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Vermicomposting: A Valorization Alternative for Corn Cob Waste

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Abstract: As vermicomposting has become a viable alternative for the valorization of organic waste; the objectives of this research were to (1) assess the feasibility of said process for corn cob waste (corn cobs and corn husks) and (2) evaluate the operation conditions for the biodegradation of different mixtures with load material (LM). LM did not include animal excreta as a nitrogen source, a practice widely used in a range of studies. The experiment consisted of an initial phase of pre-composting in order to obtain a partially stabilized substrate. Subsequently, four separate mixtures were made consisting of corn cob waste mixed with consistent load material (LM) containing vegetable waste and eggshells (CR, M1, M2, M3) to obtain a balance substrate able to facilitate degradation using *Eisenia fetida* earthworms. The following parameters were analyzed during the control process: temperature, pH, humidity, organic material (OM), total organic carbon (TOC), total nitrogen (TN) and carbon/nitrogen (C/N) ratio. The analysis of the final values of the stabilized mixtures showed that vermicomposting is indeed a feasible alternative for the degradation of corn cob waste for use as a soil improver.

Keywords: pre-composting; vermicomposting; corn cob waste; valorization; physicochemical parameters

1. Introduction

Worldwide corn production is estimated to be 1133.9 million tons for the 2020/2021 cycle [1]; making it the most produced grain, and second most produced crop. The American continent produces nearly 55% of the world's total production, followed by Asia, Europe, and Oceania. Its uses include human food, animal feed and feedstock for a large quantity of industrial products as well as biofuels [2].

The industries in which corn-based products are applied include the automotive, pharmaceutical, cosmetic as well as the clothing and footwear industries, where it is a source of furfural for the manufacture of nylon and phenol-formaldehyde plastics, the fabrication of petroleum-based lubricants and a purifier of butadiene in the production of synthetic rubber, an ingredient in the production of organic marine algae fertilizers, among others [3].

In corn cultivation, 50% of the yield is harvested as grain and the remaining 50% is made up of residues such as stalks, leaves, husks, and panicles, among others. This waste is used in the process of obtaining fiber for animal feeding and ethanol production or for ground cover [4]. Its use has also been reported to produce furfural and production of paper pulp [5].

Agroindustrial untreated waste such as corn cob waste is, on the whole, not properly disposed of (common methods being burning, dumping or unplanned landfilling), which

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causes environmental pollution, resulting in an increase in greenhouse gases and climate change [6].

Another waste management alternative is its treatment through biological processes, the most reputable being anaerobic digestion and composting. One of the modalities of the latter is vermicomposting, a rapid, simple, and easy-to-control energy-saving method, which allows the bioconversion of organic waste through a non-thermophilic process that generates a quality product known as vermicompost [7–9]. Due to the environmental issues generated by the produced residue, this process has become an emerging treatment option that is effective for a large array of industries with a greater potential for nutrient recovery [10].

Vermicomposting studies have shown favorable results for obtaining soil improver [11]. Chen et al. performed an experiment with maize stover and chicken droppings as a substrate using *Amynthas hupeiensis* worms and a pre-composting phase spanning 15 days, concluding that earthworms could accelerate maize stover stabilization by activating lignocellulose-degrading microbes [12]. Chen et al., in a similar experiment, used maize stover mixed with chicken droppings, applying a prior pre-composting process of the substrate for 15 days to prevent any damage to the worms when temperatures went above 35 °C [13]. The species of worm used was *Eisenia fetida* and during the process, temperature was kept around 25 °C, while humidity was in the 55–65% range during the 60 days in which the experiment lasted.

In another experiment performed by Singh and Sharma, in which phase one, the pre-composting of wheat straw during a 4-day period, was inoculated with four different funguses, the results showed the production of a nutrient-enriched compost product [14]. Suthar performed a vermicomposting experiment using three different mixtures of millet straw and sheep manure, pulse bran, wheat straw and cow dung, mixed crop residues and cow dung [15]. The results showed that the higher concentrations of nutrients in the final product had the potential for agricultural waste use in sustainable crop production. Romero et al. performed a study to determine the effects of the C/N ratio in mixtures of maize (*Zea mays* L.) stubble and milk cattle manure on vermicompost quality, finding it to be a good alternative for horticultural and ornamental plant production [16].

In accordance with the aforementioned studies, the vermicomposting process through use of corn waste has been performed by different authors using mixtures including various types of animal manure. Despite most studies including a pre-composting phase, the corresponding data for mixtures of this type and vegetable matter were scarce. As a result, the objectives of this study were to (1) assess the feasibility of vermicomposting for corn cob waste and (2) evaluate the operation conditions for biodegradation of different mixtures of corn (*Zea mays* L.) cob waste substrate and load material (vegetable waste and eggshells) through the vermicomposting process at laboratory level.

2. Materials and Methods

2.1. Pre-Composting

Before the vermicomposting took place, it was decided that performing a pre-composting for corn cob waste would be advantageous for acceleration of the process [17].

2.1.1. Substrate and Load Material

The substrate used in the pre-composting process was corn waste (corn cob and corn husk) collected from local markets (10 kg). Its chemical composition includes lignin, cellulose, and hemicellulose [18]. On the other hand, load material (LM) was prepared (9 kg) a finely chopped vegetable base: lettuce (1.285 kg), chard (1.285 kg), cabbage (1.285 kg), spinach (1.285 kg), celery (1.285 kg), cress (1.285 kg), and broccoli (1.285 kg) and eggshells (1 kg) to add nutrients to the substrate. The addition of eggshells was due to their calcium (Ca^{2+}) content as well as proteins, glycoproteins and proteoglycans. In addition, Ca^{2+} is an important element in the worm's diet and can help their reproductive process [19,20]. About 95% of the dry eggshell is calcium carbonate. The average eggshell contains about

0.3% phosphorus and 0.3% magnesium and traces of sodium, potassium, zinc, manganese, iron and copper [21].

