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COMPOSTING PROCESS IN THE PRODUCTION OF LETTUCE SEEDLING SUBSTRATES: EFFECT OF COVERING AND TURNING FREQUENCY

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KEYWORDS

environmental conditions, leaching, seed germination index, Dickson quality index.

ABSTRACT

The composting of waste from a broiler chicken production chain (BCPC) promotes the mitigation of environmental impacts and allows the commercialization of compost as an agricultural input. Both the characteristics and the potential for use of the final compost depends on the operational conditions during composting. The objective of this study was to evaluate the use of organic compounds generated from composting BCPC residues and the pruning debris of urban trees in the germination and initial growth of lettuce seedlings. Six organic substrates obtained under different coverage conditions (presence and absence) and number of turns (8, 12, and 16) were evaluated using the germination index (IG) and Dickson quality index (DQI) for the production of seedlings in trays and compared with a commercial substrate. Principal component analysis demonstrated that the IG is not related to the DQI. The compounds produced without coverage showed lower levels of electrical conductivity ($p < 0.05$) and potassium ($p < 0.05$) due to the leaching of soluble salts during composting. These substrates did not inhibit seed germination (IG $\geq$ 75%), but resulted in less robust seedlings, mainly in relation to the aerial portion. BCPC residues were viable for composting treatment and the DQI of the organic compounds (0.0125) used as substrates for the initial growth of lettuce seedlings were, on average, 14% higher than that obtained from the commercial substrate (0.090), indicating that the organic compounds were of better quality.

INTRODUCTION

The use of agro-industrial residues from a broiler production chain (BPC) based on biological stabilization processes presents advantages from an environmental and economic point of view because it promotes the stabilization of environmental problems (Costa et al., 2009) and allows its commercialization as an agricultural input. The stabilization of these organic residues through the composting process has been reported both in the national (Costa et al., 2016; Bernardi et al., 2018) and international literature (Costa et al., 2017; Chiarelotto et al., 2019).

However, depending on the characteristics of the organic compost obtained at the end of composting, it can only be used either as an organic fertilizer or as a substrate for seedling production. While the use of organic compost as fertilizer presupposes its distribution on the soil surface, its use as a substrate for seedling production imposes direct contact with the seeds, directly interfering with the initial germination stage. In this sense, certain chemical and physicochemical characteristics of the compound directly affect its potential for use.

An inventory of materials suitable for use as a substrate in the production of seedlings was prepared by Abad et al. (2001) in Spain, mentioning pH values ranging from 5.3 to 6.5 as a reference for substrates. Among the variables characterizing a suitable substrate, electrical conductivity (EC) is one of the most influential for seedling development (Bustamante et al., 2008). Viana et al. (2001) evaluated the effects of six EC levels of irrigation water (0.3 to 3.8 $dS \cdot m^{-1}$) on the strength and formation of lettuce seedlings. The authors concluded that all the variables studied were affected by EC in both the germination and seedling phases, classifying lettuce as moderately tolerant

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during germination and moderately sensitive in the seedling and seedling phases. Abad et al. (2001) considered that when the EC values were less than 0.5 dS·m^{-1}, the given material could be used as a substrate for seedling production.

The physical properties of the substrate, such as the water retention capacity, porosity, and the root ball stability during the removal of the seedling for transplantation, are critical during the formation of the seedling. Furthermore, Kratz et al. (2013) stated that the physical properties are decisive factors in choosing a particular substrate formulation. During the composting process, certain management strategies can directly affect the characteristics of the organic compost, favoring its use as a substrate for seedling production. The degradation of waste during the composting process is affected by the number of turns (Costa et al., 2016), resulting in the release of carbon, primarily in the form of CO_2, and nitrogen, in the form of ammonia, into the atmosphere (Bernal et al., 2009). This causes the concentrations of other nonvolatile elements such as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) to increase. This phenomenon occurs due to the mineralization and subsequent loss of organic fractions (Vico et al., 2018), which can result in an increase in EC in the final compound. However, the characteristics of the composting yard (presence or not of patio cover), consequently, bring changes in the chemical characteristics of the final compost (Carneiro et al., 2013), including the EC but not in the pH (Costa et al., 2016).

Therefore, the objective of this study was to evaluate the use of organic compounds generated from the composting of BPC residues and urban tree pruning in the germination and initial growth of lettuce seedlings.

