Co-composting of agricultural waste from spring onions, chicken manure, and biowaste

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Research Article

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Abstract

Composting is an adequate method for treating and valorizing agricultural waste such as those from Spring onions (SO) cultivation and chicken breeding (chicken manure -CM). However, the low content of Total Organic Carbon in the waste from SO and the high concentration of total nitrogen in CM are limitations for the composting process. This research studied the co-composting of SO and CM in a paramo ecosystem, together with locally available co-substrates such as biowaste (Bw) and woodchips (Wc), focusing on the effect of co-composting in process development and end-product quality. A pilot-scale experiment was carried out using three treatments in triplicated composting piles: i) Treatment A: 43%CM+41%Bw+16%Wc (dry weight); ii) Treatment B: 52%CM+ 32%SO+16%Wc (dry weight), and iii) Treatment C: 70%SO + 30%Wc (dry weight). Treatments A and B reached thermophilic temperatures after two days of the process start and remained at that level for 17 days. However, treatment B reached environmental temperature during curing in a shorter time (43 days) than treatment A (53 days). Treatment C did not achieve thermophilic temperatures. Tests carried out at the end of the process showed end-product stability and non-phytotoxic characteristics (germination indexes 80%). From the perspective of agricultural use, products from the three treatments had limitations due to deficiencies in essential nutrients like phosphorus. Still, they had potential as a soil amendment for restoration processes. The fertility index of the products showed that treatments A and B presented values of 4.3 (over 5.0) while treatment C obtained a value of 2.5.

Article Highlights

- Mixture of spring onion with biowaste and wood chips generate a product of value
- Chicken manure reduced the cooling phase (10%) compared to biowaste treatment
- Spring onion waste has characteristics that restrict composting as the only substrate

1. Introduction

The agro-industrial sector is one of the greatest producers of agricultural waste (AW) in the world in the form of manure and residual biomass from fruit and vegetable crops minimally processed (De Corato et al., 2018). AW is wastage of valuable resources and an environmental problem due to soils' impairment, surface and groundwater pollution, the release of greenhouse gases, and odor generation (Esparza et al., 2020). Thus, the treatment and use of AW is highly relevant for agricultural development and environmental protection (Chen et al., 2018).

Spring onion (SO) is a typical crop from high-mountain ecosystems such as paramo, where the average temperature is 10°C and production vary depending on the geographic region (Nile et al., 2018). For instance, the Berlin paramo in Colombia has an estimated production of 180,000 tons/year of SO, and agricultural practices frequently involve synthetic agrochemicals, unstable chicken manure (CM), and improper irrigation.

SO waste and CM are two types of AW with environmental pollution potential, and composting is an alternative within the circular economy that could be used to take advantage of waste generating products with value as fertilizers. However, SO waste is characterized by their high moisture (> 60%) and deficiencies in Total Organic Carbon (TOC < 20%) and Total Phosphorous (PT < 1%). On the other hand, CM generally has high moisture (> 60%), high total nitrogen (TN > 3%), and high electrical conductivity (CE > 3mS/cm). Therefore, when SO waste or CM are treated alone, process efficiency could be limited and end product quality deficient. For instance, Horiuchi et al. (2004) assessed the composting of SO and found that the process was feasible, but the end-product had nutritional deficiencies. Likewise, Rizzo et al. (2013) in the composting of CM using different co-substrates evidenced the need to reduce nutrient loss such as nitrogen during the process aiming to improve end-product quality. In that regard, Onwosi et al. (2017) recommend assessing different strategies that increase the composting process's efficiency.

The use of amendment materials (AM) and bulking agents (BA) improves the characteristics of substrates with physicochemical limitations such as nutrient unbalance and high water content, enhancing process conditions and end-product quality (Awasthi et al., 2020). Woodchips, green waste, rice straw, and straw are common BA; Woodchips (Wc) being the most popular due to its TOC contribution and low water content (Li et al., 2013; Soto-Paz et al., 2019). On the other hand, recently, Oviedo-Ocaña et al. (2019) have shown the benefits of using biowaste (Bw) as AM to provide the macro and micronutrients needed to stimulate biological activity during the composting process. However, the good selection of substrates with AM or BA is fundamental to optimizing the composting process and end-product quality (Soto-Paz et al., 2019).

