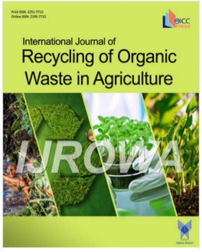

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Vermicomposted corn waste in the organic cultivation of cherry tomato seedlings and its effects on the soil-plant system

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Original Research

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Abstract:

Purpose: In this study, vermicomposted corn waste was applied to the organic cultivation of cherry tomato seedlings under the edaphoclimatic conditions of the Brazilian semiarid region, and the effects were evaluated in the soil–plant system.

Method: The vermicomposts were prepared by mixing corn waste in an organic substrate. The experiment was divided into two parts: sowing in trays and growing seedlings in pots. In both steps, the following biometric attributes were evaluated: plant size, root length, root weight, aboveground biomass, leaf weight, and leaf area. Three vermicompost concentrations were assessed: 1.5%, 3.0%, and 6.0% (m/m). As a control, a soil sample without vermicompost was also evaluated.

Results: In general, plants that grew in a substrate containing vermicompost developed more when compared to the sample control (19.2 – 22.0 *vs* 15 cm). Furthermore, in general, plants cultivated with higher vermicompost concentrations presented better results in all evaluated parameters. In addition, a sample composed of a mixture of corn straw and cob showed the best results, indicating that joint management of both residues is advantageous for all assessed attributes.

Conclusion: The results confirm the expectation that it is possible to apply vermicomposted corn residues in the organic cultivation of cherry tomatoes and that the strategy of carrying out germination in a tray, followed by transplantation into pots, had a positive effect on the development of seedlings. When compared to other studies, the climatic and edaphoclimatic conditions experienced in this work did not interfere with plant development, since the seedlings showed good development results in all evaluated parameters.

Keywords: Environmental technologies; Agricultural waste; Organic agriculture; Agrarian development

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1. Introduction

Numerous challenges have been faced by small farmers located in the tropics for many decades, resulting in low food and energy productivity, generally associated with soil fertility (low levels of nutrients, inadequate management, and exacerbated land use, in addition to edaphoclimatic factors) (Mittler and Blumwald, 2010; Lima et al., 2016). Many studies have demonstrated how organic matter (OM) is important for modernizing agricultural practices, influencing soil quality, and being an important factor in the development of sustainable agriculture (Mittler and Blumwald, 2010; Campos-Silva et al., 2021).

Despite these problems, corn (*Zea mays* L.) is a culture well adapted to the semiarid climate and is one of the main sources of income for small farmers. Despite climatic conditions and unfavorable soil quality, maize is distributed throughout the Brazilian semiarid region and has great cultural, economic, and social importance, intended for human consumption and animal feed (Carvalho et al., 2000; Lopes et al., 2019; Tiammee and Likasiri, 2020). In addition to corn production, a large amount of waste is also generated, which includes mainly corn straw and cob. Normally, these residues are reused by rural farmers as animal feed or just burned or discarded on the ground, which can cause serious consequences for the environment, such as soil contamination and eutrophication of water bodies (Dores-Silva et al., 2013; Rajkhowa et al., 2019; Vieira-Júnior et al., 2020; Chaves et al., 2021). In this sense, vermicomposting has been consolidated as a viable alternative in the recycling of agricultural waste for the production of organic inputs, adding value to the residues (Bhat et al., 2018; Campos-Silva et al., 2021). Vermicomposting is an environmental technology that transforms fresh OM into stabilized OM based on the combined action of earthworms and microorganisms that live in their digestive tracts, treating and altering the organic structures of waste. During the process of OM stabilization, the feedstock is transformed into a more stable material with greater agronomic potential for plant production. During vermicompost production, chemical compounds are released in the form of organic and mineral nutrients, which are easily assimilated by plants (Dores-Silva et al., 2011; Cotta et al., 2015; Nunes et al., 2016; Scaglia et al., 2016; Devi and Khwairakpam, 2020).

In this case, the recycling of agricultural waste by vermicomposting has been one of the solutions that organic agriculture has found to reduce possible environmental impacts caused by conventional agriculture, as well as to increase productivity and improve soil quality, promoting a model of sustainable agriculture less aggressive to the environment (Campos-Silva et al., 2021).

The use of vermicompost is recommended for different crops, with emphasis on the cultivation of vegetables and fruits, e.g., tomatoes and their varieties. The cherry tomato (*Solanum lycopersicum* var. *cerasiforme*), from the *Solanaceae* family, is a plant well adapted and resistant to diseases and climate change. However, special care is required throughout its cultivation, especially during germination, flowering, and fruit growth periods (Munir et al., 2013; Widjajanto et al., 2023; Martínez-Cuenca et al., 2020).