MATERIAL AND METHODS

Characterization of organic substrates after composting

The substrates were obtained after composting the residues from the BPC mixed with the pruning debris of urban trees. Six composting piles with a total mass of 480 kg (natural matter) were set up in the rural perimeter of Cascavel/Brazil, with geographic coordinates 24°48’S and 53°26’W and an average altitude of 760 m. The region's climate, according to the Köeppen classification, is Cfa (humid mesothermal subtropical). The municipality has rainfall between 1,550 and 1,650 mm·year^{-1}. Summers are hot with concentrated rain. In winter, frosts are uncommon, and the area does not have a defined dry season. The average annual temperature is 19.3–20.1 °C, and the average relative humidity is 75% (Aparecido et al., 2016). The residues used to produce the piles were: a) a mixture of seven different BPC residues: cellulosic casing (16%), flotation sludge (15%), hatchery residues (13%), wheat straw (10%), silo waste (5%), broiler feed leftover (5%), and boiler coal (4%); or b) crushed tree pruning (32%).

Three piles were operated in a composting yard equipped with reinforced concrete floors and covered with zinc tiles, with humidity correction of approximately 60% during each turnover to guarantee an ideal level of microbial metabolism (Vico et al., 2018). An additional three piles were built in an environment without cover, without protection from natural precipitation. During the first month, all piles were turned twice a week, and thereafter, only once weekly. (Table 1). After finishing the rotations, the piles remained in the composting yard until their internal temperature reached room temperature.

TABLE 1. Strategies for conducting the composting process.

Substrates/ Piles	Number of turnings	Coverage	Turning period		
			1st month	2nd month	3rd month
1	8	Present	Twice a week	0*	0
2	12			1**	0
3	16			1**	1
4	8	Absent	Twice a week	0*	0
5	12			1**	0
6	16			1**	1

*piles kept in without turning; **piles turned once a week after the 2nd month.

After the composting period, the generated organic substrates were sieved (less than 10 mm) and stored in 20 L plastic bags in a covered place and at room temperature until the beginning of lettuce seedling germination tests. A commercial substrate (Humusfertil brand) composed of pine bark, vermiculite, vermicompost, and sand was used as a control, allowing comparison with the organic compounds.

The substrates produced in this work by the composting process are classified as Class A Substrates according to Normative Instruction (IN) 5/2016 (MAPA/Brazil): “products that use raw materials for vegetable, animal, or agribusiness processing exempt from sanitary waste, where toxic heavy metals, potentially toxic elements or compounds are not used in the process, resulting in a product for safe use in agriculture”.

The commercial substrate had a pH of 6.0 ± 0.5 and an EC of 1.5 ± 0.3 mS·cm^{-1}. The pH and EC determinations of the commercial substrate and organic composts were performed in triplicate using a aqueous extract supernatant prepared with distilled water in a 1:10 (mass/mass) ratio, according to Awasthi et al. (2016). A fraction of the organic compost was dried at 50 ℃, ground in a knife mill, and subjected to Kjeldahl total nitrogen (KTN) determinations (Meng et al., 2018).

An extract using the dry and crushed fraction was prepared by nitro-perchloric digestion for the determination of phosphorus (P) using a spectrophotometer (Femto 700 Plus) and potassium (K) using a flame spectrophotometer (Digimed- model DM- 62) (Costa et al., 2009). The amount of organic carbon was determined by dividing the value of volatile solids obtained by ignition in a muffle furnace at 550 °C by a factor of 1.8 (Van Amburgh et al., 2019). A fraction of the samples *in Natura* was also used to determine the humidity at 105 °C, and at the end of the determinations, the humidity of the samples was corrected and the results were expressed in dry mass.

Compost phytotoxicity evaluation

The phytotoxicity in the composts was determined by adapting the methodology recommended by Zucconi et al. (1981). An extract using 5 g of compost and 50 mL of distilled water heated to 60 °C was prepared and stirred for 30 min. After stirring, the solution was filtered twice using qualitative filter paper (Nalgon brand with 3 µm porosity) and cotton and a third time using only the filter paper.

The phytotoxicity assays were performed with 3 mL of the filtered solution and 20 naked seeds of curly lettuce (Lactuca sativa), which were added to five Petri dishes previously lined with qualitative analysis filter paper (Nalgon with 3 micas porosity) and autoclaved at 121 °C for 15 min. The experiment was maintained in a BOD incubator at a controlled temperature of 25 °C for 72 h and a photoperiod of 12 h. The phytotoxicity tests were performed in triplicate for all treatments, including the commercial substrate. The germination index (GI%) was calculated by counting the seeds that germinated in each dish and by measuring the length of the roots of five germinated seeds that were chosen randomly (Equation 1). The length of the roots was measured from the hypocotyl to the radicle, that is, from the stem to the root tip.

$$GI = \%\,G\,.\left(\frac{Ls}{Lc}\right) \quad (1)$$

Where:

GI: Germination index;

%G: Germination percentage in relation to control;

Ls: Average length of the sample roots (cm);

Lc: Average length of control roots (cm).