2.1.2. Process

For the pre-composting process, corn cob waste was placed in an experimental reactor that consisted of a plastic container measuring 35 cm wide, 35 cm long and 35 cm high, with a total volume of 0.043 m^3. Small holes were made in the bottom base of the container to allow leachate to be extracted [22–24]. The reactor was covered with a thin mesh to allow gaseous exchange [25]. Every third day, wastes were sprayed with clean water to maintain it within the required range of humidity [26]. LM was not subjected to the pre-composting process because of its quick biodegradation.

2.2. Vermicomposting

After the pre-composting process, mixtures were made with the substrate and the LM was then added to the vermicomposting process using earthworms of the *Eisenia fetida* species, which were obtained from a vermicomposting plant.

2.2.1. Substrate

The substrate used for the vermicomposting process consisted of a mixture of corn cob waste and LM. Every reactor had 2000 g of this mixture, as is shown in Table 1.

Table 1. Proportion of feedstock and load material in vermicomposting process.

Reactor	Feedstock-Corn Cob Waste by Weight g (%)	Load Material		Number of Earthworms
		Vegetable Waste by Weight g (%)	Eggshell by Weight g (%)	
Control reactor (CR)	1000 (50%)	750 (37.5%)	250 (12.5%)	0
Mixture 1 (M1)	1000 (50%)	750 (37.5%)	250 (12.5%)	50
Mixture 2 (M2)	1200 (60%)	600 (30%)	200 (20%)	50
Mixture 3 (M3)	800 (40%)	900 (45%)	300 (15%)	50

2.2.2. Process

For each of the mixtures (CR, M1, M2, M3), four experimental reactors were used, consisting of plastic containers measuring 16.5 cm wide, 26.5 cm long and 15.5 cm high, with a total volume of 0.0068 m^3. As with the pre-composting process, each reactor had holes drilled into its underside to facilitate leachate drainage, as well as being covered with a thin mesh. Such as in the pre-composting process, every third day, wastes were sprayed with clean water to maintain it within the required range of humidity [26].

2.3. Physicochemical Parameters

The physicochemical parameters determined during the pre-composting and vermicomposting processes were temperature, pH, humidity, organic matter (OM) and total organic carbon (TOC). In addition, total nitrogen (TN) and C/N ratio were determined for the vermicomposting process. All determinations were performed thrice.

Temperature and pH were measured daily, while the rest of the parameters were determined on a weekly basis using techniques established by local norms [27–29].

2.4. Statistical Analysis

Data generated on organic matter, total organic carbon and total nitrogen at the beginning and end of the vermicomposting process for all mixtures were subjected to analysis of variance (ANOVA) and pairwise comparison using the Tukey test ($p < 0.05$). The JMP 8.0 Software Package program was used.

3. Results and Discussion

3.1. Pre-Composting

As per the results obtained with the physical chemical characterization, it was found the pre-composting process for the substrate (corn cob waste) lasted 6 weeks.

3.1.1. Temperature

Figure 1 shows environment temperature (ET) and corn cob waste temperature (CWT). ET had an initial value of 21.33 °C with a tendency to increase during week 3 to 26.42 °C later decreasing to 15.46 °C.

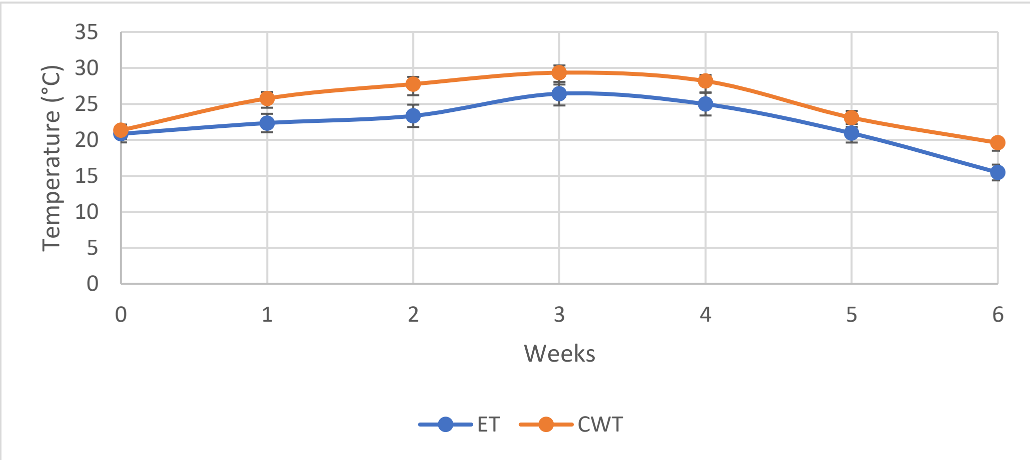

Figure 1. Environmental temperature (ET) and Corn Cob Waste Temperature (CWT) behavior in pre-composting.

The initial CWT value was 21 °C, and an increase of up to 29.33 °C was observed in the third week. This behavior is due to microorganism activity, which degraded easily assimilable, soluble compounds such as sugars, starches, amino acids and lipids, leading to heat production, elevating temperatures [30–32].

A CWT decrease is shown later, which indicates that most of the easily degradable materials have been assimilated, thus giving way to the slow decomposition phase where more complex compounds are degraded by certain bacteria, leading to stabilization in the process [30,33].

The final value shown by CWT was 19.6 °C, which aligns with the 19 °C reported by Nair et al. for the pre-composting of kitchen waste [34]. CWT behavior obeyed the size of the reactor used, as heat generation is proportional to volume, while loss is to surface [35]. During the pre-composting process, the temperature did not reach the thermophilic range since the experiment was performed at laboratory level. According to Petiot and De Guardia (2004), reactors of small size do not allow the self-heating of the substrate, or at least do not allow the temperature to stay in the thermophilic zone, due to high heat losses through the external surface [36,37].