Many studies have shown the benefits of vermicompost in the seedling cultivation of vegetable and fruit plants (Truong et al., 2018; Silva et al., 2020; Liu et al., 2022; Wako and Muleta, 2023). Vermicomposts supply a balanced dose of essential nutrients, providing significant benefits to seedling development and favoring healthy growth (Hashemimajd et al., 2004; Manh and Wang, 2014; Oliveira et al., 2015). This work aimed to study the application of vermicomposted corn waste in the organic cultivation of cherry tomato seedlings, in addition to evaluating its effects on the soil-plant system.

2. Materials and methods

Vermicompost production

This study was conducted using vermicomposts of corn straw and cob (main residues) mixed with an organic substrate (OS, composed of goat manure and sawdust) (Campos-Silva et al., 2021).

The vermicomposters were set up in 25 L plastic barrels containing different proportions of fresh wastes (based on dry volume). The proportion of the substrates was determined by a combination of their C:N ratio. The following samples were analyzed: *i.* Corn straw mix (S); *ii.* Corn cob mix (C); and *iii.* Corn straw + cob mix (CS). For comparison, a vermicomposter with no corn waste was also prepared (standard sample-STD) (Campos-Silva et al., 2021).

After the mixtures were made, the material rested for 1 week; then, all of the contents were turned manually once a week. For vermicompost production, 250 newborn earthworms (*Eisenia fetida* L.) were added to each vermicomposter. Each vermicomposting treatment was performed in triplicate. In addition, vermicomposters were covered with dry leaves of *Tabebuia impetigosa*, favoring earthworm acclimatization (Campos-Silva et al., 2021).

After vermicomposting (120 days), the following chemical and fertility attributes were determined in the vermicomposts: total solids (ST), pH, electrical conductivity (EC), cation exchange capacity (CEC), base saturation (BS), organic matter (OM), and total organic carbon (TOC) (Table 1), in addition to the contents of macro- and micronutrients (Table 2) (EMBRAPA, 2017).

Soil

Samples of Ferric Lixisol (USDA: Oxic Paleustalf) were collected on the campus of the Federal Rural University of

Table 1. Chemical attributes of the vermicomposted corn waste.

Sample	TS %	pH –	EC μ S cm^{-1}	CEC cmol$_c$ kg^{-1}	BS %	OM %	TOC %	N %	C:N ratio –
STD	92.79a	7.11b	136.45b	410.47a	99.58a	62.87d	31.45b	2.11a	4.99a
S	91.42a	6.86a	133.93a	495.05b	99.72a	59.13cd	31.05b	2.25a	5.53ab
C	96.95b	6.82a	133.60a	564.76c	99.68a	49.88a	27.6a	2.37ab	5.90b
CS	92.48a	6.86a	137.78b	648.48d	99.72a	53.66b	30.07ab	2.49b	4.59a

Mean followed by one-way ANOVA bootstrap and Duncan's test, n = 3, $p < 0.05$, on dry matter basis. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. TS Total solids, EC Electrical conductivity, CEC Cation exchange capacity, BS Base saturation, OM Organic matter, TOC Total organic carbon.Values in the same column followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

Pernambuco (UFRPE) in the municipality of Serra Talhada, Pernambuco, Brazil (7°57′11.4″S 38°17′41.0″W). The material was sieved to 2.0 mm and air-dried. Soil collection and preparation were conducted in June 2021 under an average temperature of 26° C and precipitation of 21 mm. To characterize the soil, the following attributes were determined: total solids (ST), pH, electrical conductivity (EC), exchangeable acidity (A), sum of bases (SB), cation exchange capacity (CEC), base saturation (BS), organic matter (OM), total organic carbon (TOC), micro- and macronutrients, particle-size distribution, and soil texture (Table 3) (EMBRAPA, 2017).

Cherry tomato cultivation

Sowing in trays

The agronomic tests were divided into two stages: seedlings (in trays) and seedling cultivation (transplanted in pots). Tests were carried out using cherry tomato seeds (*Solanum lycopersicum* var. *cerasiforme*) (Feltrin R, Farroupilha, Brazil).

For seedling cultivation, three substrates were prepared from a mixture of soil and vermicomposts at three concentrations: 1.5%, 3.0%, and 6.0% (m/m). In addition, a control sample was also prepared, which used only soil (without the addition of vermicompost).

Each tray contained 36 culture cells of 25 mL. The cells were filled with the substrate, and 1 seed was placed per cell. The trays were watered daily with 5 mL of water per cell.