This work assesses the co-composting of SO with other organic materials locally available such as CM, Bw, and Wc. Although the scientific literature includes research on the composting of a variety of agricultural waste like pig manure, cow manure, and food waste (Oviedo-Ocaña et al., 2019), reports from the composting of crops such SO are limited. On the other hand, experiences reported on the composting of CM mixed with different materials include wheat straw (Rizzo et al., 2013), biocarbon (Dias et al., 2010), and vegetable waste (Bres et al., 2018). However, there are no studies reported for SO. Thus, this research contributes to identifying strategies to improve postharvest waste management and reduce fertilization practices with negative environmental impact, helping soil preservation and ensuring the hydrological services provided by the high-mountain ecosystems dependent on soil health.

2. Methodology

Experimental units

The experiment was carried out in the solid waste management facilities of the Berlin village, Tona municipality (Colombia), where the average environmental temperature is 8°C, and the annual average rainfall is 700 mm. Three treatments were assessed in 150 Kg-composting piles, with conical shape and 1m- approximate height: i) Treatment A: 43% CM + 41% Bw + 18% Ws (all wet weight), ii) Treatment B: 52% CM + 32% SO + 16% Wc (all wet weight), and iii) Treatment C: 70% SO + 30% Wc (all wet weight).

Treatments were defined taking as criteria that both SO and CM were the predominant substrates, and the C/N ratio from the resultant mixture was equal to or higher than 15 (Onwosi et al., 2017). Each treatment was set up by triplicate, starting the process in the nine piles the same day, ensuring identical environmental conditions, and keeping a distance of at least one meter between the piles.

Characterization of substrates and co-substrates

SO and CM were used as substrates, and other wastes with the potential to mix with them were identified to improve the physicochemical quality of the mixture. According to Arias (2017), a variety of waste is produced in the study area, such as cattle and sheep manure and potato and vegetable waste; however, the quantities produced were limited. Thus, biowaste (Bw) from the organic fraction of municipal solid waste from the village and Wc were used as complementary materials. The farmers from the study area provided waste from SO and CM. Bw was obtained from houses and restaurants in the town. Wc was transported from the nearest city capital, located 40 Km away.

Before the experimental setup, representative samples from each substrate and the mixtures from each treatment were taken using the quartering technique, following the protocol proposed by Edjabou et al. (2015), and transported to the laboratory of Consultas Industriales de la Universidad Industrial de Santander for physicochemical analysis. All the substrates were analyzed considering the parameters in Table 1, following the Colombian Technical Norms (ICONTEC, 2011).

Table 1
Physicochemical characteristics of substrates

Parameter	SO	CM	Bw	Wc
pH	6.6 ± 0.2	8.5 ± 0.3	5.7 ± 0.8	6.3 ± 0.1
Water content (%)	67.5 ± 1.3	74.6 ± 1.8	78.3 ± 2.1	10.8 ± 0.3
TOC (% C dw)	18.8 ± 0.4	44.2 ± 7.7	24.1 ± 1.5	33.7 ± 3.4
TN (% N dw)	1.6 ± 0.2	3.6 ± 0.7	1.4 ± 0.5	0.8 ± 0.1
TP (%P_2O_5 dw)	0.20 ± 0.0	1.05 ± 0.0	0.2 ± 0.1	1.33 ± 0.0
EC (mS/Cm)	1.2 ± 0.3	6.2 ± 1.1	3.5 ± 0.4	0.3 ± 0.1
C/N	11.6 ± 0.8	12.3 ± 0.6	17.2 ± 0.6	13.5 ± 0.5

Note: TOC: Total Organic Carbon; TN: Total Nitrogen: TP: Total Phosphorus; EC: Electrical Conductivity; C/N: Carbon – Nitrogen ratio; dry weight (dw); SO: Srping Onion; CM: Chicken Manure; BW: Biowaste; Wc: Woodchips

SO had high water content and EC and low contribution of organic matter, possibly due to the degradation of a SO fraction. At the same time, CM also had high water content and TN and a high EC, which show a contribution of salts contained in manure, a characteristic of this substrate (Rizzo et al., 2013). On the other hand, Bw had typical food waste characteristics: high water content, acidic pH, lack of TP, and low C/N (Oviedo-Ocaña et al., 2019; Soto-Paz et al., 2019). Regarding Wc, this co-substrate had high C/N ratios, adequate to be added to substrates TN-rich; likewise, it has low EC and water content.