3.1.2. pH

Figure 2 shows corn cob waste pH behavior where it can be observed an initial value of 6.33, which later began to increase; the highest value it reached was 6.7, caused by the release of ammonia as a result of the degradation of proteins and loss of organic acids [33,38].

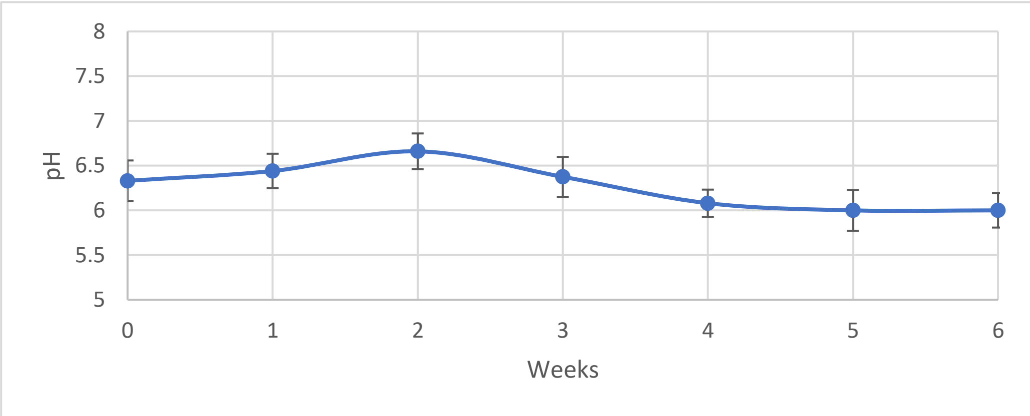

Figure 2. Corn cob waste pH behavior in pre-composting.

A subsequential pH decrease to 6.37 was manifested during week 3; due to the liberation of organic acids due to the degradation of organic matter [17]. Ultimately, a pH of 6 was observed, indicating that the process had stabilized [39]. The pH range during the pre-composting process remained between 6 and 6.7 in accordance to values reported in the literature [32,40,41].

3.1.3. Humidity

The initial humidity value for the pre-composting process for corn cob waste was 80.6%. It subsequently dropped to 76.3% by week 2, increased to 81% in week 5 and ended at 79.6% (Figure 3).

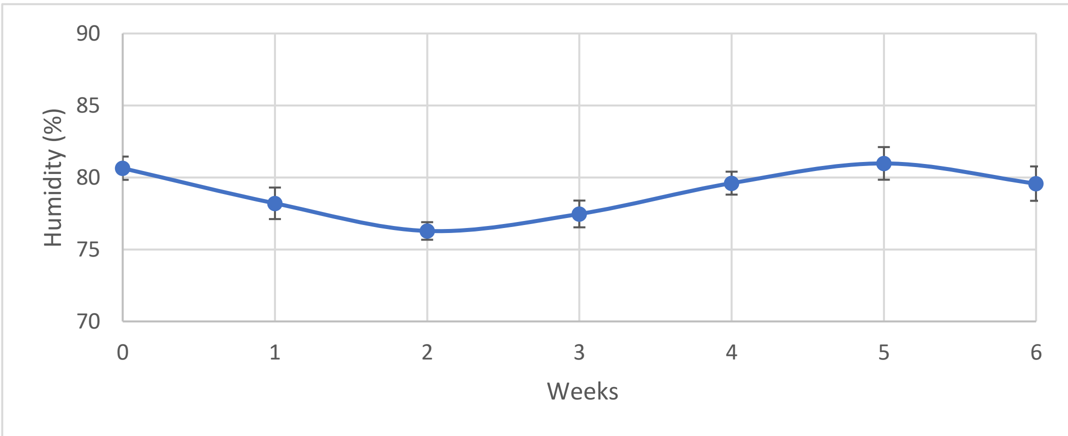

Figure 3. Corn cob waste humidity behavior in pre-composting.

The process values were found to be within the 75–85% humidity range. This coincides with the values reported by Li et al. for dairy manure, corn stalks and tomato residue, with values between 77.5% and 84.3% [33]. Other studies have reported values between 4%0 and 60% [40], and 50–60% with wheat straw, corn straw, rice straw and soybean straw substrates [42].

3.1.4. Organic Matter

Figure 4 shows the OM behavior for corn cob waste where the initial value was 82.2%, coinciding with 80.54% for corn residue and cow manure [16]. During this process, OM values tended to decrease due to mineralization and carbon loss in the form of carbon dioxide [43].

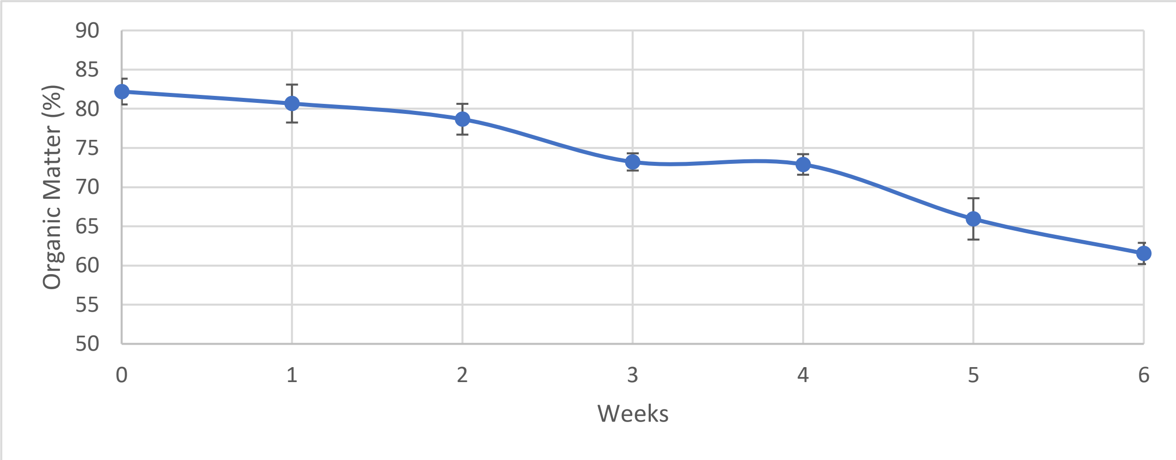

Figure 4. Corn cob waste organic matter behavior in pre-composting.

