaged across all levels of another factor B (PH), by calculation (2–4).

$$Mean\ de\ A_1\ for\ both\ level\ of\ B_1 : \mu_1 = \frac{1}{2}(A_1B_1 + A_1B_2) \tag{2}$$

$$Mean\ de\ A_2\ for\ both\ level\ of\ B_2 : \mu_1 = \frac{1}{2}(A_2B_1 + A_2B_2) \tag{3}$$

$$\text{Principal Effect} : \mathrm{I}_3 = \frac{1}{2}(\mathrm{A}_2\mathrm{B}_1 + \mathrm{A}_2\mathrm{B}_2) - \frac{1}{2}(\mathrm{A}_1\mathrm{B}_1 + \mathrm{A}_1\mathrm{B}_2) \tag{4}$$

For calculating the main effects of the factor average °C vs factor PH_R1; Average °C vs PH_R2; Average °C vs PH_R3 and Average °C vs PH_R4 was done the procedure by Table 9.

Table 6
Typical data for an unifactorial experiment of the vespertine °C factor.

Treatment	Observations																														Totals	Average
°C V_R1	25	25	24	22	24	24	24	25	24	25	25	24	23	22	23	23	23	23	22	23	24	23	21	22	22	23	24	23	22	23	700.38	23.35
°C V_R2	25	25	23	23	24	23	24	24	23	24	24	24	23	22	23	22	23	23	22	23	24	23	22	22	22	23	24	23	22	23	696.37	23.21
°C V_R3	24	25	23	22	24	23	24	25	23	24	24	24	23	22	23	22	23	24	22	23	24	23	21	22	22	23	25	23	22	23	692.79	23.09
°C V_R4	25	25	24	22	24	23	25	25	24	25	25	24	23	23	24	23	23	23	23	24	25	24	21	21	22	24	25	24	23	23	706.19	23.54

Table 7
Unifactorial fixed effects analysis of variance for evening °C.

i) Hypothesis formulation

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$$
$$H_1: Not\ all\ means\ are\ equal$$
$$\mu_1: Mean\ °C\ C\_R1\ with\ canine\ inoculum$$
$$\mu_2: Mean\ °C\ C\_R2\ with\ caprine\ inoculum$$
$$\mu_3: Mean\ °C\ C\_R3\ with\ rabbit\ inoculum$$
$$\mu_4: Mean\ °C\ C\_R4\ without\ inoculum$$

j) Significance level α=0.1

k) Calculate the critical value F = $F_{0.05,4-1,120-4}$=2.132

l) Calculate F_0, by unifactorial fixed effects ANOVA

Source of Variation	Squares Sum	Degrees of Freedom	Squares mean	F_0	Valor de P
Between treatments	$SS_{Treatments}$=3.302	a-1=3	$MS_{Treatments}$=1.1007	1.19	0.316
Error (In treatments)	SS_E=107.011	N-k=116	MS_E=0.9225		
Total	SS_T=110.313	N-1= 119			

Table 8
Tukey's 90 % simultaneous CIs °C morning.

Factor	Estimation	CIs
°C M_R2 - °C M_R1	0.0196667	−0.689360, 0.728693
°C M_R3 - °C M_R1	0.0303333	−0.678693, 0.739360
°C M_R4 - °C M_R1	0.260667	−0.448360, 0.969693
°C M_R3 - °C M_R2	0.0106667	−0.698360, 0.719693
°C M_R4 - °C M_R2	0.241	−0.468026, 0.950026
°C M_R4 - °C M_R3	0.230333	−0.478693, 0.939360

3. Results

The results of the statistical analysis in the experimentation show:

3.1. Unifactorial fixed effects analysis of variance for pH

3.1.1. Experiment PH distribution

The distribution of pH in the anaerobic digestion inoculated with canine, goat manure, and without inoculum shows that 25 % ranges between $6 \leq pH < 7$, 50 % $7 \leq pH \leq 8$ and 25 % $8 < pH \leq 9$. On the other hand, the pH at the DA with rabbit manure presents 25 % between $6 \leq pH < 6.75$ and the 75 % oscils $6.75 \leq PH \leq 8$. According to the previous results, the pH distribution is ideal in the anaerobic digestion. However, the rabbit manure inoculation presents less variation, as shown in Fig. 4.