Germination was monitored daily, and the number of germinated cells was recorded. The germination rate (%GR) was calculated based on the percentage of germinated seeds in relation to the total number of cultivated seeds.

After 14 days of cultivation, the seedlings were removed, washed, and air-dried. Thus, the following morphometric and biomass attributes were recorded: plant size (h), root length (RL), aboveground biomass weight (AW), root weight (RW), and leaf weight (LW).

The experiment was carried out in a greenhouse at the Federal Rural University of Pernambuco, municipality of Serra Talhada, Pernambuco, Brazil (7° 57′ 09.4″S 38° 17′ 42.9″W). According to Koppen-Geiger, the local climate is of the BSwh' type (semiarid and hot climate, with dry winter), with an average annual rainfall of 642 mm (Alvares et al., 2013). During the experiments, air temperature and relative air humidity were measured as 24.8° C and 62%, respectively.

Seedling cultivation in pots

After reaching 3 cm in the trays, the cherry tomato seedlings were transplanted into pots. Ten pots (replicates) were prepared for each sample at concentrations of 1.5%, 3.0%, and 6.0% (m/m). The plants were watered daily with approximately 50 mL of water. Irrigation was carried out using the Hargreaves and Samani (1982) model, estimating evapotranspiration and daily temperatures.

For the organization of the experiment, the pots were distributed randomly on benches, with 10 pots distributed on two benches, with a size of 6.0 × 0.6 m. In total, 10 pots were arranged in a 2 × 5 system (column × row). Each column corresponded to one board. The distance between the pots was 10.0 cm, and positions were changed weekly at random. Positions were modified to minimize possible external influences, e.g., shade and wind.

During cultivation, the size of the seedlings was measured every three days. After 30 days, the seedlings were removed, and the following morphometric parameters were determined: plant size (h), root length (RL), above-ground biomass weight (AW), root weight (RW), and leaf weight (LW). The leaf area was determined using Im-age-Pro ® PLUS software.

Leaf analysis

Macro- (N, P, K, Ca, S, and Mg) and micronutrient (B, Cu, Mn, Zn, and Fe) contents were determined in the leaves of seedlings grown in pots. The leaves were dried in a ventilated oven for 24 h and then crushed in a ball mill.

Table 2. Contents of macro- and micronutrients in the vermicomposts.

Nutrients	STD	S	C	CS
N (%)	2.01a	2.19b	2.17b	2.19b
P (%)	0.55a	0.57a	0.60a	0.65a
K (%)	2.82b	2.22a	2.31a	3.17c
Ca (%)	1.64a	1.62a	1.70b	2.10c
Mg (%)	0.61ab	0.57a	0.66b	0.69b
S (%)	0.37a	0.44a	0.42a	0.48a
B (mg kg^{-1})	4.31a	4.29a	4.33a	3.76a
Cu (mg kg^{-1})	7.92b	6.55a	6.21a	7.83b
Mn (mg kg^{-1})	0.99a	0.89a	0.89a	1.03a
Zn (mg kg^{-1})	0.12a	0.14a	0.09a	0.16a
Fe (g kg^{-1})	1.89a	2.01ab	2.22b	2.18b

Mean followed by one-way ANOVA bootstrap and Duncan's test, n = 3, $p < 0.05$, on dry matter basis. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. Values in the same row followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

Samples were prepared in digester tubes using H_2SO_4 9.0 mol L^{-1} and HNO_3 2.0 mol L^{-1} at $180-200°$ C for 3 h. The determination of macro- and micronutrient contents was performed using an ICP OES Optima 8000 Dual View, Perkin Elmer (Waltham, USA) (EMBRAPA, 2017).

Statistical analysis

Initially, data were tested for normality (Shapiro-Wilk test) and homoscedasticity (Bartellet test) at $p < 0.05$ and different values of n, depending on the test. Parametric and homoscedastic data were compared by one-way bootstrap ANOVA, and differences between means were evaluated using Duncan's multiple amplitude test (MRT).
Nonparametric and heteroscedastic data were compared using one-way ANOVA, and differences between medians were assessed using the Kruskal-Wallis test. IBM SPSS v.20 was used for data analysis (licensed software).

Laboratory procedures

Laboratory procedures, analytical or not, including agronomic tries, were carried out following the requirements, when applicable, of the ISO/IEC 17025 — General Requirements for the Competence of Testing and Calibration Laboratories — and with the principles of Good Laboratory Practices (GLP) to guarantee data traceability and quality management, adding value and credibility to the obtained results.