The final value was 61.5%, similar to 52.4–60.1% reported from a study using maize straw and dewatered sewage sludge [44]; thus, the removal efficiency was found to be 25.18%. Zhao et al. reported an OM decrease of 24.1% for corn residue [45].

3.1.5. Total Organic Carbon

Figure 5 shows TOC behavior for corn cob waste during the pre-composting period. Initial value was 47.68%, coinciding with other authors who used similar substrates like dairy cattle and swine manure mixed with barley straw (44.7%) as well as wheat straw (46%) [46,47].

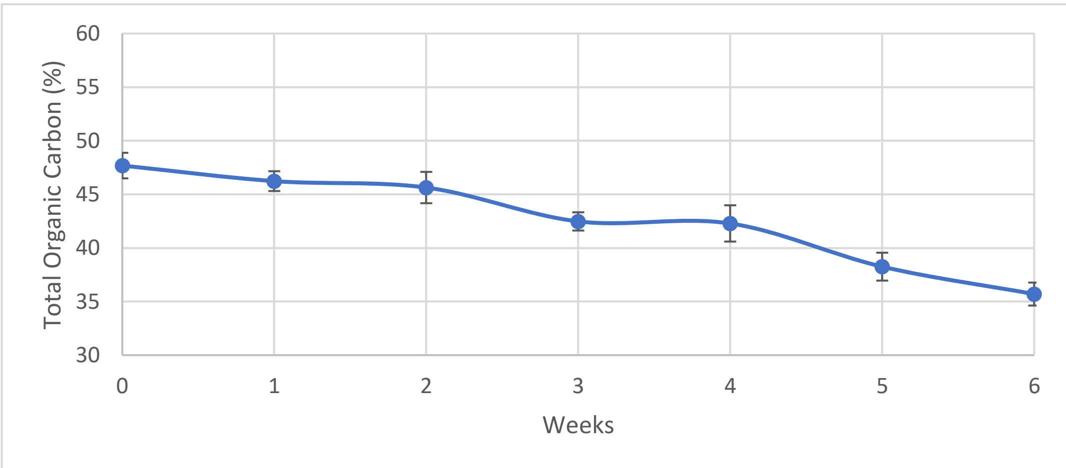

Figure 5. Corn cob waste total organic carbon behavior in pre-composting.

During this process, it was observed that the concentration of TOC decreased due to the fact that it was utilized by microorganisms as a source of energy to carry out metabolic activities and the synthesis of cellular constituents [41].

The final value was 35.7%, similar to the 32.75% result reported using pulse bran residue, wheat straw and cow dung [15].

The percentage of removal of TOC was 25.13%, which ended up being higher in comparison to a mixture of rice straw with poultry manure and oilseed rape cake (initial 39.07% and final 35.13%) reported by Abdelhamid et al. [48].

3.2. Vermicomposting Process

Then, the pre-composting process mixtures CR, M1, M2 and M3 were made with the substrate and the pre-composted materials to carry out the vermicomposting process, which lasted seven weeks.

3.2.1. Temperature

Figure 6 shows temperature variations presented in each of the mixtures (CR, M1, M2, M3) along with environment temperature (ET).

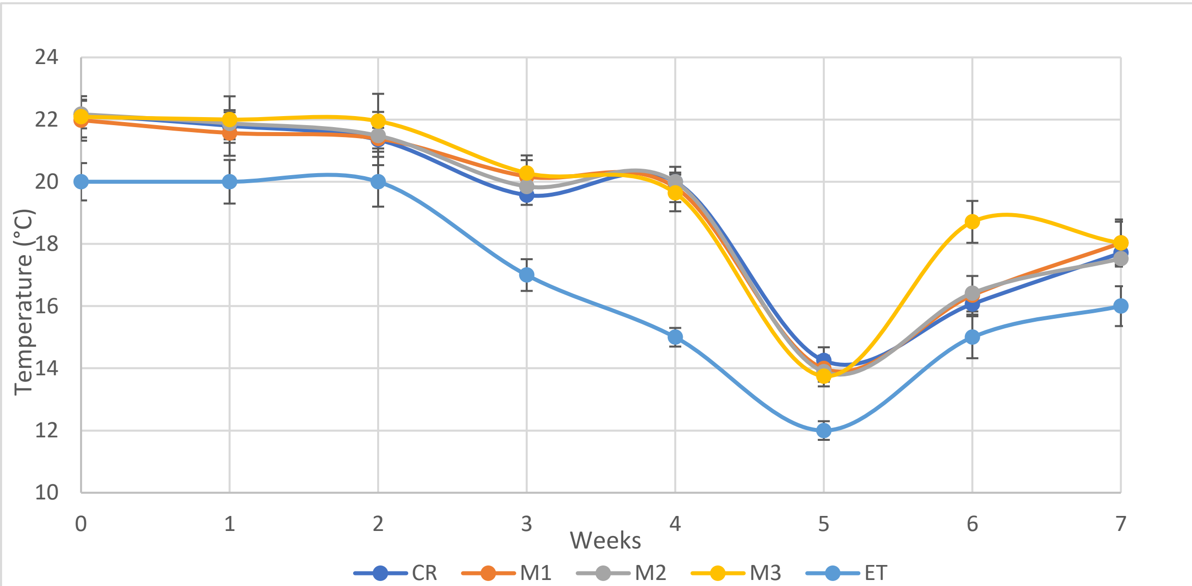

Figure 6. Enviromental Temperature (ET) and Mixtures Temperature (CR, M1, M2, M3) behavior during vermicomposting.