3.1.2. Unifactorial fixed effect analysis of variance for pH

The results of the ANOVA test indicate acceptance $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$ with 90 % of confiability, what is observed is that the type of inoculum does not significantly influence the variation of pH in the AD process, corroborated by the simultaneous Tukey confidence interval, Fig. 5.

3.2. Analysis of unifactorial fixed effects variance for morning °C

The results indicate acceptance $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$, this means that the temperature remains without significant variations in

Table 9
Calculation of main effects.

PH_R1	Average °C	Principal Effect	PH_R2	Average °C	Principal Effect	PH_R3	Average °C	Principal Effect	PH_R4	Average °C	Principal Effect
6	22.64		6	20.41		6	20.41		6	21.05	
6	21.47	21.72	6	21.05	21.39	6	21.05		6	21.39	21.69
6	21.05		6	21.47		6	21.39	21.47	6	22.64	
7	21.94		6	22.64		6	21.47		7	20.41	
7	20.41		7	20.56		6	21.73		7	20.56	
7	22.56	21.40	7	21.21		6	21.94		7	20.72	
7	20.72		7	21.48		6	22.34		7	21.47	21.41
7	21.57		7	21.56		7	21.36		7	21.61	
7	21.21		7	21.65	21.58	7	21.56		7	22.09	
8	22.34		7	21.73		7	21.81	21.99	7	23.00	
8	21.81		7	22.09		7	22.56		8	20.27	
8	23.00		7	22.34		7	22.64		8	21.21	
8	21.61		8	20.27		8	20.27		8	21.23	
8	21.73		8	20.52		8	20.52		8	21.33	
8	20.56		8	20.72		8	20.56		8	21.36	
8	21.33		8	21.33		8	20.72		8	21.42	
8	21.48		8	21.36		8	21.21		8	21.48	
8	21.56		8	21.39		8	21.23		8	21.56	
8	21.39	21.56	8	21.57	21.62	8	21.33		8	21.57	21.64
8	22.09		8	21.61		8	21.42	21.49	8	21.65	
8	20.27		8	21.81		8	21.48		8	21.73	
8	20.52		8	21.94		8	21.57		8	21.81	
8	21.65		8	22.56		8	21.61		8	21.94	
8	21.42		8	23.00		8	21.65		8	22.16	
8	22.16		8	23.05		8	22.09		8	22.56	
9	23.05		9	21.23		8	22.16		8	23.05	
9	21.36	21.88	9	21.42	21.60	8	23.00		9	20.52	21.43
9	21.23		9	22.16		8	23.05		9	22.34	

the AD process, Fig. 6.

3.2.1. *Distribution of morning temperature in the experimentation*

The distribution of confidence intervals in the morning temperature parameter $(21.370 \leq \mu \leq 22.087^{\circ}C)$. It remains constant among the reactors with inoculum; meanwhile, the temperature in the AD without inoculum increases from $(21.631 \leq \mu \leq 22.348^{\circ}C)$, Fig. 7.

3.3. *Unifactorial fixed effects analysis of variance for evening °C*

The results of the ANOVA test indicate acceptance $H_0 : \mu_1 = \mu_2 = \mu_3 = \mu_4$, this means that the means of the evening temperatures do not vary, Fig. 8.

3.3.1. *Distribution of the evening temperature in the experimentation*

The distribution of confidence intervals in the evening temperature parameter remains relatively constant, due to the variation of the temperature intervals is not significant, as shown in Fig. 9.

3.4. *Main effects analysis*

The main effects analysis between temperature and pH by type of inoculum indicates that a pH of 9 for canine manure raises the temperature to 21.87 °C, while that of goat manure stabilizes the temperature with minimal variation. It is noteworthy that optimal pH levels of 6, 7, and 8 were obtained in the AD process in the four reactors to generate biogas, and a pH close to 7 results in efficient digestion [7], Fig. 10.