3. Results and discussion

Sowing in cultivation tray

Data of *S. lycopersicum* sown in trays are shown in Fig. 1 and Table 4 (germination rate, %GR); and Table 5 (morphometric indices).

Initially, seeds that received vermicomposts (samples STD, S, C, or SC) germinated and developed more in comparison with the sample control (only soil) during the first 14 days of cultivation. In addition, plants that received higher doses of vermicompost developed more, presenting higher average growth (doses $6.0 > 3.0 > 1.5$ m/m). In the comparison between the types of vermicompost, the addition of corn waste positively affected the %GR, since the sample STD (only vermicomposted organic substrate, without the addition of corn waste) presented results below the other vermicompost samples. The best results were obtained in samples C/6.0% and CS/6% (%GR = 74.4% and 73.3%, respectively) (Table 4).

Analyzing the growth (h), plants that received vermicomposts at 6.0% developed more concerning the sample control (soil) in addition to the vermicomposts at 1.5% ($1.8-2.3$ against $3.3-3.6$ cm), with values significantly different between groups (bootstrap ANOVA, $p < 0.05$) (Table 5). The

Table 3. Chemical attributes and nutrient contents of Ferric Lixisol used in cherry tomato organic cultivation.

Attributes	Soil
ST (%)	99.12 ± 0.03
pH	5.08 ± 0.04
CE (μS m^{-1})	89.83 ± 4.23
OM (%)	2.12 ± 0.17
TOC (%)	0.43 ± 0.02
A ($cmol_c$ kg^{-1})	32.07 ± 0.13
SB ($cmol_c$ kg^{-1})	29.11 ± 0.26
CEC ($cmol_c$ kg^{-1})	61.18 ± 0.33
BS (%)	47.58 ± 0.22
Nutrients:	
N (%)	1.23 ± 0.01
P (%)	0.42 ± 0.03
K (%)	1.42 ± 0.10
Mg (mg kg^{-1})	26.42 ± 0.04
Ca (mg kg^{-1})	12.44 ± 0.26
Na (mg kg^{-1})	< LOQ
B (mg kg^{-1})	< LOQ
Cu (mg kg^{-1})	189.24 ± 23.62
Mn (mg kg^{-1})	276.75 ± 19.33
Zn (mg kg^{-1})	127.81 ± 6.37
Fe (g kg^{-1})	73.73 ± 12.92
Particle-size distribution:	
Sand (%)	58.32 ± 4.28
Silt (%)	11.07 ± 1.07
Clay (%)	30.61 ± 4.91
Soil texture	Sandy clay loam

Mean followed by standard deviation, n = 3, $p < 0.05$, on dry matter basis. TS Total solids, EC Electrical conductivity, OM Organic matter, TOC Total organic carbon, A Exchangeable acidity, SB Sum of bases, CEC Cation exchange capacity, BS Base saturation. LOQ Limit of quantitation.

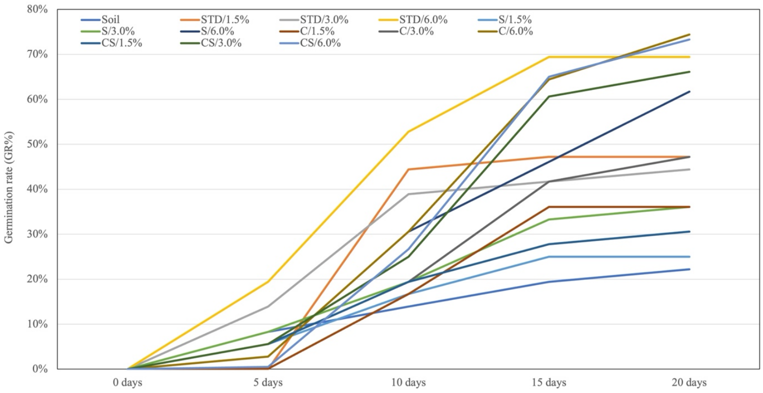

Figure 1. Germination rate (%GR) of cherry tomato (*S. lycopersicum*) sown in trays.

plant sizes (h) were also proportional to the vermicompost concentration: higher vermicompost concentrations led to higher plant heights (6.0 > 3.0 > 1.5 m/m). Higher values of h were reported at a dose of 6% of each vermicompost. Samples C/6.0% and CS/6.0% reached 3.3 and 3.6 cm, respectively, without significant differences (ANOVA bootstrap, $p < 0.05$). The smallest growth was obtained in the sample control (1.8 cm) and in the plants that received 1.5% vermicompost (2.3 – 2.7 cm) (Table 2).

