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RESEARCH ARTICLE

PHYSICAL AND CHEMICAL CHARACTERIZATION OF THE COMPOSTING PROCESS PREPARED WITH BORA (*Eichhornia crassipes*), COFFEE HUSK AND GARDEN WASTE

MAGALYS RIVAS-NICHORZON[1], RAMÓN SILVA -ACUÑA[2], NICOLETA-MARICICA MAFTEI[3], ANA-MARIA PELIN[3], ANA RAMOS-VILLARROEL[4*]

[1]Water and soil laboratory, Juanico campus, School of Agricultural and Environmental Sciences. University of Orient, Monagas, Venezuela, magalysrivas@gmail.com
[2]Postgraduate in Tropical Agricultura, University of Orient, Juanico campus, Maturín. Venezuela, drramonsilvaa@gmail.com
[3]Department of Pharmaceutical Sciences, Faculty of Medicine and Pharmacy, "Dunarea de Jos" University of Galati, Galati, Romania, naron@ugal.ro, anapelin@gmail.com
[4]Laboratory Assessment and Use of Marine Resources, Venezuelan Institute of Scientific Research, Center of Oceanology and Antartic Studies, Venezuela, ay2170@gmail.com

*Corresponding author: ay2170@gmail.com (Ana Yndira Ramos Villarroel)

Abstract: The physical and chemical characteristics of compost vary with the handling conditions, type of material used in its preparation, and environmental conditions, therefore it is important to monitor the evolution of the composting process. The objective of this work was to evaluate the temperature at two depths in the pile, pH, organic matter (OM), organic carbon (CO), total nitrogen (TN), carbon/nitrogen ratio (C/N); electrical conductivity (EC) and the contents of phosphorus (P) and potassium (K) during the composting process of substrates based on bora, coffee husk and garden waste. The quantified values were examined by analysis of variance, the statistical design used was random blocks with repeated measurements over time, the treatments evaluated came from a 3x3 factorial arrangement, types of compost and evaluation times, respectively, and four repetitions. Three days after the composting process began the highest temperature values were obtained, corresponding to the thermophilic stage that lasted for five days, and the maturation phase began 45 days into the process. The values of pH, electrical conductivity and K varied depending on time and type of compost. The variables pH, percentages of OM, CO, C/N ratio and P content decreased during the composting process, while EC increased.

Keywords: compost, organic waste, quality

Introduction

Organic fertilizers improve the physical, biological and chemical characteristics of soils (ICA, 2015) and have been classified mainly as fertilizer, substrate or amendments (Campos-Rodriguez *et al*., 2016).

Among the techniques to make humus, there is composting., which is the aerobic biological process, where microorganisms act quickly on organic remains, which allow the obtainment of "compost", an excellent quality fertilizer for agriculture (Espinosa *et al*., 2017; Maestripieri, 2022). There are three types of raw materials used to make compost, the first supply energy, others volume and the third provide a combination of both (Freire ad Aroca, 2021).

The word compost comes from Latin, it means to gather; therefore, compost is the set of organic remains that undergoes a fermentation process, obtaining a dark brown, odorless or humus-smelling product (Simpson, 2011).

Compost increases the content of nitrogen, phosphorus, potassium and micronutrients, similarly, the cation exchange capacity (C.I.C); In addition, it is a source of storage of nutrients for crops (Morais *et al*., 2019; Olieira and Amaral, 2019).

Various stages occur during composting: the initial stage or mesophilic, the thermophilic and maturation stages (Alves *et al*., 2023). In the initial stage the temperature rises very quickly to 40°C. Depending on the source product for the compost and the environmental conditions, the thermophilic stage usually lasts a week in accelerated systems, and one to two months in slow fermentation systems. During this phase of high temperatures, which exceed 70ºC, pathogenic germs, larvae and seeds are eliminated. Then, the temperature slowly decreases to 40-45°C and mesophilic microorganisms predominate (Lai *et al*., 2024).

Two types of factors affect the composting process, those corresponding to monitoring variables and those related to the substrate. Those related to monitoring must be observed and measured during the composting process, including temperature, humidity, pH, aeration and free space and, on the other hand, those related to the substrate, such as particle size, C/N, C/P relationships, nutrients, organic matter and electrical conductivity, which must be quantified at the end of the process (Antahuanca and Rivera, 2024)

The moisture content in the compost is a critical factor to achieve proper composting, the optimal values vary according to the material being used, which range between 50-60% and are the most appropriate; however, excessive humidity generates percolation of substances and loss of fertilizing elements, as well as causing anaerobic fermentation (Anayett *et al*., 2024).

For the composting process, the ideal size of the particles should be between 1 to 5 mm, particles larger than 1 mm give rise to large pores providing aeration and those smaller than 1 mm form medium to small pores providing water retention, greater ease for microbial attack, consequently greater speed of transformation (Barbaro, 2019).

The elemental composition of the material processed in composting depends greatly on the types of basic materials processed; However, carbon (C) and nitrogen (N) are essential for the composting process, whereas the first element provides the primary source of energy, the second is essential for the development of the microbial population (Stoffella and Kahn, 2004). From the above, the importance of the correct C/N ratio (organic-C/total-N) is evident; to achieve efficient composting, this ratio must be between 15 and 35 (Román *et al*., 2013).

The composting process will depend largely on the environmental conditions, the method used, and the raw materials used, as well as intrinsic factors. Among the materials used is bora (*Eichhornia crassipes*), which is also known as water hyacinth, it is an aquatic plant that has bulbs with air that allow it to float and has purple flowers, it is used as a soil fertilizer. For this reason, this research was proposed with the objective of evaluating the physical and chemical characteristics during the composting process of garden waste, coffee husk and bora.