4. Discussion

The experimental analysis of temperature and pH parameters in the AD of our four reactors led to the following significant findings. The results of the one-factorial fixed-effects analysis of variance and Tukey test show that inoculum type does not significantly influence pH variation, and temperature shows minimal variation, which is consistent with the observations made in different state-of-the-art works [6,13]. Regarding PH, it remained without significant variations PH-R1 = 7.4, PH-R2 = 7.5, PH-R3 = 7.37, and PH-R4 = 7.43 almost neutral which allows optimal DA initiation [15], and differs with [3,6] who in their experiment maintained a stable alkaline PH = 6.5. Concerning the type of inoculum [13], inoculated with pig manure to study the ambient temperature, the biogas quality, and the methane production. They found that the source of the inoculum affected the yield of AD and suggested conducting an

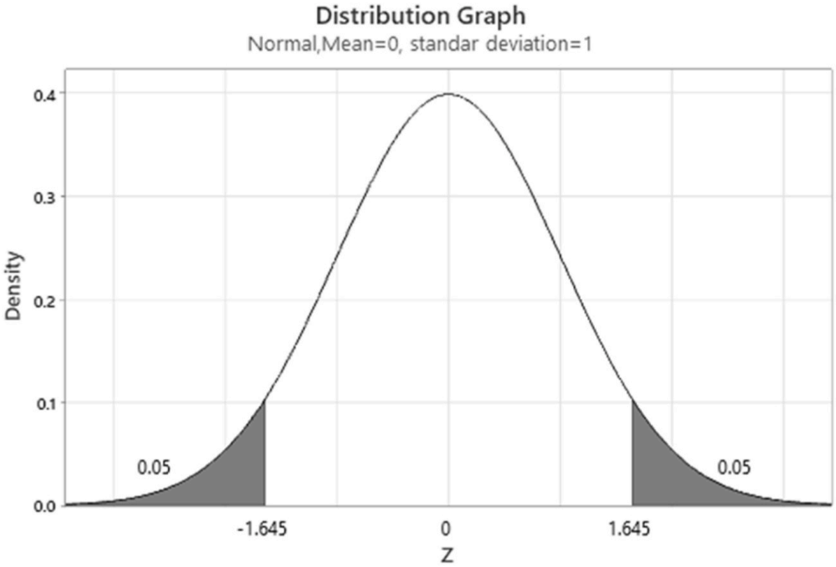

Fig. 3. Distribution grapH normal.

$$\underline{X} - Z_{\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right) \leq \mu \leq \underline{X} + Z_{\frac{\alpha}{2}}\left(\frac{S}{\sqrt{n}}\right) \tag{2}$$

$$21.73 - 1.645\left(\frac{1.206}{\sqrt{30}}\right) \leq \mu \leq 21.73 + 1.645\left(\frac{1.206}{\sqrt{30}}\right) = 21.370 \leq \mu \leq 22.807^{\circ}C \text{ CI canine inoculum}$$

$$21.75 - 1.645\left(\frac{1.026}{\sqrt{30}}\right) \leq \mu \leq 21.75 + 1.645\left(\frac{1.026}{\sqrt{30}}\right) = 21.390 \leq \mu \leq 22.107^{\circ}C \text{ CI goat inoculum}$$

$$21.76 - 1.645\left(\frac{1.413}{\sqrt{30}}\right) \leq \mu \leq 21.76 + 1.645\left(\frac{1.413}{\sqrt{30}}\right) = 21.401 \leq \mu \leq 22.117^{\circ}C \text{ CI rabbit inoculum}$$

$$21.99 - 1.645\left(\frac{1.050}{\sqrt{30}}\right) \leq \mu \leq 21.99 + 1.645\left(\frac{1.050}{\sqrt{30}}\right) = 21.631 \leq \mu \leq 22.348^{\circ}C \text{ CI not inoculum}$$