Regarding the influence of vermicompost on root length (RL) (Table 5), plants that received vermicomposts S, C, and CS at doses of 3.0 and 6.0% presented the smallest root (1.5 – 1.8 cm) compared to the samples control, STD/1.5%, and STD/3.0% that presented the longest (3.9 – 4.1 cm), with data significantly different between these groups (bootstrap ANOVA, $p < 0.05$). These results indicated that the S, C, and CS vermicomposts provided better nutrition for the plants, not requiring greater root growth in the search for water and nutrients, as observed in the other samples. Therefore, sowing with smaller roots is associated with a greater nutritional potential of the vermicompost produced from corn residues.

Regarding root weight (RW), values varied randomly and were unrelated to the root length (RL) data (Table 5).

Plants that received vermicomposts S, C, and CS presented higher contents of aboveground biomass (AW) compared to the sample control and STD/1.5%. Values of AW also increased according to the vermicompost concentration. The best results were obtained in CS/6.0% (0.0189 g), whereas the lowest results were obtained in samples STD/1.5% and control (0.002 and 0.003 g, respectively), with significant differences between groups and no differences between individual values per group (bootstrap ANOVA, $p < 0.05$).

Data on leaf weight (LW) (Table 5) also indicated that plants cultivated with vermicompost presented higher leaf weight when compared to the control. In addition, at higher vermicompost concentrations, a more stimulating effect on leaf production was observed, which is also associated with

Table 4. Germination rate (%GR) of cherry tomato (*S. lycopersicum*) sown in trays using soil and vermicomposted corn waste at different concentrations (1.5%, 3.0%, and 6.0%) (n = 36; n° of cells).

Sample	**5 days**	**10 days**	**15 days**	**20 days**
	(%)	**(%)**	**(%)**	**(%)**
Soil (control)	8.3	13.9	19.4	22.2
STD/1.5%	0.0	44.4	47.2	47.2
STD/3.0%	13.9	38.9	41.7	44.4
STD/6.0%	19.4	52.8	69.4	69.4
S/1.5%	5.6	16.7	25.0	25.0
S/3.0%	8.3	19.4	33.3	36.1
S/6.0%	2.8	30.6	46.1	61.7
C/1.5%	0.1	16.7	36.1	36.1
C/3.0%	5.6	19.4	41.7	47.2
C/6.0%	2.8	30.6	64.4	74.4
CS/1.5%	5.6	19.4	27.8	30.6
CS/3.0%	5.6	25.0	60.6	66.1
CS/6.0%	0.5	26.7	65.0	73.3

STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw.

greater plant development. Sample STD/6% presented the highest LW (0.0124 g). In general, sample control and vermicomposts at a dose of 1.5% presented the smallest results, with no significant differences in LW values (bootstrap ANOVA, $p < 0.05$). Other values of LW varied randomly.

Seedling cultivation in pots

Table 6 presents the results obtained in the seedling cultivation of cherry tomato (*S. lycopersicum*) in pots. In general, the trend observed during sowing in trays was also reported in seedling cultivation in pots. The treatments containing vermicomposts presented a better result concerning the sample control, in addition to the plant growth that increased proportionally to the vermicompost doses in the substrates (6.0% > 3.0% > 1.5% m/m) (Fig. 2).

Seedlings with the highest sizes (h) were obtained in the S/6,0% and CS/6,0% samples (21.6 and 22.0 cm, respectively). On the other hand, the smallest growth was obtained in the sample control (15.0 cm) and in the treatments that received vermicomposts at a concentration of 1.5% (15.5 – 16.8 cm), except for the S/1.5% sample (20.5). The samples that received vermicompost at concentrations of 3.0% and 6.0% did not show significant differences in their results, nor did the control sample and the plants that received vermicompost at a dose of 1.5% (ANOVA bootstrap, $p < 0.05$).

Regarding the root lengths (RL), the seedlings that received vermicomposts at higher doses presented smaller roots (12.5 – 14.4 cm), except for the vermicomposts STD. Samples control and STD presented longer roots (21.0 – 29.2 cm) (Table 6). The results of the elements in each group did not show significant differences between them, but the data were significantly different when comparing groups (bootstrap ANOVA, $p < 0.05$). This finding reinforces that vermicomposted corn waste provides a greater amount of nutrients for plant nutrition, reducing the need for root growth to supply water and nutrients, as observed in the other samples.

Values of root weight (RW) varied randomly (Table 6). Regarding the aboveground biomass (AW), seedlings cultivated with vermicomposts S, C, and CS presented higher weights when compared to the soil and STD samples. The sample with the highest AW was CS/6.0% (3.5 g). On the other hand, the sample that presented the lowest AW was C/1.5% (1.4 g).