Materials and methods

Location of the experiment

The research was carried out at the Experimental Microstation of the Institute of Agricultural Research of the University of Orient (IIAPUDO), Campus Juanico, of the Monagas Nucleus, Maturín, Monagas State, geographically located at 9º 45' LN and 63º 11' LO, with altitude 65 m, total annual precipitation of 904 mm and average annual temperature of 28.27ºC.

Material collection

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The main organic materials to be composted were bora, coffee parchment, garden waste from the Juanico Campus of the University of Orient, complemented with bovine manure, the mousekiller leguminous tree or mother coca (*Gliricidia sepium*), Cuban Taiwan grass (*Pennisetum* spp.), coffee pulp and mature compost. The bora (*Eichhornia crassipes* Mart. Solms) was collected in Laguna Grande, located in the San Agustín de la Pica sector, Maturín, Monagas state. The husk and coffee pulp were obtained at the "Las Acacias" Hacienda Caripe, Monagas state. The mousekiller, Cuban Taiwan and bovine manure were obtained from the Luis Pérez Guillen Dual Purpose Unit of the School of Zootechnics, located in Jusepín, Monagas state, and the mature compost was obtained at the IIAPUDO Microstation. The substrates were dried in the sun and then ground in an industrial mill with a 4 mm sieve.

Weighing and preparation of materials

Three metal composters were used, closed on both the side and back, whilst being open at the top. In the front part it was closed with ½" rods spaced 15 cm apart, which serve as support for the aviary mesh and in this way prevents the escape of the substrate. The dimensions of the composters corresponded to 77.5 x 62.5 x 75.0 cm. With a CAZ brand watch weight, with a capacity of 15 kg, each of the materials to be composted was weighed (Table 1).

Table 1. Amounts of organic waste to mix in the different treatments

Materials	**Treatments (quantities in kg)**		
	1	**2**	**3**
Bora (*Eichhornia crassipes)*	15		
Coffee parchment		15	
Garden waste			15
Mousekiller leguminous (*Gliciridia sepium*)	4	5	5
Bovine manure	5	5	5
Coffee pulp	7	8	8
Mature compost	9	10	10
Cuban Taiwán (*Penisetum* spp.)	10	7	7
Total	50	50	50

The quantities of the materials in each of the treatments were calculated based on the carbon/nitrogen ratio with theoretical reference data, where their total ranges between 15-16 respectively, then they were mixed in an enveloping manner until they were completely homogenized using a masonry shovel.

Determination of physical and chemical variables of compost

The physical variable temperature was quantified directly in the composters and the chemistries were carried out by sampling data in the Soil Laboratory of the Tropical Agriculture Postgraduate Program at the Juanico Campus, UDO Monagas.

Temperature

The temperature was quantified twice a week, for the first month and then once a week until the composting process was completed, for a total of 18 observations with four repetitions, each of them being taken at 10 and 30 cm, respectively, from the surface of the stack. A mercury thermometer was used, Sper Scientific model, with a reading range between -10 to 150ºC and another digital soil thermometer, Hanna Instruments® brand, model Calcheck T-12.5 HI145, with a reading range between -50 to 250ºC.

Chemical variables

The pH was evaluated by potentiometry in water in a 1:2 ratio, the Hanna Instrument pH meter model pH211 meter was used; electrical conductivity (EC) by the Termo Electron conductivity meter model Orion 3 Star Conductivity Benchtop following the methodology described in NTC (NTC, 2004). The percentage of organic matter (OM) and organic carbon (OC) was determined by the colorimetric method of Walkley and Black (Walkley, 1947). To determine the total nitrogen (TN), the Kjeldahl methodology described by Fernández *et al*. (Fernández *et al*., 2006) and the C/N ratio was calculated as described by NMX AA 67 (NMX AA 67, 1985). Phosphorus (P) was determined by the Bray method No. 1 in ascorbic acid (García and Ballesteros, 2006). Potassium (K) analyzes were performed by atomic absorption spectrophotometry (COVENIN, 1979).

Sampling and experimental design

Three samplings were carried out, 20, 40, 60 days after the composting process. Each composter was divided into four quadrants, from each quadrant 5 random sub-samples were taken and mixed to homogenize, thus obtaining 4 representative samples of the composter. These were placed in 500 g plastic bags, labeled and taken to the laboratory for their respective analyses.

The randomized block design was used with a structure of repeated measures over time, considering each composter as an experimental unit with the treatments coming from a 3x3 factorial arrangement. Three types of compost were studied based on the following factors: Factor A: based on bora, coffee parchment and garden waste and Factor B: the days of composting: 20, 40 and 60, and the four repetitions. The pH, EC, OM, OC, TN, C/N, P and K values were processed by a general linear model using Mauchly's test of sphericity to determine the use of the analysis (univariate or multivariate), through the software statistical IBM SPSS Statistics 22.0. For temperature, the average values of the readings during the composting process were determined.

Results and discussion

Temperature during the composting process

Temperature is one of the most important factors that determine the speed of the biochemical reactions (Nemet *et al*., 2021). In Figure 1 it can be seen the variation in temperature taken at 10 and respectively 30 cm from the surface of the compost pile. A similar behavioural trend is observed. From the beginning of the process, the temperature began to rise, the initial mesophilic phase was not appreciated in detail, due to the temperature quantification intervals from day 0 being too wide, which is why Finore *et al.* (2023) highlighted the fact that in the initial mesophilic phase, the temperature reaches between 10 to 42 ºC in a few hours, or in a couple of days.