The initial temperature value for the four mixtures was 22 °C, similar to other studies using wheat residue and corn stover with values of 22 °C and 25 °C respectively [49].

Waste temperatures were maintained within the range of 20 to 22 °C during the initial three weeks, decreasing to a value of 13.75 °C in week 5, mostly due to climate conditions in the area where the experiment was performed. The final temperature values presented by the four mixtures were in the 17 to 18 °C range.

Temperatures must remain between 15 and 20 °C during the vermicomposting process; this allows the earthworms to reproduce and develop better [50,51]. In alignment with this, earthworms had optimal conditions for their development as temperatures were kept within the aforementioned range.

3.2.2. pH

Figure 7 shows pH behavior in each of the four mixtures. In the beginning M2 and M3 showed values of 7.0 and 6.9 respectively, in alignment with the values of 6.5 and 7.9 reported by Yadav and Garg with wastewater treatment plant sludge of a food industry and cow dung [52]. On the other hand, CR and M1 showed values of 7.5 and 8.0, similar to the 8.25 reported in studies using millet straw, pulse bran, wheat straw and cow dung [15].

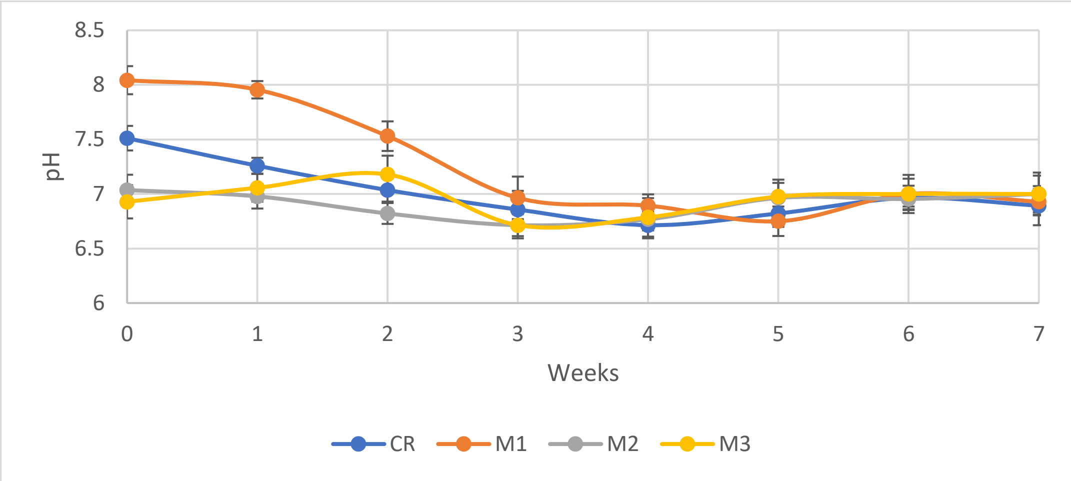

Figure 7. pH behavior in mixtures (CR, M1, M2 and M3) during vermicomposting process.

This figure shows a trend toward pH decreases in all four samples during the initial three weeks. This is owed to the degradation of organic matter, which produced carbon dioxide, ammonia, nitrates and volatile fatty acids [53].

Starting on week 3, pH values for all four samples essentially stabilized toward neutrality (6.9 to 7), also in coincidence with other studies using wheat straw and rice straw with values of 6.65–6.84 and 7.24, respectively [54,55]. Furthermore, final values were also found to be within the range of 5.5 to 8.5 established by local norms for a quality vermicompost and international standards from the World Health Organization (WHO), cited by Pirsaheb et al. (2013) [56,57].

As per Yadav and Garg, acceptable pH range for the vermicomposting process is between 5.5 and 8 [58,59]; while Ali et al. have pointed out that a neutral pH is adequate for the proper development of worms, although they may survive in a range of 4.5 to 9 [10].

3.2.3. Humidity

Figure 8 shows humidity behavior in vermicomposting. Values presented in the first week for all four mixtures (CR, M1, M2, M3) were 75.50%, 79.40%, 70.36% and 77.19% respectively.

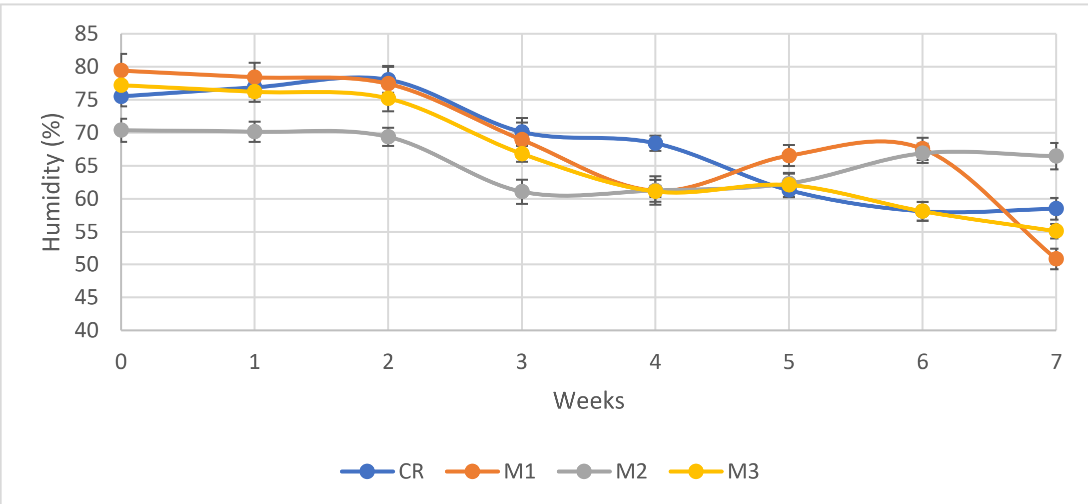

Figure 8. Humidity behavior in mixtures (CR, M1, M2 and M3) during vermicomposting process.