Analytical methods

For the analysis of critical parameters, an integrated sample was made using 200g with subsamples taken from the centroid and peripheral points in each treatment pile. Samples were stored at 4°C up to 24 hours before the laboratory analysis to prevent the degradation process. pH was measured using a pHmeter (WTW Model 315i, Wissenschaftlich-Technische Werkstatten GmbH, Weilheim, Germany) by taking a solid sample (10g) diluted in distilled water (1:10 p/v). EC and cation exchange capacity (CEC) were measured from the same diluted sample. Water content was determined at 105°C up to the sample achieved a constant weight, while ash content was estimated at 550°C. TOC was measured by titulometry. TN was measured using the Kjeldah titulometry method, TP by colorimetry, and Total Potassium (TK) by atomic absorption. The concentration of trace elements (Ca, Mg, Na, and Zn), water retention capacity (WRC), and density were established following the NTC 5167 (ICONTEC, 2011). The self-heating test was carried out using Dewar vessels, according to Lü et al. (2018).

Monitoring of the composting process

Once the experimental setup was ready, process monitoring started using temperature, water content, and pH. The temperature was measured daily in the pile centroid using a bimetallic thermometer of 70cm-length. Water content was measured daily during the first three weeks, then three times and two times a week up to the end of the process. For that, representative samples were taken from four opposite sites in the pile that were then integrated.

The oxygen saturation concentration was measured at least twice a week to establish the need for turning the piles in the treatments. In addition, turning was made to control temperature, homogenize the material, or during moisturizing. Process monitoring was carried out until each treatment reached a stability degree IV or V, measured through the self-heating test, conducted on days 46, 56, and 69 of the process. The germination index (GI) test was also performed on the same days of the self-heating test, using Equations 1, 2, and 3, according to Komilis y Tziouvaras (2009), using radish seeds due to their sensitivity to phytotoxicity. Treatments with a GI lower to 80% were considered indicators of inhibition.

$$RGP = \frac{GS}{GSC} \times 100 \text{ Equation 1}$$

$$RRG = \frac{RG}{RGC} \times 100 \text{ Equation 2}$$

$$GI = \frac{RGP \times 100}{100} \text{ Equation 3}$$

Where RGP is the relative germination percentage; GS is the number of germinated seeds in the extract of the end-product; GSC is the number of germinated seeds in the control; GR is root growth in the extract of the end-product; GRC is root growth in the control; RRG is the relative root growth.

Analysis of end-product quality

Once the process ended, manual sieving of products was carried out using a 1.25 cm-sieve to prepare representative samples for end-product quality analysis in parameters such as water content, pH, density, WRC, EC, CEC, TOC, ashes, TN, C/N ratio, TP, TK, trace elements (Ca, Na, Mg, Zn). The end-product quality results were compared with the Colombian regulations (NTC 5167) and with data reported by the literature for the European context (Cesaro et al., 2015). On the other hand, as a complementary quality indicator, the fertility index proposed by Saha et al. (2010) (Eq. 4) was estimated for the end-products. This index uses the parameters TOC, TN, TP, TK, C/N. Each parameter was assigned a weight from 1 to 5, 5 representing the highest importance from the agricultural point of view (see Table 2).

$$FI = \frac{\sum_{n}^{i=1}\left(S_i * W_i\right)}{W_i} \text{ Eq. 4}$$

Table 2
Criteria to assign scores and weights to calculate the Fertility Index.

Parameter	**Scores (S_i)**					**Weights**
	5	**4**	**3**	**2**	**1**	**(W_i)**
Total Organic Carbon (% db)	> 20.0	15.1–20.0	12.1–15.0	9.1–12.0	< 9.1	5
Total Nitrogen (% db)	> 1.25	1.01–1.25	0.81–1.00	0.51–0.80	< 0.51	3
Total Phosphorus (% db)	> 0.60	0.41–0.60	0.21–0.40	0.11–0.20	< 0.11	3
Total Potassium (% db)	> 1.00	0.76-1.00	0.51–0.75	0.26–0.50	< 0.26	1
Carbon/ Nitrogen	< 10.1	10.1–15	15.1–20	20.1–25	> 25	3
Adapted from Oviedo-Ocaña et al. (2019). Note: db – dry base						

Where S_i is a score between 1 and 5, depending on the magnitude of parameters, and 'Wi' is the weight assigned to the parameters on a scale from 1 to 5. Table 2 includes the criteria to assign scores and weights (Oviedo-Ocaña et al., 2019).