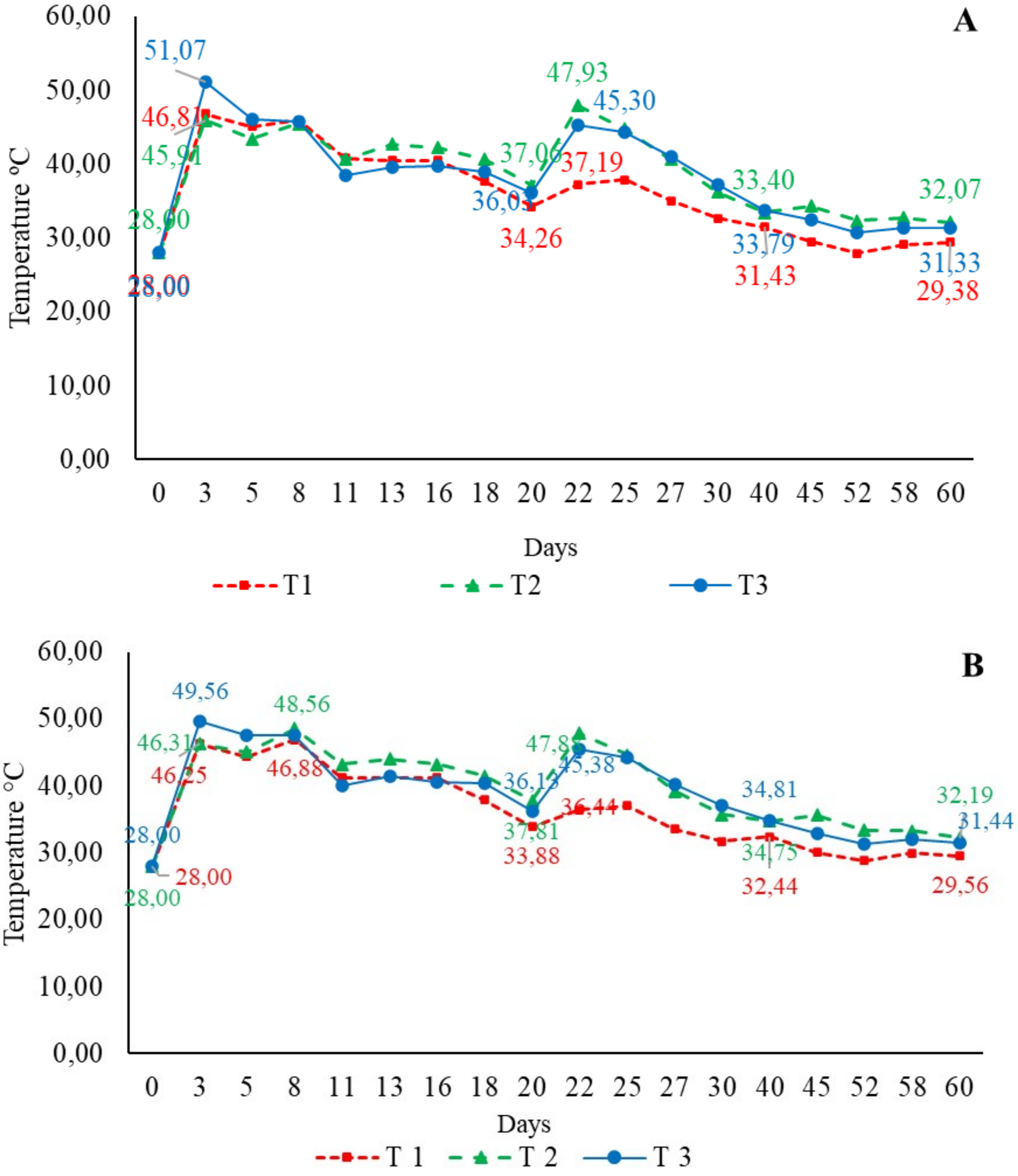

Figure 1. Evolution of temperature in the different treatments during the composting process taken (A) at 10 cm from the surface of the compost pile and (B) at 30 cm.

The experienced increase in temperature is provided by the microbial growth that occurs, for this reason, López *et al.* (2021) mentions that microorganisms multiply in the first stages because of the changing conditions of the environment, which makes them suitable for the successive microbial group. This activity involves metabolic processes that causes a marked increase in the temperature.

Three days after the start of the process, the highest temperature values were obtained, achieving the thermophilic stage very quickly, and at 10 and 30 cm in the treatment with garden waste, the highest value was observed with 51.07 and 49.56 ºC, respectively. Yu *et al.* (2011) when evaluating the temperature and humidity of the compost pile at different depths, they found that as the samples were taken further towards the bottom of the pile, both values of the variables decreased, a behavior attributed to the migration of moisture from above down. The maximum thermophilic temperature reached in the piles was lower than that observed by Salazar (2014), who obtained the maximum average of 58ºC after 14 days using plant remains and bovine manure. Campos-Rodríguez *et al.* (2016), when evaluating the addition of two microbial inoculum to the material to be composted, observed maximum temperatures between 53-55ºC 4 days after starting the process; while Colín-Navarro *et al.* (2019), observed temperatures of 40.6 and 47°C in goat manure compost piles during days four and seven, respectively, decreasing after the seventh day until stabilizing. The thermophilic phase was maintained until the eighth day after mixing the materials (DDMM), this stage is important so that the material is sanitized and the greatest numbers of pathogens that may present during composting are eliminated. The establishment of a thermophilic flora depends on several factors, including the availability of organic plant compounds, as well as humidity, combined with the favorable spatial arrangement of plant fibers and air renewal (Ullé, 2009). Hang *et al.* (2015), made compost using mixtures of bovine manure and sawdust, verifying that in the piles the temperatures repeatedly reached values higher than 55°C, and were maintained at least in two periods for 3 consecutive days, which ensures pathogen reduction.