Seedling growth assessment

Seedling growth assays were performed using pelleted seeds of Brida lettuce in trays containing 100 cells 53 mm high, 28 mm wide, and with a volume of 16 mL (one seed per cell) in a completely randomized design (CRD). The trays were kept for 30 days in a greenhouse with natural lighting and an automatic sprinkler set for three times a day with a 10 mm irrigation blade for a period of 10 min and daily rotation. At the end of the experiment, the following variables were determined: number of leaves (unit), length of the aerial part (cm), length of the root (cm), diameter of the stem (mm), and dry mass of the root (g) and of the aerial part (g) (Kratz et al., 2013).

The seedling growth efficiency from the application of the different composts produced was analyzed using the Dickson quality index (DQI). For the DQI, 20 plants were randomly selected, and the following parameters were evaluated: seedling height, stem diameter, and shoot and root dry mass (Rodrigues et al., 2017; Meng, et al., 2019).

$$DQI = \frac{TDM}{\left(\frac{H}{SD}\right) + \left(\frac{SDM}{RDM}\right)} \quad (2)$$

Where:

DQI: Dickson quality index;

H: seedling height (cm);

SD: stem diameter (cm);

SDM: shoot dry mass (g);

RDM: root dry mass (g);

TDM: total dry mass (g).

Statistical analysis

The data were analyzed statistically using Minitab 17 software. Initially, the normality of the data was analyzed using the Anderson–Darling test ($p < 0.05$). The parameters that showed normal data distribution were analyzed using the Tukey means comparison test ($p < 0.05$). The t-test was applied to detect statistically significant differences between the sample means of two independent groups (presence and absence of coverage). Multivariate statistics were used, through principal component analysis (PCA), to summarize and interpret the relationships between the seven substrates (six produced substrates and a commercial substrate) and the quality of the lettuce seedlings using a correlation matrix with standardized variables. For the criterion of selection of the two main components, the accumulated percentage of explanation was greater than 70%.

RESULTS AND DISCUSSION

Chemical and physico-chemical characteristics of substrates

After the composting period, the organic substrates showed a pH between 6.8 and 7.9 (Table 2), above the values recommended by Abad et al. (2001) of 5.3–6.5. The substrates generated in the presence of a patio cover (piles 1, 2, and 3) resulted in an average pH of 7.2, while an average value of 7.8 was recorded for the substrates generated without cover (piles 4, 5, and 6). However, the difference between the two was not statistically significant (p-value = 0.142).

TABLE 2. Characterization of organic substrates after the composition period.

Parameter	CS	Substrates/Piles with coverage 1	2	3	without coverage 4	5	6	Average*	SD*	p-valor**
pH	6.4	6.8	7.4	7.5	7.9	7.6	7.9	7.5	0.4	0.142
EC (mS cm^{-1})	0.7	1.6	2.3	2.1	0.6	1.1	0.5	1.4	0.8	0.020
P (g kg^{-1})	N.D.	5.0	5.2	6.3	5.8	6.0	6.2	5.8	0.5	0.356
K (g kg^{-1})	N.D.	9.1	13.2	13.2	5.1	4.8	4.8	8.4	4.1	0.037
NTK (%)	N.D.	1.8	2.2	2.2	1.7	1.8	1.8	1.9	0.2	0.161
C (%)	N.D.	22.9	26.6	27.5	23.6	20.8	22.7	24.0	2.5	0.136
C/N	N.D.	12.8	12.3	12.5	13.9	11.7	12.4	12.6	0.7	0.860

CS: commercial substrate; 1 - 6: piles 1 to 6; N.D.: not determined; EC: electrical conductivity; P: phosphorus; K: potassium; TKN: Kjeldahl total nitrogen; C: carbon; C / N: carbon / nitrogen ratio. * average and standard deviation of substrates from piles 1 to 6;
** p-value of the test of comparison of means of the composts generated with and without coverage (t test, α = 0.05).