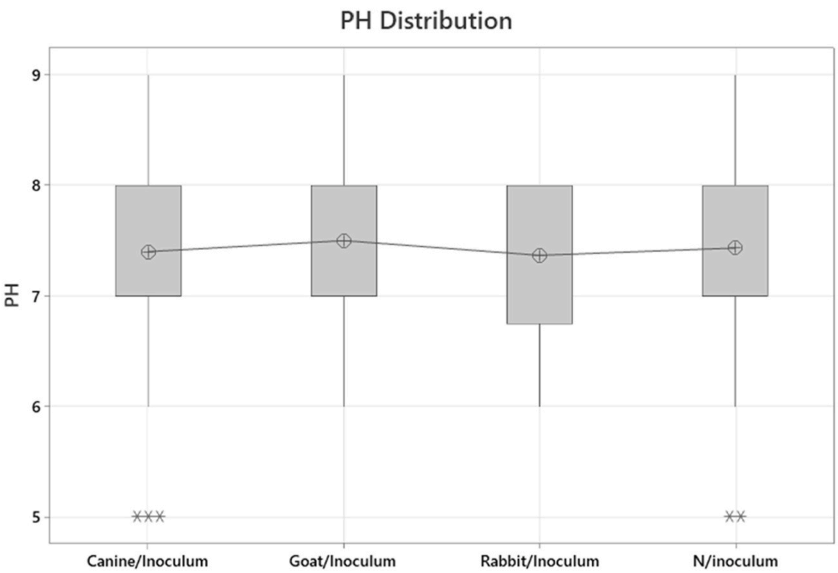

Fig. 4. pH/inoculum distribution.

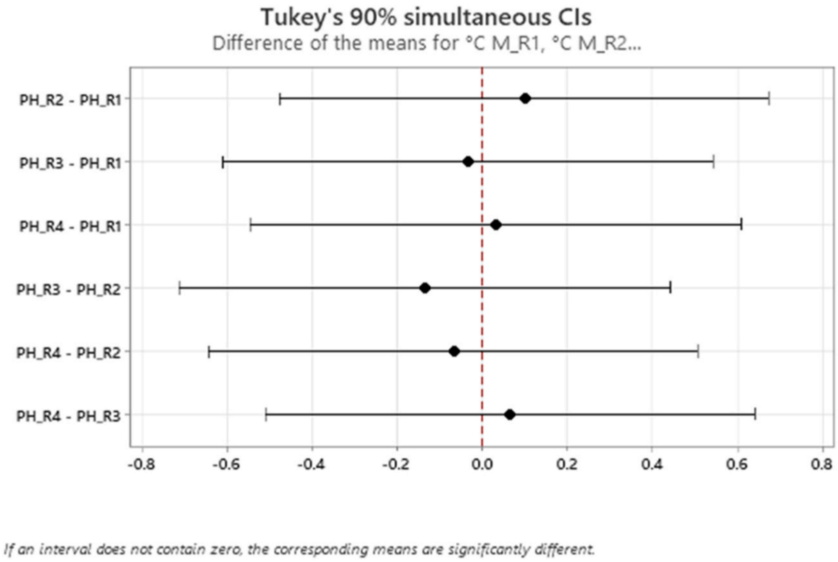

Fig. 5. Tukey's 90 % simultaneous CIs of pH.

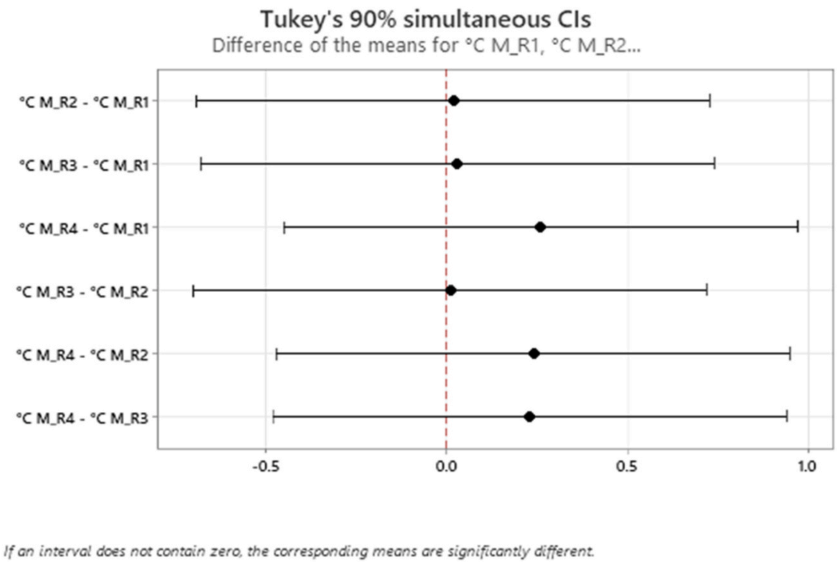

Fig. 6. Tukey's 90 % simultaneous CIs of °C morning.

in-depth analysis to determine the frequency of inoculation in the experiment. On the other hand [24], applied goat and cattle manure inoculum to analyze the relationship between pH and Hydraulic Retention Time using the non-linear regression technique. These two related works differ from our research on the inoculums used in the experimentation. Analyzing all the factors involved in the AD process will make it possible to control parameters, obtain stable digestate, and estimate methane production. Finally, domestic reactors represent an eco-technological alternative for the sanitation and management of organic waste that easily adapts to the lifestyle of the population [6,25].