Hernandez *et al.* (2004) observed in compost from bovine manure, after 4 days of composting, temperatures of 42.56ºC at 15 cm from the surface of the pile and 36.04ºC at 30 cm, which were the highest, the temperatures found in this test present themselves in a similar way, as they were also composted with bovine manure and other materials, so it is admitted that organic waste influences the process and its quality.

From 11 DDMM onwards, the temperature decreased, and the mesophilic stage predominated. After 20 days the first turning was carried out. Before this activity temperatures ranged from 34.26 to 37.06ºC at 10 cm depth, while at 30 cm it ranged from 33.88 to 37.81ºC, with the treatment with coffee husk being superior, for which means greater microbial activity. In this sense, such results are confirmed with those obtained by Rivas-Nichorzon *et al.* (2017) who found the highest counts for fungi after 20 days of the composting process for the treatment based on garden waste and coffee husk with 6.11 log10 $CFU \cdot mL^{-1}$ and 6.06 log10 $CFU \cdot mL^{-1}$, respectively. The turning favored the aeration of the pile and therefore the increase in temperature as observed at 22 DDMM, being higher in the treatment with coffee parchment with 47.93ºC at 10 cm and 47.88ºC at 30 cm. The turning of organic material during the composting process is a very important factor that allows maintaining aerobic activity, that is, the entry of oxygen into the system, which stimulates the biodegradation of the material to be composted, because it reduces the size of particles and exposes new surfaces to attack by microorganisms (Matiz, 2009, Vega *et al*., 2023).

The treatment with coffee husk was when the highest temperature was obtained after turning, it contained a greater amount of fibrous material in relation to the other two treatments, as well as there was greater availability of other types of nutrients for the microorganisms present in the pile of compost. In this regard, Ortiz *et al.* (2021) points out that after 22 days of composting, after the sugars, starches and amino acids are exhausted, the degradation of slowly decomposing lignocellulosic waste begins.

At 40 DDMM another turning was carried out, but no significant changes in temperature were recorded as in the first one. The temperature trend at both sampling times was to decrease; From 45 onwards, an approximately constant temperature behavior was recorded that oscillated until the end of the process on day 60 between 29.38 and 32.07ºC at 10 cm depth, and for 30 cm between 29.56 and 32.13ºC. In the treatment with coffee husk, the highest temperature predominated until the end of the process. Al Meena *et al.* (2021) points out that the temperature reaches a time when it stabilizes, such a condition indicates the maturation phase and according to Finore *et al.* (2023) can last weeks or months depending on the material used. On the other hand, Ortiz *et al.* (2021) indicates that for compost with coffee parchment, the maturation stage was reached after 30 days of composting, higher than that observed in this study.

Chemical variables during the composting process

Hydrogenion potential and electrical conductivity

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The pH values met the assumptions of the analysis of variance and normality of the errors. The pH and electrical conductivity varied significantly over time during the composting process, assuming sphericity according to Mauchly's W statistic with univariate approximation (Table 2).

Table 2. Summary of the analysis of variance for the variable pH and electrical conductivity (EC) during the composting process

Source of variation	**DF**	**Half squares**	
		pH	**EC**
Time	2	0.702**	3.193**
Time x treatment	4	0.033**	0.973**
Error (Time)	18	0.02	0.163

DF= degrees of freedom **Significant at 1% probability by the F test

Hydrogen potential (pH)

The pH in the three composts prepared tended to decrease, starting at values between 6.66 and 7.26 after 20 days of the process (Figure 2), and this last value corresponded to the treatment with coffee husk, coinciding with the high values of pH with the highest average temperatures in the compost mass.

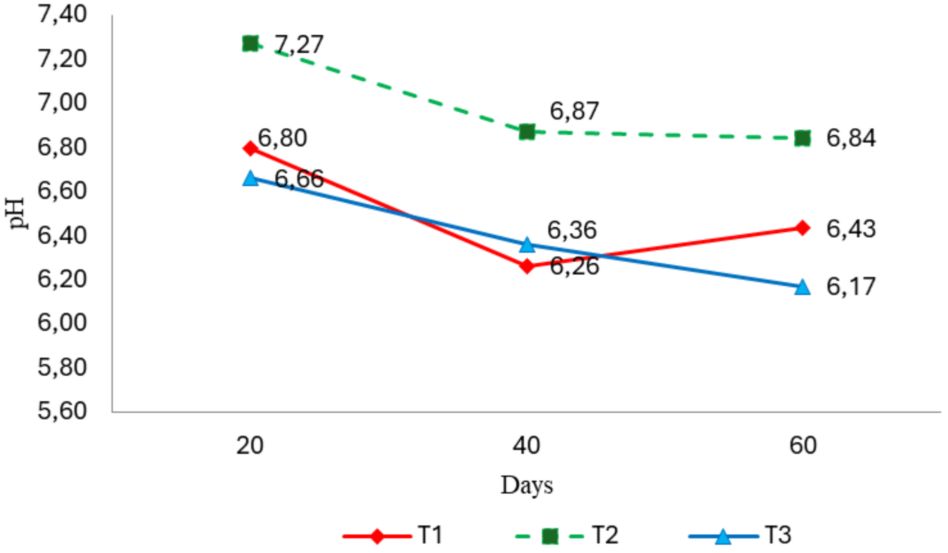

Figure 2. Average pH values in the different treatments during the composting process

According to the results obtained, it can be inferred that temperature influences pH and in a similar way with the microbial activity that develops in the pile. Likewise, 40 and 60 days after mixing the materials (DDMM), the treatment with coffee parchment maintained the highest pH and jointly presented the highest temperature values in relation to the other two composts evaluated. In this regard, Corrales *et al.* (2024) point out that pH is influenced by temperature and affects microbial activity due to the alkalinity that the compost may present during the process.