Concerning the leaves, the weight (LW) varied randomly, and area (A) followed a trend: the control and samples that received 1.5% of vermicompost presented leaves with smaller areas ($2.1 - 2.8$ cm^2), which were significantly different from the others. Higher vermicompost doses induced higher leaf areas (6.0% > 3.0% > 1.5% m/m). Better results were obtained in the C/6.0% and CS/6.0% samples (4.9 and 4.8 cm^2, respectively).

Leaf analysis

The following tables present the contents of macro- (Table 7) and micronutrients (Table 8) determined in the leaves of *S. lycopersicum* seedlings.

In general, samples control and STD presented the highest levels of macronutrients, followed by the treatments that received 1.5% of vermicompost, with emphasis on S (1.21 – 1.10%), N (2.34 – 1.37%), and K (6.61 – 5.21%). In addition, some nutrients were determined in lower concentrations, indicating a nutritional deficiency of plants with smaller development, e.g., Mg (0.12%) and Ca (1.31%) in the sample control.

Regarding micronutrients, sample control showed intermediate nutrient levels when compared to treatments containing vermicompost. However, the visual analysis of their leaves indicated a yellowing characteristic of nutritional deficiency associated with the chlorosis of plant tissues (Malavolta et al., 1997; Malavolta, 2006; Faquin, 2005).

Table 5. Morphometric indices of cherry tomato (*S. lycopersicum*) sown in trays using soil and vermicomposted corn waste at different concentrations (1.5%, 3.0%, and 6.0%).

Sample	h	RL	RW	AW	LW
	cm	cm	g	g	g
Soil (control)	1.8a	3.9cd	0.0009ab	0.0030ab	0.0019ab
STD/1.5%	2.7abc	4.1d	0.0011ab	0.0020a	0.0051cde
STD/3.0%	2.9abc	4.1d	0.0036f	0.0066de	0.0065de
STD/6.0%	3.4c	2.8bc	0.0016bc	0.0068bcd	0.0124g
S/1.5%	2.4abc	2.6abc	0.0017de	0.0036abc	0.0026abc
S/3.0%	2.4abc	1.8abc	0.0032ef	0.0062cde	0.0041cd
S/6.0%	3.1bc	2.1abc	0.0036bc	0.0067de	0.0078f
C/1.5%	2.3ab	1.4abc	0.0007a	0.0052cde	0.0025abc
C/3.0%	3.4bc	1.3a	0.0011ab	0.0080e	0.0027abc
C/6.0%	3.6c	1.6abc	0.0023cd	0.0116g	0.0057bcd
CS/1.5%	2.3ab	1.6ab	0.0017bc	0.0063cd	0.0012a
CS/3.0%	2.3ab	1.6abc	0.0016bc	0.0070de	0.0052de
CS/6.0%	3.3c	1.5abc	0.0016bc	0.0189g	0.0067bcd

Mean followed by ANOVA one-way bootstrap and Duncan's test, n = 36, $p < 0.05$, on dry matter. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. h Plant size, RL Root length, AW Aboveground biomass weight, RW Root weight, and LW Leaf weight. Values in the same row followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

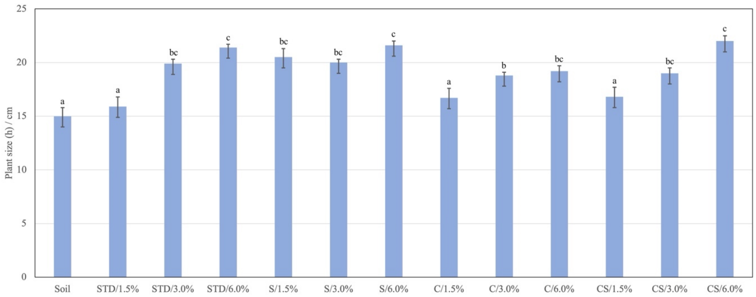

Figure 2. Average growth of tomato seedlings in pots after 30 days of cultivation.

Treatments with higher vermicompost concentrations presented lower levels of micronutrients. Sample STD/6.0% presented the highest levels of B (132.32 mg kg^{-1}) and Zn (125.34 mg kg^{-1}). In the S/6.0% sample, the highest

Table 6. Morphometric indices of cherry tomato seedlings (*S. lycopersicum*) cultivated in pots using soil and vermicom-posted corn waste at different concentrations (1.5%, 3.0%, and 6.0%).