An Analysis of variance was carried out using the R software version 3.6.5® to determine if there were statistically significant differences ($p < 0.05$) regarding the end-product quality obtained.

3. Results And Discussion

Process monitoring

Temperature: Temperature is a widely used parameter to describe the composting process behavior (Waqas et al., 2018). Figure 1 shows the temperature profiles of treatments. Table 3 summarizes the time required in each treatment to reach the thermophilic phase and its length, maximum temperature, time to reach environmental temperature, and the total amount of water added during the humectation phases.

Table 3
Temperature behavior in each replicate per treatment

Treatment	Time to the start of the thermophilic phase (days)	TMAX (°C)	Time to TMAX (days)	Duration of the thermophilic phase (days)	Time to TENV ± 3°C from process start (days)	Added water (L)	pH - initial	pH final
TA	2	57.3	4	17	54	72.0	8.4	8.9
TB	2	57.0	4	17	49	75.3	8.4	8.8
TC	2	33.3	3	0	47	78.7	8.5	8.7

Note: TA: Treatment A; TB: Treatment B; TC: Treatment C; TMAX Maximum temperature, TENV environmental temperature.

Treatments A and B had a typical behavior of the composting process, with sequential mesophilic, thermophilic, cooling, and maturation phases. According to Soobhany (2018), the thermophilic phase starts at temperatures higher than 45°C. This condition was achieved on the second day of the process, in agreement with results from Waqas et al. (2018) in biowaste composting and Rizzo et al. (2013) in the composting of chicken manure. These results are associated with the predominance of readily biodegradable polymers present in substrates such as carbohydrates, proteins, and amino acids from the Bw, and CM and due to the action of microbial consortia, which increase heat generation with the consequent temperature growth. On the other hand, treatment C (70% So and 30% Wc) did not reach temperatures over 45°C, which is associated with the characteristics of SO tending to acidity, which could affect the biodegradation kinetics of the present TOC and consequently heat generation; furthermore, the low C/N ratio (15) in this treatment, the storage period of SO (1 month) and thus, certain degradation degree, could have limited the biological activity.

Regarding sanitization, the treatments did not reach temperatures above 65°C, which is the recommended temperature for disinfection and destruction of larvae and insect seeds (Waqas et al., 2018). However, treatments A and B showed, for at least three consecutive days, temperatures above 55°C, which according to Hemidat et al. (2018), allow pathogen destruction; in addition, no statistically significant differences were found between treatments ($p = 0.081$). On the other hand, treatment C did not fulfill this condition, for which it could represent a potential risk if directly applied to the soil (Lasaridi et al., 2006). The maximum temperature was achieved in treatments A and B, in both cases with 57°C (Table 2), and in an average time of four days. The length of the thermophilic phase was 17 days in both treatments, which indicates process efficiency (Cáceres et al., 2016).

Figure 1 here

The cooling phase started between process days 19 and 21 in all treatments. Treatment B achieved a temperature closer to ambient (10 ± 5°C) in lower time (49 days) compared to treatment A (54 days), with statistically significant differences between the treatments (p = 0. 035). This behavior could be associated with a higher organic matter content in treatment B due to the fraction of CM that provides TOC, TN, and nutrients that stimulate biological activity. This shows that the mixture of CM and SO (Treatment B) reduces the processing time compared to the mixture of CM, Bw, and SO (Treatment A), which could have lignocellulosic components coming from the Bw that could increase processing time. These results are similar to those from Hemidat et al. (2018) in the composting of Bw, indicating that materials with cellulose and lignin take longer to degrade.

pH: The pH allows following process conditions; in the first phase, a typical pH decrease occurred linked to the high rate of organic matter degradation that generates organic acids and CO_2. Figure 2 shows the pH dynamics in each treatment. At the start of the process, pH was alkaline (> 8) in all treatments due to the presence of CM in all the mixtures; however, as the process continued, a slightly pH decrease happened in all treatments due to the generation of short-chain fatty acids as intermediate products of the bacterial metabolism of the organic matter degradation. The higher pH values during the process were obtained in treatments A (10.19) and C (10.00), both on day 46. These results show statistically significant differences (p = 0.041) compared to the maximum pH in treatment B (9.77). The rapid pH increase during the thermophilic phase could be related to the release of ammonia as a result of protein degradation in the treatments for the presence of Bw and CM (Rizzo et al., 2013; Cáceres et al., 2016), the decomposition of organic acids and the release of CO_2 during pile turning (Waqas et al., 2018).