Changes in pH during the process are due to constant changes in the chemical composition of the substrate. The pH in compost is influenced by three acid-base systems: The carbon system, with dioxide (CO_2) that is formed during decomposition and can escape into the atmosphere as a gas or dissolve in liquids, forming carbonic acid (H_2CO_3), bicarbonate (HCO_3^-) and carbonate (CO_3^-) which increases low pH and reduces high pH. The second system is ammonium ($NH_4^{+)}$ – ammonia (NH_3), which is formed when proteins are decomposed, and the third system is composed of several organic acids in which acetic acid and lactic acid predominate (Villar *et al*., 2016).

The pH of composting depends on the materials of origin, aeration, humidity and temperature (Corrales *et al*., 2024); furthermore, it varies in each phase of the process (from 4.5 to 8.5). These three systems are combined to form the typical composting pH curve, where there is a decrease in the initial phase due to the formation of organic acids (Villar *et al*., 2016), as well as an increase in the phase of maximum activity, to finally stabilize at values close to neutral (Román *et al*., 2013). The treatment with coffee husk ended with average pH values close to neutrality and those of bora and garden waste slightly acidic.

The pH of the compost decreased as the composting process progressed, with the bora-based treatment decreasing after 40 days and then increasing at the end of composting, but with lower values than those quantified after 20 days. This could be since the pH tends to stabilize, in this sense Wang *et al.* (2023) observed that when the pH increases again it seeks to approach neutrality, after the microorganisms consume the acids produced and at the same time carry out the ammonification processes.

Electrical conductivity (EC)

The figure 3 shows the electrical conductivity (EC) values expressed in µs·cm^{-1}, which increased with composting time, with the bora-based treatment being superior during all samplings, in relation to the other treatments.

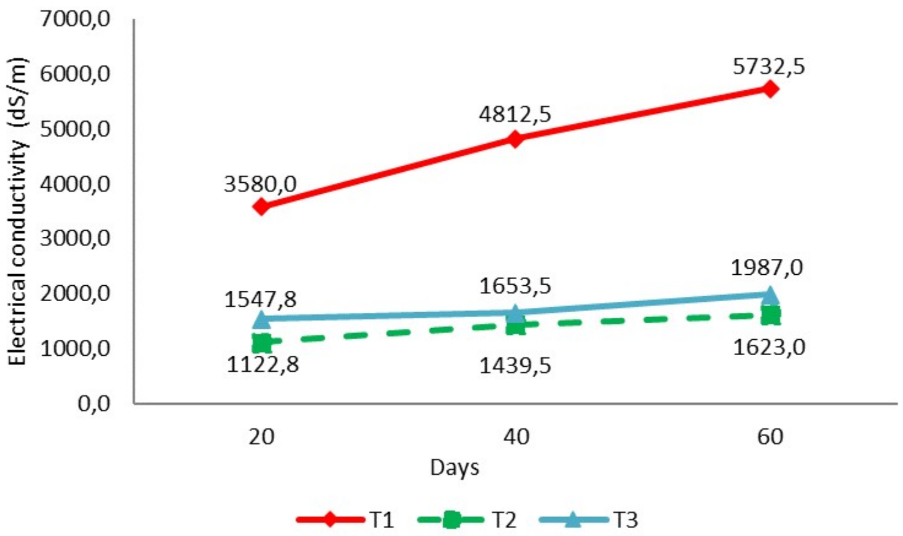

Figure 3. Electrical conductivity (EC) in the different treatments during the process of composting

Castro *et al.* (2016) reported that it is important to consider this variable since it relates the content of salts; thus, excess salts can be harmful to plants, and the application of mature compost for composting increases the EC between 29% and 36%. Antacahuana y Rivera (2024) indicated that the EC of a compost is determined by the nature and composition of the starting material, fundamentally by its concentration of salts and to a lesser extent by the presence of ammonium or nitrate ions formed during the process, this variable generally tends to increase during the process due to the mineralization of organic matter, a fact that produces an increase in the concentration of nutrients. On the other hand, Salazar (2014) points out that the EC values tended to decrease from the fifth week of mixing the materials; such behavior may be due to the leaching of salts during the process because of irrigation. Twice a week, carried out in all composters.

Tenors of organic matter (OM), organic carbon (OC), total nitrogen (TN), C/N ratio and phosphorus

When calculating Mauchly's W test for the variables OM, OC, TN and C/N ratio, it was significant ($p \leq 0.05$); Therefore, sphericity is not assumed for the within-subject effect (time)

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and the multivariate approach is taken, without showing a significant effect for the time by treatment interaction (Table 3).

Table 3. Summary of the multivariate analysis of the variables organic matter (OM), organic carbon (OC), total nitrogen (TN), C/N ratio and phosphorus (P), during the composting process using the Pillai Trace Statistic

SV	DF	Variables				
		OM	**OC**	**TN**	**R C/N**	**P**
Time	2	0.997**	0.997**	0.997**	0.842**	0.801*
Timo x Treat.	4	0.658^{ns}	0.659^{ns}	0.659^{ns}	0.061^{ns}	0.413^{ns}

SV= Source of variation, DF= degrees of freedom; ns= notsignificant; ** Significant at 1% probability by the F test

Organic material

Figure 4 shows the percentage of organic matter (OM) at 20 DDMM with 17.50%, its decrease occurred as composting progressed until reaching 60 days at 8.61%. The OM decreases during the composting process (Salazar, 2014; Palomo, 2015), with a reduction of 55.6%, being more resistant when the compost piles do not have manure (Nemet *et al*., 2021; Ullé and Galetto, 2009).