5. Conclusions

It should be noted that the experiment involved four treatments: canine, goat, rabbit manure, and a control without manure in domestic reactors. These reactors were fed with unsorted household organic waste and rainwater, facilitating the evaluation of the effects of each type of inoculum on the AD process. The unifactorial fixed effect analysis of variance showed that the type of inoculum does not influence the pH and temperature parameters. However, the analysis of main effects of the °C average and pH indicates that the goat inoculum tends to stabilize the temperature with minimal variation, while in the other experiments, the variation is more

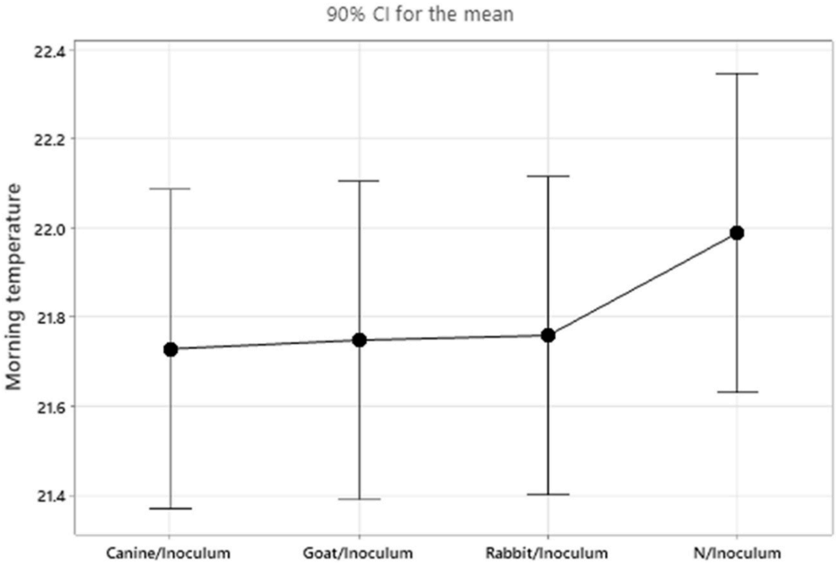

Fig. 7. Inference temperature by type of inoculum.

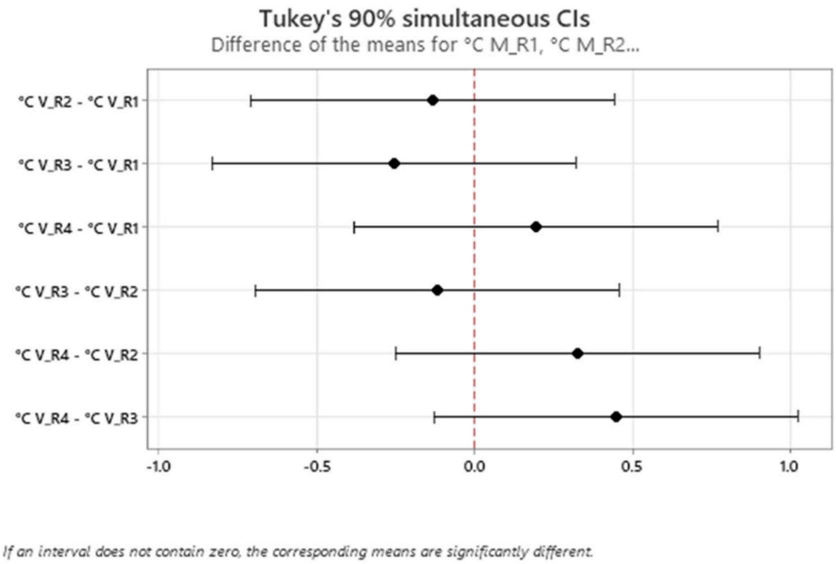

Fig. 8. Tukey's 90 % simultaneous CIs of °evening.

heterogeneous. It is worth mentioning that the research is ongoing, and all four treatments are being experimented with for observation, recording, and analysis of other factors that intervene in AD to establish the efficiency of the domestic reactor.