The average EC of the organic substrates was 1.4 ± 0.8 mS cm^{-1}, which is below the maximum limit of 4.0 mS·cm^{-1} recommended by Meng et al. (2019) for the use of organic composts as a substrate for seedling production. For lettuce seedlings, EC below 1.3 to 1.5 mS·cm^{-1} is recommended, since higher values can negatively affect their development, especially in seed germination and young root growth (Klein et al., 2012; Rodrigues et al., 2015).

The environmental conditions during the composting process (presence or absence of patio coverage) directly impacted the salt content (EC) of the substrates. This phenomenon was evidenced by the lower EC levels of the substrates produced in an uncovered patio (average EC of 0.7 mS·cm^{-1}) in comparison with the EC values of the substrates from a covered patio (average EC of 2.0 mS·cm^{-1}) (Table 2), according to the t-test for two samples (p-value = 0.020).

During the 14-week experimental period, there was accumulated precipitation of 680 mm in Cascavel/Brazil (Meteorological System of Paraná-SIMEPAR). The absence of cover, combined with rainfall during the composting period, led to the carriage of soluble salts from the piles, which was also observed by Pelegrín et al. (2018). The reduction in the EC contents of the substrates produced in the absence of coverage corroborates the conclusions of Carneiro et al. (2013), who found that the coverage of the composting pile is an important factor in reducing the loss of soluble minerals contained in the composts (K, Mg, Na, and N). Furthermore, the impact of leaching on potassium levels was also verified (Table 2). The substrates obtained in a covered patio had an average potassium concentration of 11.8 g·kg^{-1}, which was significantly higher (p = 0.03) than the average potassium content of the substrates generated without coverage (4.9 g·kg^{-1}).

As for the number of turns, there was an increase in the concentration of soluble salts increased with the number of turns, evidenced by the higher EC values in piles 2 and 5 that were turned 12 times (average EC 1.65 mS·cm^{-1}), compared with piles 1 and 4 that were turned only 8 times (average EC 0.85 mS·cm^{-1}), regardless of the patio coverage. This is due to the degradation of organic fractions and the consequent concentration of nutrients retained during the composting process, as reported by Bernal et al. (2009). However, with the continuation of the composting process for another 30 days, after 16 turns, there was no difference in the concentrations of soluble salts (Table 2). This indicates that with the increased process time and, consequently, number of turns, there was more loss of soluble minerals than in concentration, reducing the EC contents of the substrates. Soluble minerals can be lost in covered windrows due to irrigation to ensure the maintenance of humidity during the experiment (Pelegrín et al., 2018).

In this context, if there is a loss of nutrients, mainly soluble salts, decreasing the agronomic value (N, P, and K) when commercialized in the form of organic compost, the loss can be compensated by using the organic matter as a substrate for the production of seedlings. Compared with organic compost available in the regional market (western Parana/Brazil) (BRL 140.00 per ton in March 2019) and the commercial organic substrate for vegetable seedling production (BRL 30.00, 15 kg package), there is an economic advantage in favor of the produced substrate. Considering these values, the value per kilogram of the organic compost (BRL 0.14/kg) is 14 times lower than that of the substrate produced for seedlings (BRL 2.00/kg).

Abad et al. (2001) characterized more than 100 different organic residues generated by productive, industrial, and consumer activities, with the potential to obtain substrates for cultivation. From this study, an inventory of suitable organic materials (63) was prepared, and the significant physical, chemical, and biological properties were determined, serving as a reference for the Spanish Ministry of Agriculture, Fisheries and Food and for other scientific research. The authors consider the reference values of pH (5.3–6.5) and electrical conductivity (≤0.5 dS·m^{-1}) for an ideal substrate. Among the parameters evaluated in the organic compounds of the current study, it was observed that even though the pH and EC values were not within the range proposed by Abad et al. (2001), the substrates were adequate for the formation of lettuce seedlings. The values referring to the total organic matter meet the proposed range for all composts.

However, because of the different materials (seven BPC residues and residues from tree pruning) used to produce the organic substrates, biological tests were necessary to certify the efficiency of their use because the seedlings may or may not develop in different culture media (substrate) due to their adaptability. This fact justifies the expressive number of references in which alternative substrates from composting varied organic waste are evaluated for phytotoxicity (Pereira et al., 2012; Meng et al., 2018).