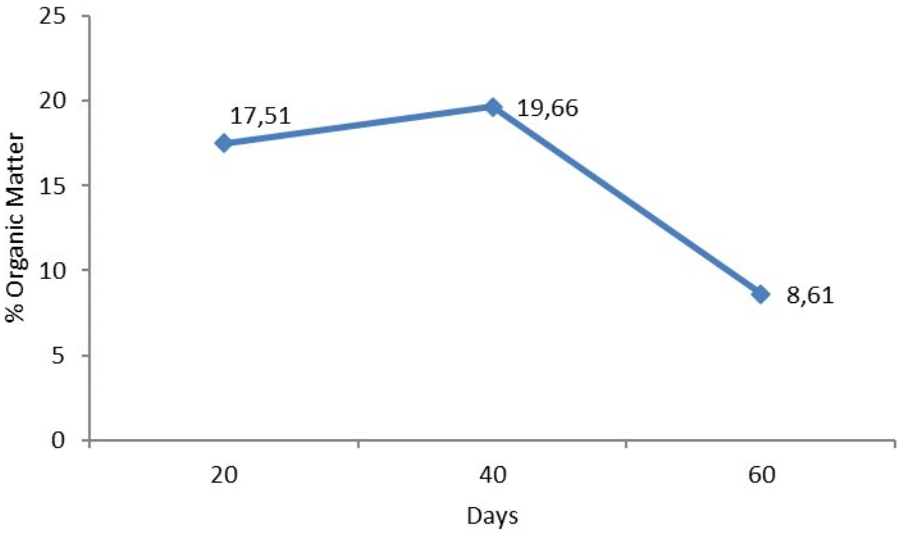

Figure 4. Trend curve for the average percentage of organic matter in the treatments

studied during the composting process

The OM content can warn of the progress of the process, including the maturity of the compost; it should always be assessed with caution because it depends greatly on the starting point. It cannot be appreciated absolutely but relatively (Soliva, 2011). It has been shown that composting is effective in the degradation of organic contaminants whose behavior depends on the composting conditions, activated microbial populations and interactions with organic matter (Zhang *et al*., 2014).

During composting, the OM tends to decrease due to its mineralization and the subsequent loss of carbon in the form of carbon dioxide; these losses can represent almost 20% by weight of the composted mass. This decrease in organic matter occurs in two fundamental stages. In the first, a rapid decrease in carbohydrates occurs, transforming long carbon chains into shorter ones with the production of simple compounds; some of which regroup to form complex molecules giving rise to humic compounds. In the second stage, once the labile compounds are consumed, other more resistant materials such as lignin's slowly degrade and/or transform into humic compounds (Antacahuana and Rivera, 2024).

Organic carbon

Figure 5 shows the percentages of organic carbon (OC) during the composting process. At 20 days the treatments contained 7.67%, at 40 days it increased to 8.73%, such variation could be due to the existing microbial population. In this regard, Wang *et al.* (2023) point out that OC decreased over time, as did OM, but during the process a slight increase was observed that could be caused by the increase in microbial biomass.

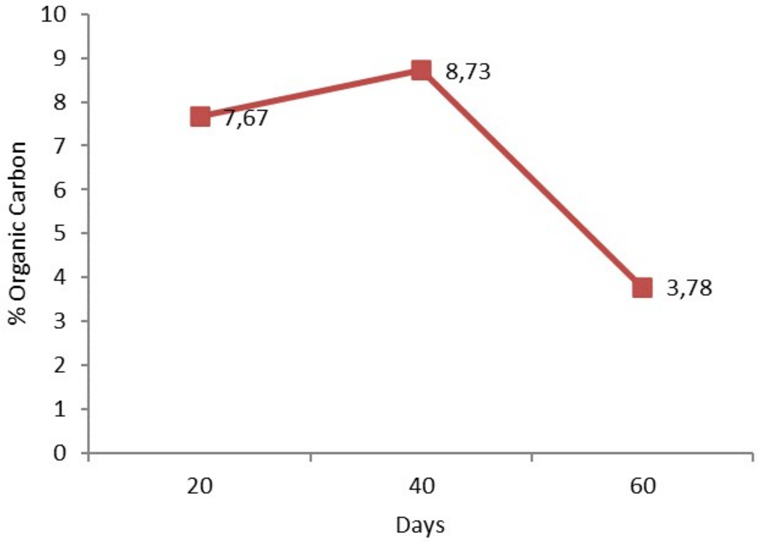

Figure 5. Trend curve for the average percentage of organic carbon in the treatments studied during the composting process

Da Costa *et al*. (2018) reported that during the composting process the evolution of total organic carbon (TOC) tends to decrease. In this regard, Stegenta-Dąbrowska *et al*. *(*2024) mention that the decrease in OC is due to the depletion of easily degradable carbon sources; these are lost in the form of carbon dioxide, which intensifies as time passes, therefore, the amount of carbon is less.

Total nitrogen

The percentage of total nitrogen (TN) presented the same trend as the percentage of OM and OC (Figure 6).