Sample	h	RL	RW	AW	LW	A
	cm	cm	g	g	g	cm^2
Soil (control)	15.0a	21.0bc	0.3c	2.5ab	1.0ab	2.2a
STD/1.5%	15.9a	26.1bc	0.3bc	2.4ab	1.2ab	2.1a
STD/3.0%	19.9bc	29.2c	0.4c	3.5b	1.4b	3.2b
STD/6.0%	21.4c	20.3bc	0.1a	3.1ab	1.3ab	4.0b
S/1.5%	20.5bc	19.4bc	0.1a	3.2ab	1.5b	2.8a
S/3.0%	20.0bc	17.4b	0.1a	3.0ab	1.7b	3.5b
S/6.0%	21.6c	12.5a	0.2ab	3.7b	1.3ab	3.5b
C/1.5%	16.7a	17.5ab	0.1a	1.4a	1.0ab	2.9ab
C/3.0%	18.8b	13.1a	0.1a	2,2ab	0.6ab	4.4bc
C/6.0%	19.2bc	13.2a	0.2ab	3.2ab	1.9a	4.9c
CS/1.5%	16.8a	20.9bc	0.1a	2.7ab	1.2ab	2.7a
CS/3.0%	19.0bc	18.5bc	0.2ab	3.4b	1.4b	4.1b
CS/6.0%	22.0c	14.4abc	0.2ab	3.5ab	1.7ab	4.8c

Mean followed by ANOVA one-way bootstrap and Duncan's test, n = 10, $p < 0.05$, on dry matter basis. Time = 30 days. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. h Plant size, RL Root length, AW Aboveground biomass weight, RW Root weight, LW Leaf weight, and A Leaf area. Values in the same column followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

Table 7. Macronutrients quantified in leaves of cherry tomato seedlings (*S. lycopersicum*) cultivated in pots using soil and vermicomposted corn waste at different concentrations (1.5%, 3.0%, and 6.0%).

Sample	N	P	K	Ca	Mg	S
						%
Soil (control)	1.87ab	0.31a	5.21b	1.31a	0.12a	1.10b
STD/1.5%	2.34b	0.43a	6.61b	2.13ab	0.49ab	0.69ab
STD/3.0%	1.94ab	0.51ab	6.60b	2.09a	0.41a	1.01ab
STD/6.0%	2.21b	0.21a	5.37b	2.27c	0.69ab	1.21b
S/1.5%	1.73ab	0.35a	4.99b	3.01c	0.68ab	1.19bc
S/3.0%	1.81ab	0.49ab	5.12b	2.89c	0.61ab	0.79b
S/6.0%	1.36a	0.57b	5.88b	2.00ab	0.49a	0.81ab
C/1.5%	1.61a	0.41a	5.79b	2.03ab	0.69ab	0.73ab
C/3.0%	1.88ab	0.52a	5.42b	2.33b	0.66ab	1.00ab
C/6.0%	1.91ab	0.61b	5.70b	2.07ab	0.69ab	0.94a
CS/1.5%	1.54a	0.21a	2.59a	2.18ab	0.55ab	0.81a
CS/3.0%	1.72a	0.20a	2.46a	1.98ab	0.61ab	0.73a
CS/6.0%	1.44ab	0.21a	1.99a	1.88ab	0.60ab	0.67a

Mean followed by ANOVA one-way bootstrap and Duncan's test, n = 3, $p < 0.05$, on dry matter basis. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. Values in the same column followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

Table 8. Macronutrients quantified in leaves of cherry tomato seedlings (*S. lycopersicum*) cultivated in pots using soil and vermicomposted corn waste at different concentrations (1.5%, 3.0%, and 6.0%).

Sample	B	Cu	Mn	Zn	Fe
					mg kg^{-1}
Soil (control)	79.21b	1.13a	214.11bc	101.28ab	1123.46c
STD/1.5%	82.36b	0.21a	137.54a	100.48 ab	632.39a
STD/3.0%	71.45ab	0.32ab	113.49a	81.99a	543.34a
STD/6.0%	132.32c	1.24d	348.12c	125.34b	1266.24d
S/1.5%	126.46c	0.45b	201.41b	100.15a	1579.96e
S/3.0%	114.12c	0.61bc	201.52b	101.38ab	1321.47c
S/6.0%	56.16a	2.07e	117.00 to	101.35ab	863.52b
C/1.5%	81.48b	1.99e	272.42b	100.92ab	641.34a
C/3.0%	75.17ab	0.94c	99.24a	100.37ab	826.41ab
C/6.0%	51.44a	0.18a	235.07b	101.86ab	853.52b
CS/1.5%	81.22ab	0.57b	387.37d	121.47b	1126.48c
CS/3.0%	55.41a	0.31ab	301.25c	94.71a	802.25b
CS/6.0%	66.83a	0.91c	303.12c	104.23b	578.16 to