Substrate phytotoxicity evaluation

The phytotoxicity assay based on the germination index revealed that substrates 2, 4, and 6 and the commercial substrate had phyto-stimulating potential. This classification, according to Luo et al. (2018), is due to these substrates presenting GI percentages greater than 100% (Figure 1) and promote the germination and growth of seedling roots in relation to the control using only distilled water. This effect was also observed in a study by Albuquerque et al. (2012), who evaluated the phytotoxicity of digestates (liquid effluent generated from the anaerobic digestion of organic residues) and observed values higher than those obtained using control (125%). The authors related these values to the presence of nutrients or attributes that stimulate plant growth.

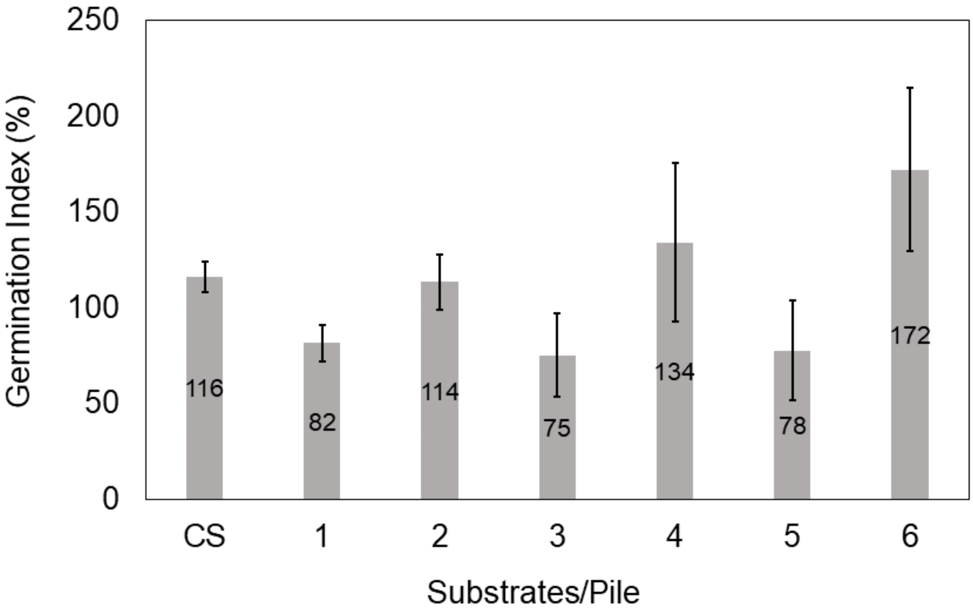

FIGURA 1. Results from the Germination Index of the substrates.

CS: commercial substrate; 1 a 6: piles 1 to 6; letters in the blocks obtained by comparison test. (Tukey's α = 0.05), where equal letters indicate treatments with statistically equal means.

Substrates 3 and 5 showed moderate phytotoxicity (GI between 60% and 80%). Compost 1, on the other hand, was characterized as non-phytotoxic (IG ≥ 80%) (Figure 1), indicating an agreement with Said-Pullicino et al. (2007), regarding the suppression of GI due to higher concentrations of soluble salts (Table 2) in the extract for the germination assay. Because none of the composts showed high phytotoxicity, all were considered suitable for the lettuce seedling assays. Regarding the GI obtained for organic composts, it was also observed that composts 4 and 6 had the highest germination percentages (GI = 134% and 172%, respectively) (Figure 1) as well as the lowest concentrations of soluble salts, determined from the EC (0.6 and 0.5 $mS \cdot cm^{-1}$) (Table 2).

Production of lettuce seedlings in tray: Effect of substrates on development and quality

All tested substrates resulted in the formation of plants with at least three leaves (Table 3), and all were superior to the results obtained using commercial substrates, thus, indicating that the seedlings reached the stage of being transplanted (Liang., et al. 2015; Yan et al., 2019). The Normality Test (Anderson-Darling, $p < 0.05$) was applied to the variables. However, the data referring to the parameters 'stability' and 'number of leaves' did not show a normal distribution; therefore, they were not included in subsequent statistical analyses.

TABLE 3. Effect of substrates on phytometric quality of lettuce seedlings.