During the cooling phase, pH values tended to decrease in treatment B, which can be linked to the production of organic acids during the decomposition of OM from CM and the nitrification process (Rizzo et al., 2013). However, at the process end, all treatments had pH in the alkaline range (higher to 8.0), treatment A with the highest values, although there were no statistically significant differences with treatments B and C (p = 0.54). Typically, pH follows a behavior pattern in the composting process characterized by low levels in the first stages and higher levels in the last stages (Waqas et al., 2018)

Figure 2 here

Electric conductivity: Electric conductivity reflects the concentration of water-soluble inorganic ions in the compost (Bernal et al., 2017). Figure 3 shows the EC behavior in the treatments. EC was higher (EC > 2 mS/cm) at the process start in treatments A and B associated with the predominance of CM, which contains salts such as sodium and calcium. A generalized trend was observed in these treatments of an increase in EC with a slight decrease concurring with the days when treatments were moisturized, thus promoting the leaching of salts. According to Gong et al. (2017), the EC increase is due to microbial mineralization of organic matter and the release of mineral ions such as phosphates, ammonia, and potassium during this process. In contrast, treatment C showed the lowest EC values related to the low EC from both SO and Wc at the process. It gradually decreased processing time, maintaining a range of relatively low values between 0.27 and 0.67 mS/cm. At the end of the process, treatments A and B had statistically equal EC values, and higher compared with treatment C (EC > 4.5 mS/cm).

Figure 3 here

End product quality

Physicochemical characteristics: Table 4 presents the end product quality obtained from the different treatments and its comparison with NTC 5167. Water content from treatment A had statistically significant differences ($p = 0.048$) with treatments B and C. B and C were not statistically different ($p = 0.06$). However, the water content in all treatments was higher to 50%, which is a value above recommendations from NTC 5167 (< 35%) and NCH2880 from Chile (30–45%); in addition, it was higher compared to values reported from some European Union countries (Cesaro et al., 2015). Although high water content in a stabilized process does not represent an end product quality problem, it could impact marketing and sales. An alternative to handle the water content values could be increasing turning in the maturation phase or implementing other processes such as solarization under controlled conditions to dehydrate and remove water (Jiang-ming, 2017).

Table 4
Physicochemical parameters from the compost obtained in each treatment

Parameter	Treatment A	Treatment B	Treatment C	NTC 5167
Water content (%)	56.1 ± 2.1 a	52.3 ± 3.6 b	47.5 ± 3.2 b	< 35
pH (%)	8.9 ± 0.2 a	8.6 ± 0.1 a	7.9 ± 0.1 b	> 4-<9
Density (g/cm³)	0.2 ± 0.1 a	0.2 ± 0.1 a	0.3 ± 0.1 a	< 0.6
WRC (%)	287.3 ± 26.3 a	322.7 ± 44.8 b	317.3 ± 37.0 b	> 100
CEC (meq/100 g)	51.3 ± 3.0 a	52.9 ± 3.3 a	44.1 ± 1.5 b	> 30
EC (mS/cm)	4.6 ± 0.6 a	4.5 ± 0.8 a	0.5 ± 0.4 b	-
Ashes (%)	18.2 ± 1.3 a	25.0 ± 2.2 a	27.5 ± 3.6 a	< 60
TOC (%)	38.0 ± 1.8 a	35.5 ± 1.8 a	36.0 ± 0.9 a	> 15
TN (%)	1.7 ± 0.1 a	1.6 ± 0.1 a	0.6 ± 0.1 b	> 1
C/N ratio	22.5 ± 2.0 a	21.7 ± 1.9 a	57.7 ± 2.9 b	-
TP (%)	0.7 ± 0.2 a	0.7 ± 0.1 a	0.1 ± 0.1 b	> 1
TK (%)	2.1 ± 0.4 a	2.1 ± 0.1 a	0.7 ± 0.1 b	> 1
Total Ca (%)	1.8 ± 0.5 a	1.9 ± 0.2 a	1.5 ± 0.9 a	-
Total Mg (%)	0.4 ± 0.2 a	0.5 ± 0.1 a	0.1 ± 0.1 a	-
Total Na (%)	1.0 ± 0.1 a	1.1 ± 0.1 a	0.9 ± 0.1 a	-
Total Zn (%)	0	0	0	-
FI	4.3 ± 0.1 a	4.3 ± 0.3 a	2.5 ± 0.1 b	