Another significant finding of the study was that the inoculum, when interacting with the temperature factor, does influence the AD process.

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Statement of informed consent

Informed consent was obtained from all subjects involved in the study.

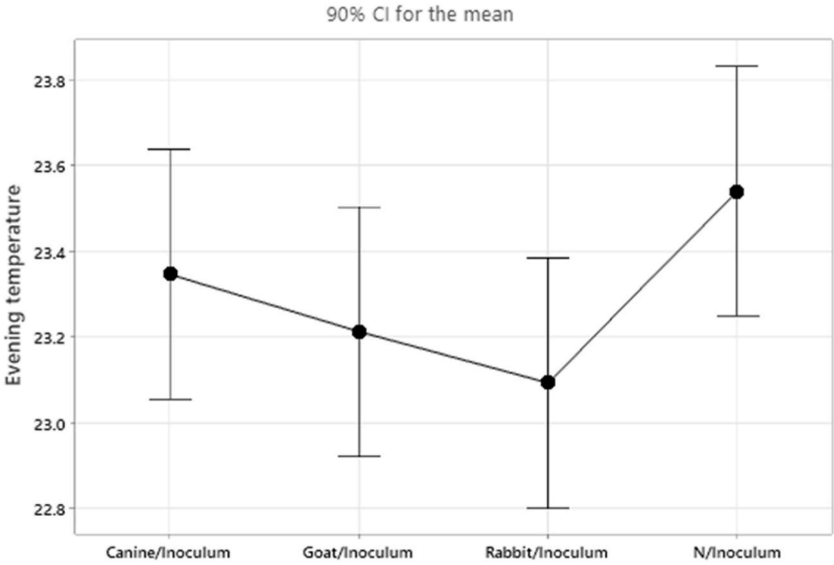

Fig. 9. Inference evening temperature by type of inoculum.

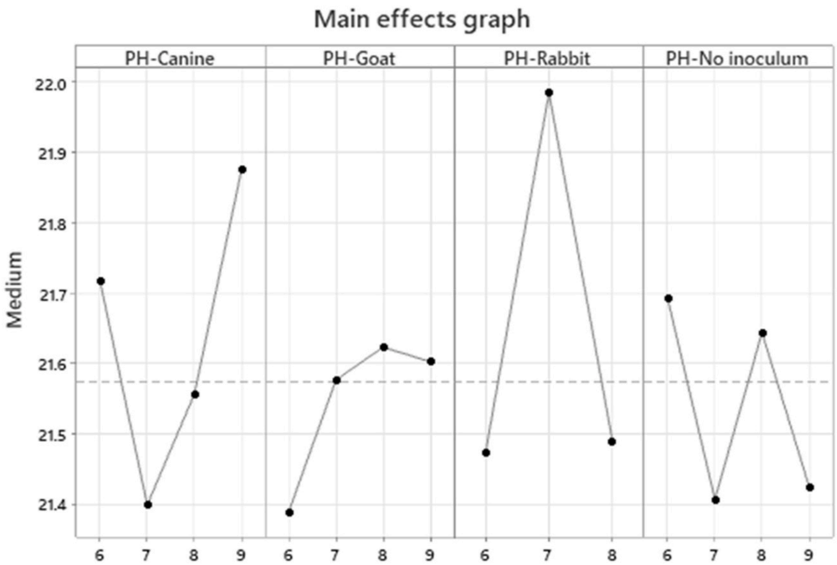

Fig. 10. PH/temperature effect.

Data availability statement

The study's data will be available in the repository of the National Technological Institute of Mexico/Technological Institute of Chilpancingo https://rinacional.tecnm.mx/handle/TecNM/149.

CRediT authorship contribution statement

L. Gómez-Muñoz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation. **C. Morales-Morales:** Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation. **M. Castro-Bello:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **A. González-Lorence:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Conceptualization. **C.V. Marmolejo-Vega:** Writing – original draft, Validation, Supervision, Investigation, Formal analysis. **S.R. Zagal-Barrera:** Writing – review & editing, Writing – original draft, Validation, Software, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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