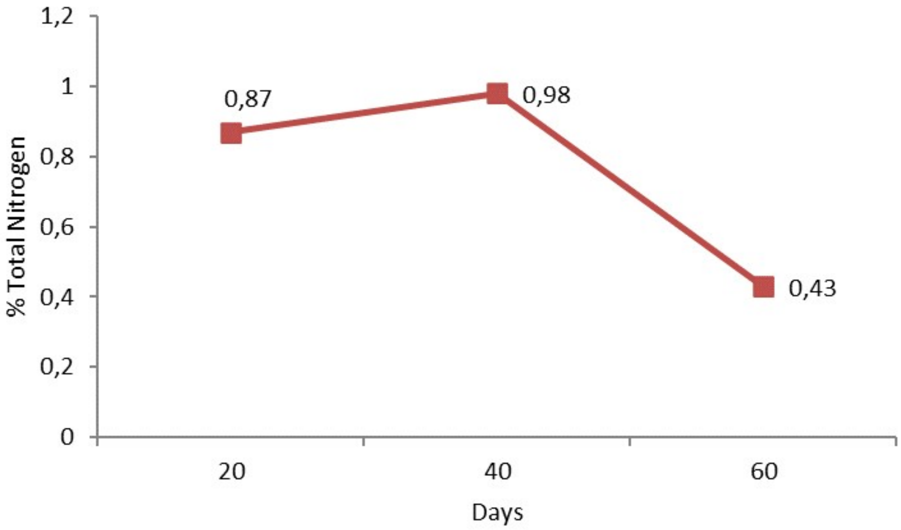

Figure 6. Trend curve of the average percentage of total nitrogen in the treatments studied during the composting process

At 20 days, the average TN values were 0.87, showing a slight increase at 40 days and then decreased during composting to 0.43, which represents a loss in TN of 49.42% since the first sampling. In this regard, Won *et al.* (2018) determined a loss of 47% for TN; Furthermore, Hang *et al.* (2022) point out that the chemical transformations of N during composting are given by ammonification, nitrification and denitrification, the main loss being due to the volatilization of ammonia.

The increase observed after 40 days is caused by the concentration of nutrients during composting, normally its concentration increases due to the decrease in total mass; However, N suffers several slight oscillations (Hong *et al.,* 2022). Nitrogen loss may be due to microbial action during the degradation of organic material.

Nitrogen plays an important role in plant growth since it is predominantly assimilated by the inorganic form NH_4^+ and NO_3^- (Hong *et al*., 2022). It is one of the most important nutrients in compost. When its total content (TN) is analyzed, the value refers to the sum of its inorganic forms such as ammonium, nitrate, nitrite, NH_4^+, NO_3^- and NO_2^- respectively and organic structures such as amino acids, proteins, nucleic acids and other organic compounds. (Tortosa, 2014).

C/N Ratio

Figure 7 shows how the C/N ratio decreases over time, caused by the loss of carbon and nitrogen during the process.

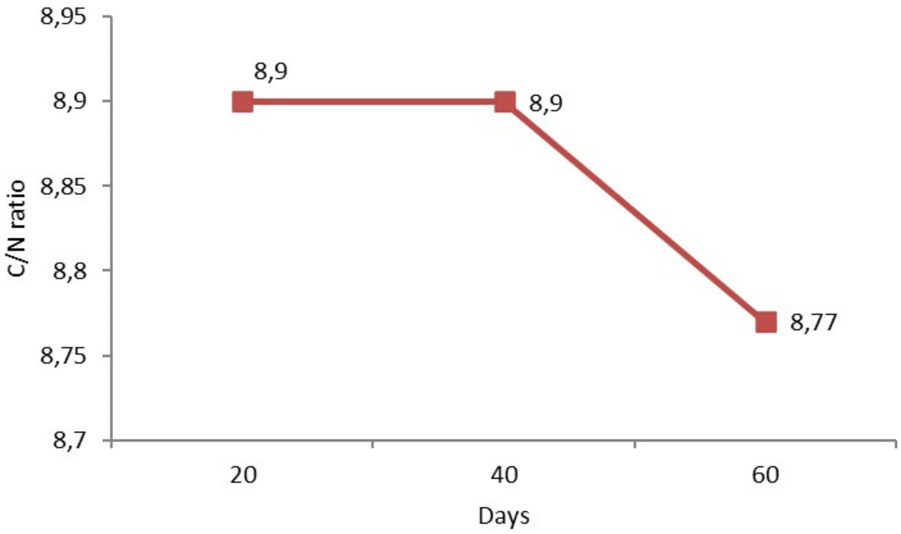

Figure 7. Trend curve for the average carbon/nitrogen ratio in the treatments studied during the composting process

Lopez *et al.* (2017) point out that the decrease in C/N throughout the process is due to the dynamics of carbon, which tends to decrease as a consequence of oxidation. As reference, Rivero and Ullé, (2009) and López-Clememte *et al.* (2015) mention that carbon during the process is lost through the release of CO_2 and nitrogen through volatilization in the form of ammonia. Nitrogen plays a fundamental role in the proper development of composting, so it is considered of interest that the starting material has an adequate C/N ratio.

The C/N ratio was low throughout the process, because it is initially calculated theoretically with values between 15 and 16. García-Ferrández and Sánchez (2007) they recommend that the initial material should have a ratio between 25 and 30, since it is considered that microorganisms consume 30 parts of carbon for each part of nitrogen. If the ratio is high, the activity will be slower and, if it is very low, excess nitrogen is lost as ammonia and the microorganisms will not be able to use it. Escobar *et al.* (2012) indicate that in carbon-rich piles with an initial ratio of C/N = 25, the decomposition of the compost is favored, obtaining a greater amount of fine material.

Phosphorus

Phosphorus (P) decreased by 73.87% during composting, levels of 14.16 mg · Kg^{-1} were observed after 20 days and ended at 10.46 mg · Kg^{-1} (Figure 8).