Note: CEC. Cation Exchange Capacity, TOC. Total Organic Carbon, EC. Electric Conductivity, WRC. Water Retention Capacity, TN. Total Nitrogen. FI: Fertility Index

Letters a and b indicate statistically significant differences ($p < 0.05$) between treatments. Treatments with the same letter did not show statistically significant differences.

According to Sundberg and Jönsson (2008), the final pH of compost is highly dependent on substrates, composting process, and addition of amendments. Lasaridi et al. (2006) propose the pH range for the end product between 6.0 and 8.5 to allow the product to be used in various plants, while NTC 5167 recommends pH values between 4.0 and 9.0. All treatments fulfilled this requirement set by the Colombian regulation, treatments A and B having statistically significant differences to treatment C (p =

0.022). The pH increase up to alkaline values could be attributed to the consumption of protons during the decomposition of volatile fatty acids, generation of CO_2 and mineralization of TN (Cáceres et al., 2016).

Regarding density, all treatments had values lower to 0.6 g/cm³, which is the value recommended by the NTC 5167, Treatment C being higher (0.30 g/cm³), without statistically significant differences with treatments A and B ($p = 0.13$). These end product characteristics could positively impact the physical properties of soils, increasing porosity and Water retention capacity (WRC). WRC is the amount of water held in soil pores after gravity loss for a specified time. The NTC 5167 recommends values higher than 100%. All treatments had WRC values above 200%, treatments B and C with statistically significant differences from treatment A ($p = 0.036$) and higher values. The high WRC values found in this research are associated with SW that increases the porosity and density of products.

The Cation Exchange Capacity (CEC) indicates the end product ability to sustain the exchange of cations such as potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) with surfaces negatively charged (Hemidat et al., 2018; Soto-Paz et al., 2019). This parameter tends to increase through the process due to the mineralization of organic matter (Waqas et al., 2018). The NTC 5167 set a minimum value for CEC of 30 meq/100 g. Thus, all treatments fulfilled this requirement, although treatment C had the lowest value (44.1 ± 1.5) and was statistically different ($p = 0.019$) compared to treatments A and B. End products with this CEC could stimulate the biological activity due to the exchange of bases with the soil. On the other hand, EC in end products from treatments A and B was around 4 mS/cm. Our results were higher (4.3 mS/cm) compared to the values recommended by the NCH 2880, Bernal et al. (2017) for agricultural use (CE < 3.0 dS/cm), and Cesaro et al. (2015) in the European context, suggesting that end products could add a potential degree of salinity to the soil. On the other hand, treatment C had the lowest CEC values from all treatments, possibly due to the absence of CM.

The Ash content was constant during composting, although, due to the loss of mass and water, it increased concentration (Bernal et al., 2017). The end products from all treatments had an Ash concentration lower to 60%, the maximum accepted value according to NTC 5167. The higher ash content was found in treatment C, which can be associated with mineral or inorganic material from the soil added to the SO waste.

Regarding TOC, all treatments had a concentration over 15%, minimum value recommended by the NTC 5167 and higher than that reported by Rizzo et al. (2013) in the composting of CM and by Soto-Paz et al. (2019) in the composting of Bw with different co-substrates. There were no statistically significant differences between treatments ($p = 0.075$), which could increase the organic matter content in degraded soils (Lasaridi et al., 2006; Hargreaves et al., 2008). Regarding TN, treatments A and B fulfilled NTC 5167 and NCH2880 (TN > 1%) and lacked statistically significant differences ($p = 0.78$). These results show a higher concentration of TN at the end of the process than in other research addressing composting of flowers and food waste with ashes. On the other hand, Treatment C had lower concentrations of TN among treatments. Thus, the operational conditions in this treatment were unfavorable for the composting process. In other conditions, introducing a bulking agent, an amendment, or both, allowed improving the media porosity, C/N ratio, and the aeration of the matrix; this could help keep ammonia in equilibrium between the water and gas phase.