Parameter	Substrates/Piles									
	with coverage				without coverage					
	CS	1	2	3	4	5	6	Average*	CV* (%)	p-valor
Number of leaves	3.0±0.3	4.1±0.3	4.0±0.0	3.7±0.5	3.9±0.3	4.0±0.0	3.9±0.3	3.9	3	N.A.
Shoot height (cm)	4.2±0.6^{e}	5.5±0.4^{a}	5.3±0.4^{ab}	4.7±0.3^{cd}	4.6±0.4^{de}	5.0±0.3^{bc}	5.0±0.3^{de}	5.0	7	0.000
Root length (cm)	9.5±1.4	10.1±1.2	9.5±2.2	9.8±1.3	9.7±1.3	9.9±1.0	10.0±1.5	9.8	2	0.324
Stem diameter (mm)	1.5±0.4^{b}	2.0±0.4^{a}	1.8±0.3^{a}	1.9±0.5^{a}	2.0±0.4^{a}	2.1±0.4^{a}	1.7±0.4^{b}	1.9	8	0.000
Shoot dry mass (g)	0.023±0.01^{d}	0.046±0.01^{a}	0.041±0.01^{ab}	0.035±0.01^{bc}	0.035±0.01^{bc}	0.039±0.01^{ab}	0.030±0.01^{cd}	0.038	15	0.000
Root dry mass (g)	0.016±0.03^{c}	0.022±0.04^{a}	0.021±0.005^{a}	0.020±0.004^{ab}	0.019±0.003^{abc}	0.021±0.04^{ab}	0.017±0.004^{bc}	0.020	9	0.000
DQI	0.009±0.001^{b}	0.014±0.002^{a}	0.013±0.001^{a}	0.013±0.003^{a}	0.013±0.002^{a}	0.014±0.003^{a}	0.010±0.002^{ab}	0.013	11	0.000

CS: commercial substrate; 1– 6: piles 1 to 6; *average and coefficient of variation (CV) of substrates from piles 1 to 6; DQI: Dickson quality index. P-value of the means comparison test (Tukey, $\alpha = 0.05$). N.A : not applicable because of the lack of normality of the data set.

For the seedling shoots, all the substrates showed values, on average, 19% higher than the commercial compost. The highest value was obtained for Compost 1, which was produced with coverage and without turning after the first month. The average shoot lengths for composts 1 and 2 were statistically similar (p-value < 0.05), indicating that regarding this parameter, the weekly turnover in the second month of operation of the windrows did not show a significant influence on the aerial part of the seedlings.

An average increase of only 3% was observed in relation to the commercial substrate for the length of the seedling roots (Table 3). However, a variance analysis indicated that there was no significant difference (p-value = 0.324) between the means. However, the composts produced white roots without dark spots on the extremities (Figure 2b), which indicates a healthy and well-developed root. Because the roots using the commercial substrate showed dark tips (Figure 2a), the possible loss of oxygen directly interfered with the metabolic activity of the roots, preventing the growth of the shoot.

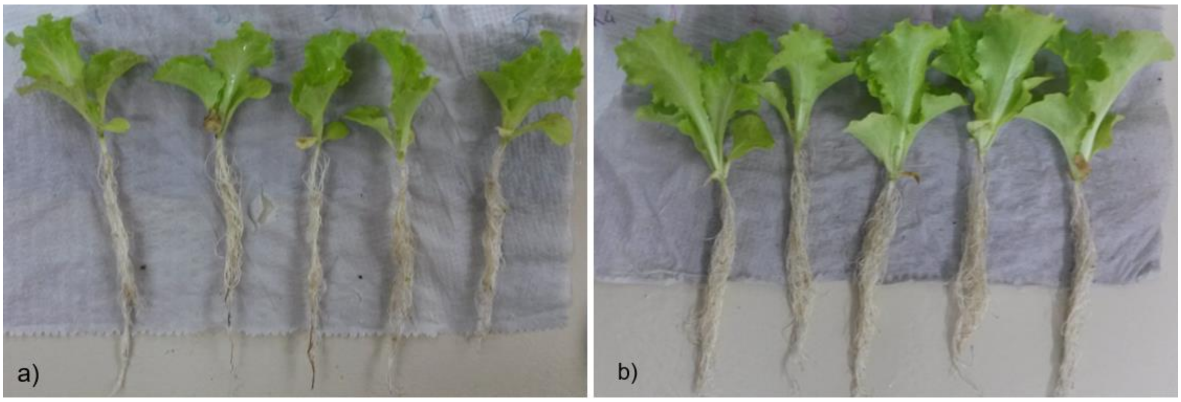

FIGURE 2. Seedling roots obtained with commercial substrate (a) and organic compost (b).