Mean followed by ANOVA one-way bootstrap and Duncan's test, n = 3, $p < 0.05$, on dry matter basis. STD Vermicompost control (only organic substrate), S Vermicomposted corn straw, C Vermicomposted corn cob, CS Vermicomposted corn cob and straw. Values in the same column followed by the same letter are not statistically different at $p < 0.05$ from each other, according to one-way ANOVA and Duncan's test.

levels of Fe (1579.96 mg kg^{-1}) and S (2.07 mg kg^{-1}) were quantified. On the other hand, sample C/6.0% presented the lowest contents of B (51.44 mg kg^{-1}), Cu (0.18 mg kg^{-1}), and Mn (99.24 mg kg^{-1}).

When comparing the results of leaf areas (Table 6) with the data of leaf analysis (Table 7 and Table 8), samples with the highest levels of macro- and micronutrients presented the smallest leaves, and vice versa. This occurred due to the nutrient dilution in plant tissues, making more developed plants present lower concentrations of some metals and nutrients. Generally, nutrient dilution in the leaf occurs when the plant presents rapid growth, and the nutrients are absorbed at a slow rate. When the growth rate is zero or negative, nutrients will continue to be absorbed and become concentrated in the vegetal tissue (Malavolta et al., 1997; Faquin, 2005; Nunes et al., 2018).

Comparing the data reported with other studies, Costa et al. (2018) investigated the effect of different combinations of cattle manure, vermicomposted slaughterhouse waste (e.g., viscera, rumen, blood), and vermiculite in the cultivation of cherry tomato seedlings. The authors used different combinations of substrates and demonstrated how the plants cultivated with higher amounts of vermicompost presented better development, as reported in this study.

Erşahin et al. (2017) evaluated the effect of vermicompost produced from a mixture of cattle manure and kitchen scraps on the germination and growth of cherry tomato seedlings. The data reported in this study are different from ours in terms of germination rate (%GR) and seedling height (h). First, vermicompost addition reduced the %GR compared to the control. In addition, the size of the plants decreased under the application of larger amounts of vermicompost. Both results were the opposite of those reported in this study. According to the authors, high pH (8.3) inhibited nutrient absorption, reducing plant development. Moreover, in our study, sowing reached a maximum size of 3.6 cm in the CS/6% sample, while Erşahin et al. (2017) reached plants of 2.4 cm (40% difference). The authors also determined the nutrient content in the leaves of cherry tomato seedlings. In general, the contents of N, P, Ca, Mg, Zn, Fe, Mn, and B were lower than those in this study, while the contents of K and Cu were higher.

In general, when comparing our results with other studies, the data reported in this work are equivalent or superior in many aspects in the evaluated attributes, indicating that vermicomposted corn waste supplies the nutritional demands of cherry tomato seedlings, in addition to supporting the expected adequate plant development.

4. Conclusion

Our findings confirmed the expectation that it is possible to apply vermicomposts from corn waste in the organic cultivation of cherry tomato seedlings. The approach of sowing seeds in trays followed by transplanting in pots presented a positive effect on seedling development. In general, the addition of vermicompost positively influenced the development of seedlings, which grew and developed more - in all evaluated aspects - when compared to the control sample (seedlings grown only in soil). In addition, higher doses of vermicompost presented better results (6.0% > 3.0% > 1.5%). Sample CS/6.0% was the best substrate evaluated, indicating that the joint processing of corn wastes (straw and cob) is more advantageous since the effect of the combined sample was more beneficial to the plants than each one of the residues separately. Levels of macro- and micronutrients showed that more developed plants were better nourished, indicating a high nutritional potential of the vermicomposts, favoring the growth of stronger, healthier, and more resistant plants. When compared to other studies, the climatic and edaphoclimatic conditions experienced in this work did not interfere with plant development since the seedlings presented good development in all evaluated parameters.

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Authors contributions

José Matheus Oliveira: Conceptualization, Visualization, Formal analysis, Data curation, Writing-original draft, Writing-review & editing. Jefferson Campos Silva: Conceptualization, Visualization, Formal analysis, Data curation. Andreza Jayane Nunes Siqueira: Conceptualization, Visualization, Formal analysis, Data curation. Ramom Rachide Nunes: Project administration, Funding acquisition, Supervision, Conceptualization, Methodology.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests

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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