The C/N ratio has been extensively used to indicate maturity and stability during composting (Bernal et al., 2017). However, Bernal et al. (2017) indicate that this relation is closer to substrates than maturity. Some authors propose admissible values for the C/N ratio of the end product. For instance, the standards from the Hong Kong Organic Resource Centre (2005): < 25. There were no statistically significant differences for C/N ($p = 0.16$) between treatments A and B, and fulfilled this requirement. In contrast, Treatment C had a slightly high value (57.7 ± 2.9) that may be because it was the only treatment with a higher quantity of sawdust, a carbon-rich substrate.

A fraction of the Total P, Ca, and Mg is present in the end product and available for the plant. Essentially, a total K in compost is available in the end product (Hargreaves et al., 2008). According to the NTC 5167, TP and TK content must be higher than 1% for organic products. The results obtained show that the treatments did not achieve the quality criteria regarding TP. Thus, end product quality has limitations and does not comply with NTC 5167 and NCH 2880 (Lasaridi et al., 2006). Treatments A and B were statistically different regards treatment C ($p = 0.027$).

In contrast, for TK, treatments A and B had concentrations above 1%, without statistical differences between treatments ($p = 0.81$), which increases the agricultural value of these products. In the case of treatment C, TK concentration was below 1%, highlighting the need to identify alternative sources of waste that contain these nutrients to improve end product quality. Regarding the presence of oligo-elements, all treatments had Ca, Mg, Na and Zn, which can be used for the microorganisms in the soil and stimulate assimilation of macronutrients and their availability for the plants (Lasaridi et al., 2006; Hargreaves et al., 2008).

The Fertility Index (FI) values were above 4.2 in Treatments A and B, making them more appropriate for use in the soil (Saha et al., 2010). In the case of treatment C, the FI was 2.6, which indicates the need to prepare raw materials with other elements to improve end-product quality. This result is associated with the limited concentration of TN and TP that reduces its soil applicability for agricultural purposes. However, this product could be used as landfill cover material.

Stability and maturity: The end products from all treatments had germination indexes (GI) associated with products considered mature (non-phytotoxic) and with high fertilization potential (Fig. 4). Treatment C had the best GI, above 100%, which according to Komilis y Tziouvaras (2009), indicates that these products increase plant growth rather than impair it. This behavior is due to the low EC values (< 1%), and consequently, less availability of salts. On the other hand, the self-heating test evidenced that all treatments had a stability degree of IV, indicating that end products were stable.

Figure 4 here

4. Conclusions

- Spring onion waste has characteristics that restrict composting as the only substrate. Thus, the incorporation of chicken manure and biowaste allowed overcoming these restrictions, generating adequate conditions for composting from the beginning of the process.
- The addition of woodchips to the mixture of spring onion and chicken manure (Treatment B) allowed the composting of spring onions to reach temperatures in the thermophilic range in lower time and higher temperatures compared to the composting of spring onion with woodchips (Treatment C). On the other hand, the introduction of chicken manure effectively reduced the cooling phase and achieved environmental temperature faster (49 days) compared to the treatment with biowaste (54 days). This shows that adding chicken manure increases effectiveness in the composting process with better conditions to sanitize the end product.
- An improvement in the end product quality was observed with the mixture of spring onion with biowaste and woodchips (treatment A) and with the mixture of spring onion with chicken manure and woodchips (Treatment B) compared to the mixture of spring onion and woodchips (Treatment C). This is demonstrated for the content of TN (1.6%), TP (0.7%), TK (2.1%) and the fertility index (4.3). These characteristics make the product suitable for agricultural purposes.

Abbreviations

AM	Amendment materials	RGP	Relative germination percentage
AW	agricultural waste	RRG	Relative root growth
BA	Bulking agents	TA	Treatment A
Bw	Biowaste	TB	Treatment B
CEC	cation exchange capacity	TC	Treatment C
CM	Chicken manure	TK	Total Potassium
EC	Electrical conductivity	TN	Total nitrogen
FI	Fertility index	TOC	Total Organic Carbon
GI	Germination index	TP	Total Phosphorous
GS	Number of germinated seeds in the extract of the end-product	SO	Spring onions
GSC	Number of germinated seeds in the control	Wc	Woodchips
GR	Root growth in the extract of the end-product	WRC	water retention capacity
GRC	Root growth in the control		