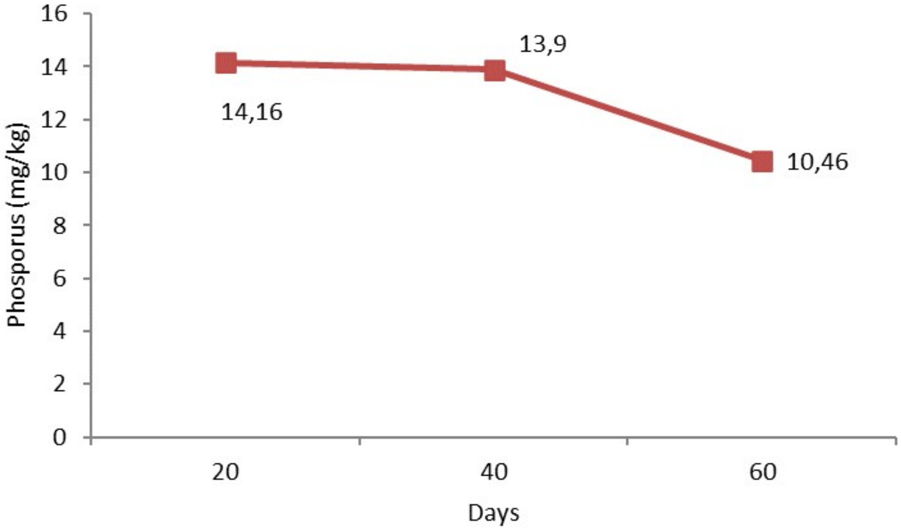

Figure 8. Trend curve for the average phosphorus content in the treatments studied during the composting process

Monguzzi *et al.* (2020) reported an 8% decrease in P during composting time for piles of manually turned plant remains; while Stegenta-Dąbrowska *et al.* (2024) found more bovine manure in the composting of plant remains, he confirmed that the phosphorus values were very similar during the decomposition time.

Potassium

The potassium contents (K) changed over time during the composting process significantly ($p \leq 0.05$), assuming sphericity according to Mauchly's W statistic with univariate approximation (Table 4).

Table 4. Summary of the variance analysis of the levels of the potassium variable during the composting process

Source of variation	DF	Half squares
Time	2	8.976.150,75**
Time x treatment	4	2.903.920,583*

Error (Time)	18	732.380,491

DF= degrees of freedom; ** Significant at 1% probability by the F test

Figure 9 shows that potassium levels decreased over time for all treatments, although in the treatment based on garden waste an increase in K content was observed at 60 days in relation to 20 DDMM. From this fact it is derived that the use of different organic materials influences the evolution of nutrients during the process.

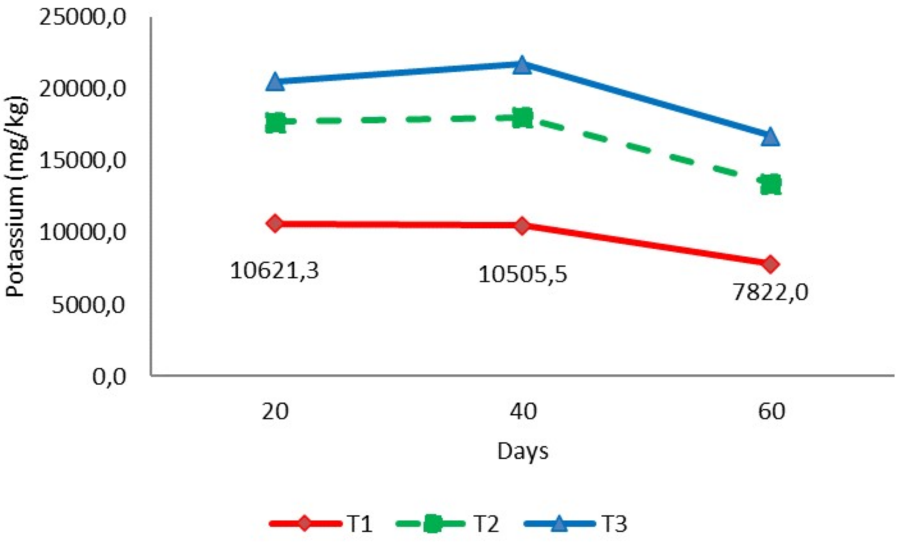

Figure 9. Trend curves for the average potassium content in the treatments studied during the composting process

Apaza-Condori *et al.* (2015) found potassium levels between 17.610 and 19.217 mg·kg^{-1} in composts made from coca leaves mixed with different biological activators, considered a medium level for this nutrient.

One of the greatest advantages of using compost as a source of organic matter is the presence of nutrients that are both immediately available and slowly released; such elements are essential for plant nutrition (Román *et al.*, 2013). When making compost it is convenient to incorporate materials of animal origin to obtain a product with greater nutritional value in terms of OM, N, P, K, Ca and Mg (Kostic *et al.*, 2020; Pérez *et al.*, 2008). The different materials influence the physical and chemical characteristics of composting and consequently the quality of the final compost (Chattergee *et al*., 2013; Crespo *et al*., 2018).

Conclusions

The temperature during the composting period presented a typical pattern for the three types of compost. The initial mesophilic, thermophilic, as well as final mesophilic and maturation phases were evident. Temperatures at 10 cm were higher than those taken at 30 cm from the compost piles. The maturation phase began 45 days after the process.

The pH, electrical conductivity and potassium content varied depending on the time and type of compost. The pH decreased as the composting process progressed. Electrical conductivity increased in all treatments due to the reduction of composted biomass and potassium content values varied during the composting process.

The variables percentage of organic matter, organic carbon, nitrogen, the C/N ratio and phosphorus content decreased during the composting process.

Finally, the materials used in the evaluated compost influenced its physical-chemical characteristics, presenting a good final quality. Therefore, its use is recommended.

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