Humidity percentages during this process were maintained within the 50% to 80% range in all four mixtures, this is adequate for vermicomposting according to multiple authors who have indicated an ideal range of between 50% and 90% [10,60–64].

3.2.4. Organic Matter

Figure 9 shows OM behavior during the vermicomposting process, initial values of 87% were observed in CR and M1 and 85% and 86% in M2 and M3 respectively. These values are close to the 80.54% reported in the vermicomposting process of corn straw substrate [16].

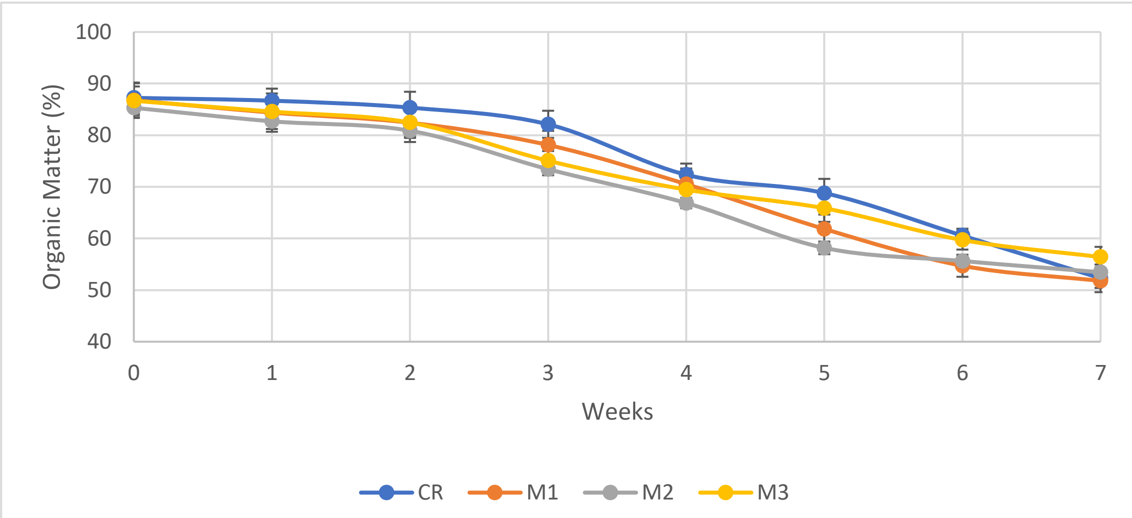

Figure 9. Organic matter behavior in mixtures (CR, M1, M2 and M3) during the vermicomposting process.

All four mixtures had an OM decrease due to its use by the earthworms to carry out their metabolic and respiratory activities; this led to an increase in population of the microorganisms responsible for OM biochemical degradation [56].

Final OM values for CR, M1, M2 and M3 were 52.20%, 51.70%, 53.40% and 56.40% respectively, in accordance with the 52.4% for the vermicomposting of dewatered sewage sludge and maize straw [44]. The values found were near to the established range (20–50%) by local norms for a quality vermicompost [56].

At the beginning of the vermicomposting process, OM values were not significantly different between the four reactors, however, at the end of the process there were statistically significant difference between M1 and M3 reactors (Table 2).

Table 2. Vermicomposting process physicochemical composition.

Physicochemical Parameters	At the Beginning				At the End			
	CR	M1	M2	M3	CR	M1	M2	M3
Total Nitrogen (%)	1.32 ± 0.02 a	1.28 ± 0.04 a	1.31 ± 0.02 a	1.31 ± 0.06 a	1.59 ± 0.04 a	1.60 ± 0.06 a	1.54 ± 0.04 a	1.52 ± 0.04 a
Total Organic Carbon (%)	50.60 ± 1.72 a	50.33 ± 0.91 a	49.48 ± 1.68 a	50.27 ± 0.75 a	30.33 ± 0.76 a,b	30.03 ± 0.78 a	31.00 ± 1.18 a,b	32.71 ± 0.98 b
Organic matter (%)	87.23 ± 2.97 a	86.77 ± 2.34 a	85.31 ± 3.30 a	86.67 ± 2.77 a	52.20 a,b	51.70 a	53.40 a,b	56.40 b
C/N Relation	38.48 ± 1.08	39.36 ± 0.79	37.70 ± 1.58	38.23 ± 1.15	19.03 ± 0.51	18.84 ± 0.55	20.20 ± 1.01	21.49 ± 1.03
Humidity (%)	75.50 ± 1.51	79.40 ± 2.54	70.36 ± 1.76	77.19 ± 1.70	58.46 ± 1.64	50.84 ± 1.58	66.43 ± 1.99	55.05 ± 1.10
pH	7.51 ± 0.11	8.04 ± 0.13	7.03 ± 0.14	6.92 ± 0.15	6.90 ± 0.18	6.93 ± 0.12	7.00 ± 0.20	7.00 ± 0.17

CR = Control reactor 50% CCW–50% LM; M1 = Reactor 50% CCW–50% LM; M2 = Reactor 60% CCW–40% LM and M3 = Reactor 40% CCW–60% LM. Mean values (mean ± SD, $n = 3$), followed by different letters are statistically different (ANOVA; Tukey's test, $p < 0.05$).

3.2.5. Total Organic Carbon

Figure 10 shows TOC behavior during the vermicomposting process. Initial values of 50.60%, 50.33%, 49.48% and 50.27% were observed for CR, M1, M2 and M3 respectively.

These values were similar to the 47.7% and 52.5% reported in vermicomposting processes for millet straw and sheep manure, and maize stover respectively [15,65].