The average stem diameter obtained from the organic substrates was 1.9 cm (Table 3), which was 27% higher than that of the commercial substrate (1.5 cm. Analysis of variance (ANOVA) showed that all the organic substrates, with the exception of substrate 6, provided a significantly larger stem diameter (p-value < 0.05), when compared with the commercial substrate (CS). According to the t-test for the two samples, there was no difference (p-value = 0.826) between the substrates obtained with or without coverage. The stem diameter is a vital factor for the production of seedlings, reflecting the robustness of the seedling in relation to the shoot length as well as substantial root and shoot lengths, which are among the most important morphological parameters to evaluate the performance of seedlings when transplanted to the field (Gomes et al., 2002).

With the exception of compost 6 for the shoot and composts 4 and 6 for the root, all other composts showed statistically superior dry mass values to the commercial substrate (Table 3). The result of the t-test for the comparison of the substrates obtained with and without coverage revealed that there was no significant difference (p-value = 0.240 for SDM and 0.261 for RDM) between the two. Substrate 1 stands out, which provided the highest dry mass values of the shoot, indicating a possible greater absorption of macronutrients. Seedlings with a greater number of leaves and leaf area possibly had adequate production of photosynthesis, resulting in greater biomass.

The difference in values between substrate 1 and the others can be explained by the conditions in which they were produced. The organic substrate is one of the most significant factors related to the quality of the seedlings because it directly influences the development of the roots, which is reflected in the growth of the shoot.

The phytometric parameters analyzed individually, even after the statistical analysis of comparison of means, were not able to clearly identify the effects of the operational conditions of the composting process on the production of seedlings. It was observed that the different isolated parameters indicated different responses in terms of phytotoxicity: shoot (higher values obtained for composts 1 and 2, considered statistically equal and superior to CS); stem diameter (composts 1 to 5 showed statistically similar values and both were higher than CS); shoot dry mass (composts 1, 2, and 5 showed values statistically similar and higher than CS); and dry root mass (composts 1–5 showed statistically similar values and all were higher than CS).

Therefore, the interpretation of seedling quality and development (phytometric parameters), as related to the characteristics of the substrates, can be summarized from the principal component analysis (PCA), expressed in only two components (PC1 and PC2) (Figure 3a and 3b). Together, these two main components can explain 79.4% of the total variance of the data.