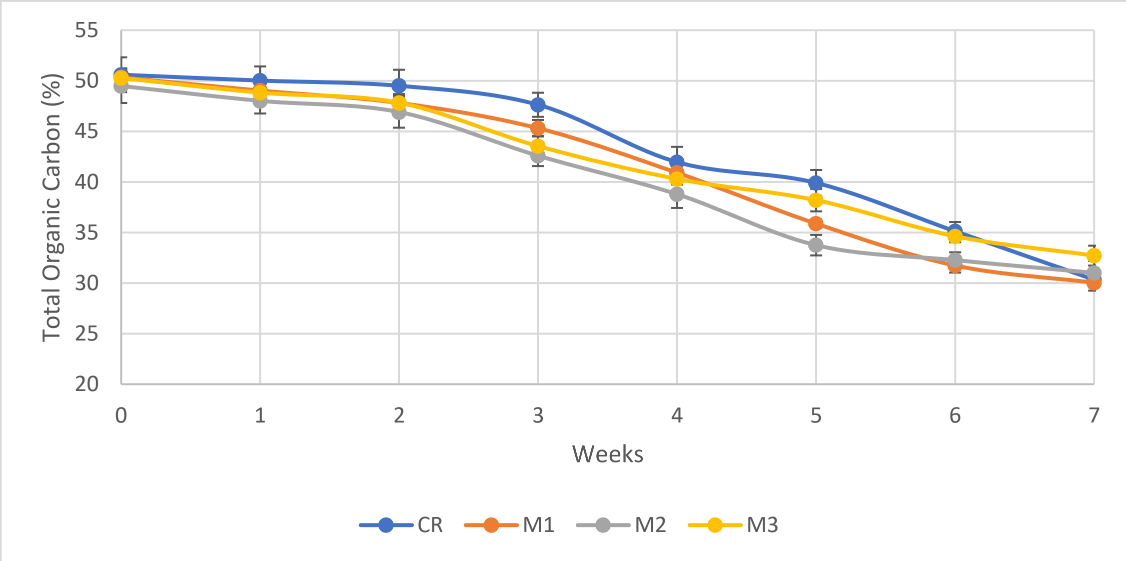

Figure 10. Total organic carbon behavior in mixtures (CR, M1, M2 and M3) during vermicomposting process.

This figure shows TOC percentage decreased due to a carbon loss due to mineralization. The combined actions of the earthworms and microorganisms are responsible for TOC loss in CO_2 form in the residue [66].

Final TOC values for mixtures CR, M1, M2 and M3 were 30.33%, 30.03%, 31.00% and 32.71% respectively, not unsimilar to the 29.2% and 33.2% in vermicomposting processes with vegetable solid waste and cow dung, as well as pulse bran, wheat straw and cow dung respectively [15,53].

TOC removal efficiency levels shown by CR, M1, M2 and M3 were 40%, 40.29%, 37.34% and 34.84% respectively. The mixtures that showed a higher level of removal were CR and M1; their results were similar to another process reported using rice straw with an initial TOC value of 38.5% and a final of 27.6% [55].

At the beginning of the vermicomposting process, TOC values were not significantly different between the four reactors, however, at the end of the process, there were statistically significant difference between M1 and M3 reactors (Table 2).

3.2.6. Total Nitrogen

Figure 11 shows TN behavior during vermicomposting. The initial values for the four mixtures CR, M1, M2, M3 were 1.32%, 1.28%, 1.31% and 1.31% respectively, similar to the 1.28% reported using vegetable waste and cow dung [53] and to 1.18–1.46% with maize stover [12,13].

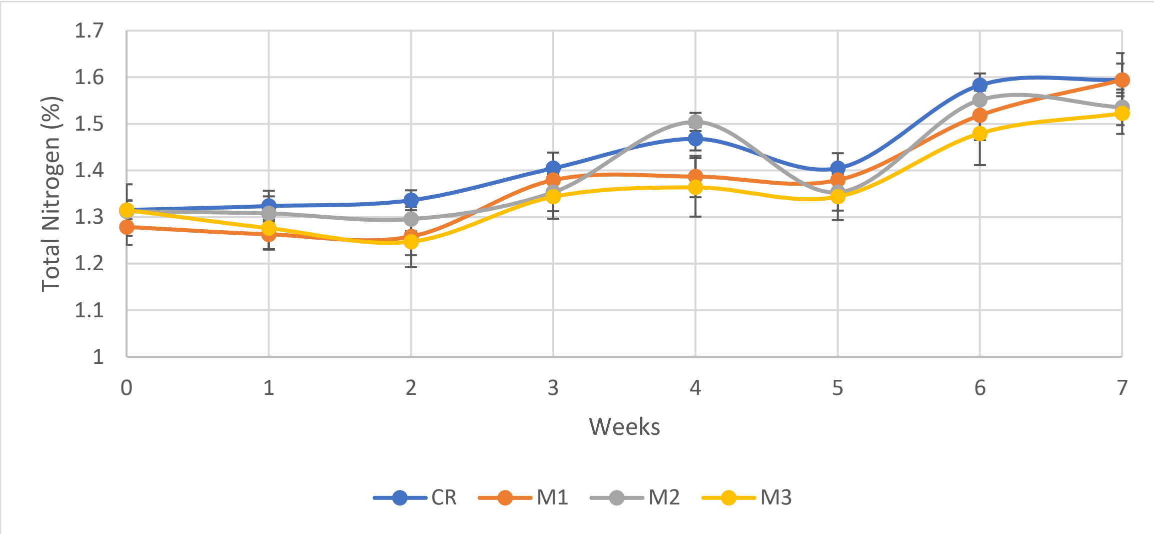

Figure 11. Total nitrogen behavior in mixtures (CR, M1, M2 and M3) during vermicomposting process.

Starting at the next few weeks, TN values increased due to organic carbon loss due to the use of substrates and metabolic activities of microorganisms and earthworms, the latter causing an addition of nitrogen in the form of mucus, nitrogenous excretory substances, body fluids, growth-stimulating hormones, and enzymes [66].

The final values for all four samples were found to be between 1.5% and 1.6%, coinciding with other studies involving corn silage (0.52–1.53%), sugar cane waste (1.4%) and rice straw (1.9 %) [55,67,68].

The TN values at the beginning and at the end of the vermicomposting process were not significantly different between the four reactors (Table 2).

3.2.7. C/N Ratio

Figure 12 shows the behavior of C/N ratio during the vermicomposting process, initial values for mixtures CR, M1, M2 and M3 were 38.48, 39.38, 37.70 and 38.23 respectively.

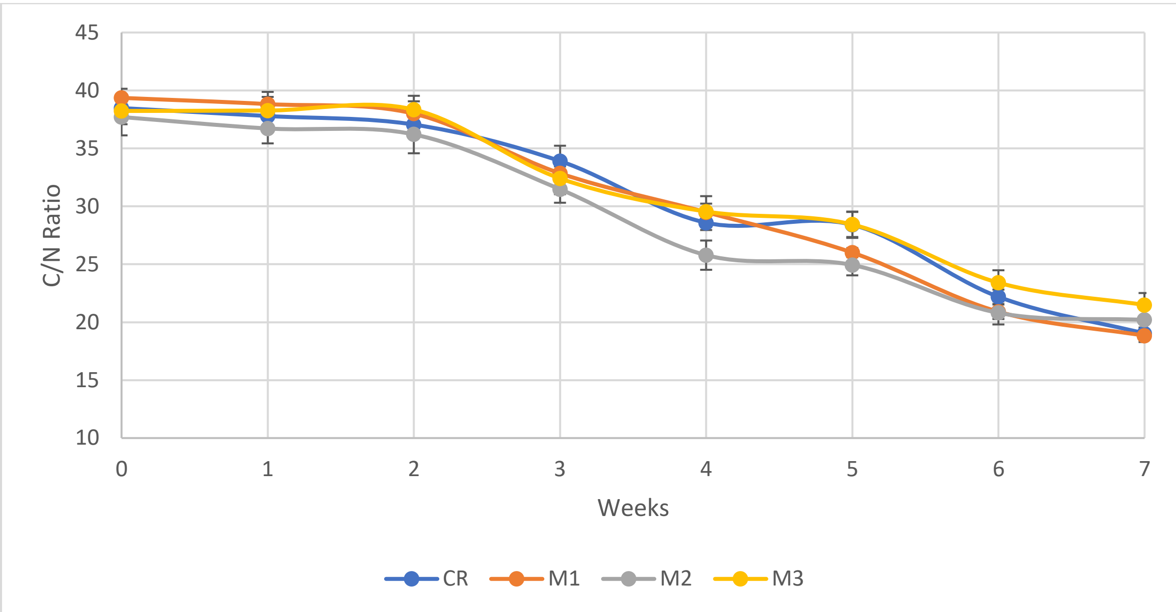

Figure 12. C/N ratio behavior in mixtures (CR, M1, M2 and M3) during the vermicomposting process.

These values are similar to initial C/N ratios of 34.32 and 35.01 in vermicomposting processes using maize stover and chicken droppings [13]. Gupta and Garg state the ideal C/N ratio for vermicomposting is 30:1 [66]. However, a study using vegetable solid waste and cow dung showed an initial C/N ratio of 50.8 [53].

A decrease in C/N ratio values was observed during the experiment as a result of carbon loss in the form of CO_2 due to microbial respiration and the addition of biological residue rich in nitrogen produced by earthworms [66,69]. This decrease in C/N ratio has been reported in research using similar substrates such as maize stover and chicken droppings [12] and wheat straw [14]. Final values for CR, M1, M2 and M3 were 19.03, 18.84, 20.20 and 21.49 respectively, like 21 and 27 reported by Romero et al. [16] and to the 23.5 obtained by Suthar [53].

3.2.8. Vermicompost Quality

Table 2 shows the physicochemical composition of the four mixtures obtained during the vermicomposting process.

In the vermicomposting process, there was a contribution of micronutrients (fiber, calcium, sulfur, iron, phosphorus, magnesium, copper, potassium, manganese, zinc, aluminum, boron, molybdenum, vitamin A, B, C, E and K, folic acid, flavonoids, fatty acids, amino acids, protein and carbohydrates) due to their content in vegetable waste and eggshell [20,21,70–75].

The evaluation of the vermicomposting process was carried out by counting the number of earthworms. Their survival was monitored during the whole process (seven weeks) and at the end of the experiment a new count was made, obtaining an increase of the number of earthworms for M1 (124), M2 (103) and M3 (90) as was reported by other authors [8,76]; therefore, this increase demonstrates the effectiveness of the vermicomposting process.

4. Conclusions

The analysis of the results obtained at the end of the pre-composting process was able to prove that the substrate reached a partial stabilization with a favorable TOC removal percentage; this contributed to facilitating the substrate degradation by the earthworms.

The load material for this experiment included vegetable waste and eggshells to balance the nutrients of the substrate, in contrast to most studies using animal manure. At the end of the vermicomposting process, the values of the parameters pH, OM, TOC, TN and C/N ratio of the four mixes were within the established range of local norms and/or WHO international standards for a quality vermicompost, which means that the final product can be used as a soil improver.

Thus, this research proves the feasibility of the vermicomposting process as an effective and sustainable alternative to the valorization of corn cob waste, avoiding inadequate disposal and its subsequent environmental impact considering its high demand as a market cereal.

Future research will require the exploration of the use of alternative mixtures for load materials to facilitate degradation of corn cob waste as well as to determine micronutrients characteristics and possible content of heavy metals, among others.

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