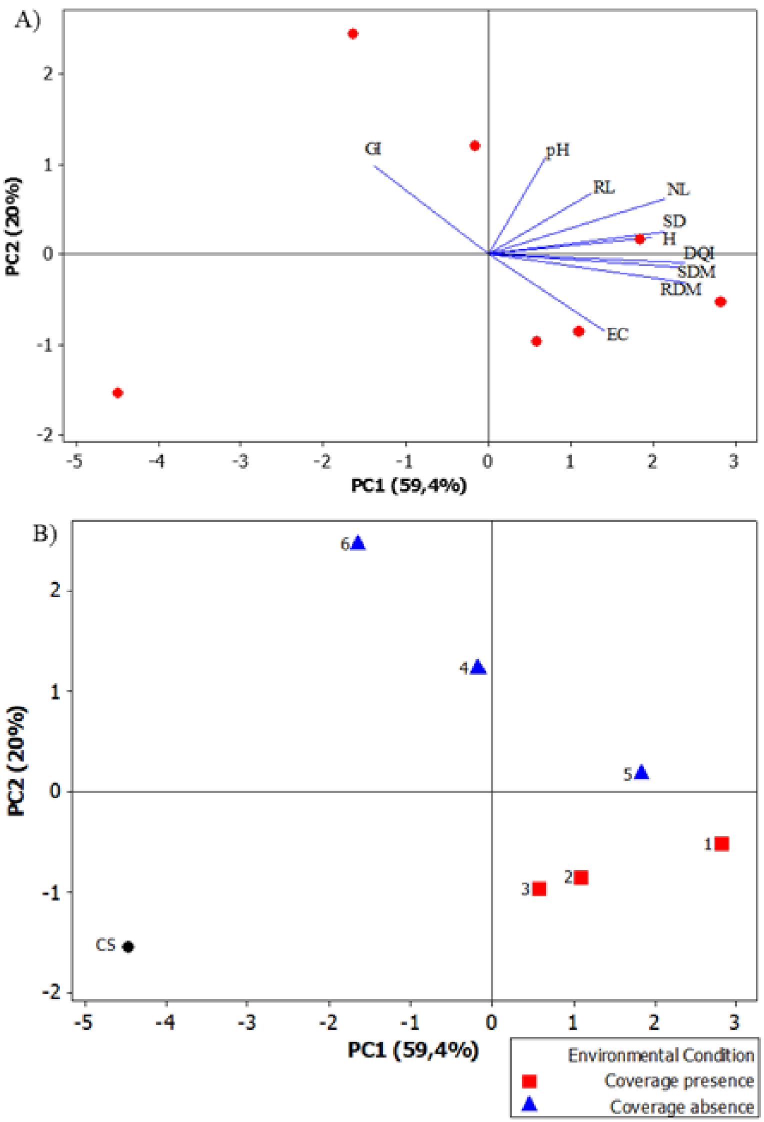

FIGURE 3. Biplot graphs generated from Principal Component Analysis (PCA) with the two main components PC1 e PC2.

a) *Loading plot* from the analyzed variables e b) *Score plot* from the analyzed substrates (substrates/piles 1 to 6 + commercial substrate (CS), categorized according to the environmental condition (presence or absence of cover). PC: principal component; GI: germination index; pH: hydrogen potential; EC: electric conductivity; RL: root length; NF: number of leaves; stem diameter; H: plant height; SDM: shoot dry mass; RDM: root dry mass e DQI: Dickson quality index.

The biplot graphs (figures 3a and 3b) showed that the environmental conditions (presence or absence of cover) during the production of the substrates influenced the development and quality of the lettuce seedlings. PC1, with 59.4% of explanation, gathered all the phytometric variables except for root length, as well as the DQI, showing a positive correlation with the variables. That is, the greater the shoot height, the greater the dry mass of the shoot and root as well as the seedling stem diameter, consequently resulting in a greater DQI.

The figures indicate the position of the substrates in relation to these phytometric variables. Substrates 4, 6 and CS, which were positioned to the left of the PC1 axis (negative region), produced seedlings with less development (phytometric) and quality (DQI and number of leaves), compared with substrates 1, 2, 3, and 5, which were positioned to the right of this axis (positive region) (Figure 3b). Therefore, the PCA revealed that the CS provided seedlings with less development and quality (greater distance). This result can be verified by the commercial substrate position (lower right corner) (Figure 3) compared with that of the other substrates produced from the BPC waste composting process.

The second component (PC2) showed that the substrates produced with coverage (1, 2, and 3) had lower values of GI and pH and higher levels of EC (negative region of the PC2 axis) compared with those produced with no coverage (4, 5, and 6) (positive region of the PC2 axis). The leaching of soluble salts from the composts produced in the absence of cover (4, 5, and 6), resulted in a decrease in EC, favoring the GI results due to the lower concentrations. This leaching did not occur in the substrates produced in the presence of coverage, corroborating the statements of Said-Pullicino et al. (2007) and Gavilanes-Terán et al. (2017) regarding the suppression of GI due to the increase in the concentration of soluble salts in the extract used for the germination assay. This antagonistic relationship between GI and EC is clearly observed in the opposition of these two variables in Figure 3A, and corresponds with the findings of Hoekstra et al. (2002) that there is a negative correlation between GI and EC (-0.58). This result is probably due to the lower levels of soluble nutrients, indicated by the lower levels of EC and TKN (Table 3), contained in the substrates produced in the absence of coverage due to leaching during the composting process.

The PCA demonstrates that the GI is not related to the DQI, that is, the composts that provide better germination indexes (GI) (Petri dish assay) will not always produce seedlings with greater quality and robustness (DQI) (seedling development in trays) (Table 3). This behavior is evidenced through the loadings of the analyzed variables (Figure 3a), in which the direction of the GI is opposed to that of the DQI. This also is probably due to the lower levels of soluble nutrients, indicated by the lower EC levels (Table 3) due to leaching. These substrates did not inhibit seed germination but provided less development of seedling grown in the trays (DIQ). Substrates with higher levels of EC may have inhibited the GI, but provided better seedling quality, probably due to the greater availability of soluble nutrients.

CONCLUSIONS

BPC residues are viable materials for composting treatments. The DQI values of the organic composts used as substrates for the initial growth of lettuce seedlings were, on average, 14% higher than that of the commercial substrate. The coverage and number of turns did not have a significant influence on the DQI ($p > 0.05$) of the organic compost. However, more robust lettuce seedlings, mainly in relation to the aerial part, were obtained from the composts generated in a covered patio (1, 2, and 3) ($p < 0.05$). The lack of coverage resulted in greater leaching of soluble salts, as observed by the lower levels of electrical conductivity and potassium in the organic composts generated under these conditions (4, 5, and 6).

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