Declarations

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Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

The authors declare to have the supports of the tests carried out

Code availability

The code used was developed on the MatLAB®2020a platform

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Edgar Ricardo Oviedo-Ocaña, Angelica Hernandez, Isabel Dominguez, and Jonathan Soto-Paz. The first draft of the manuscript was written by Angelica Hernandez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

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Figures

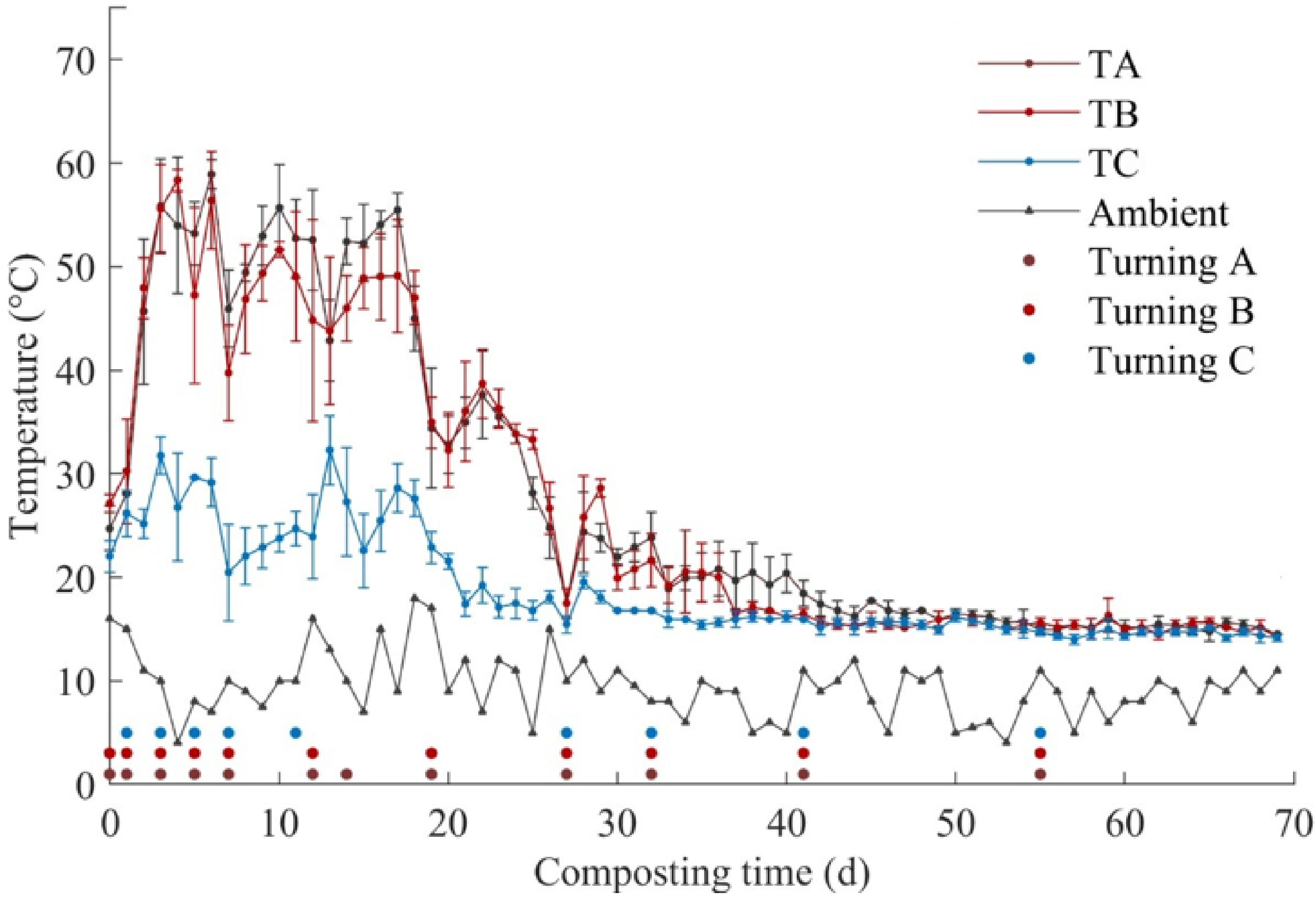

Figure 1

Temperature profiles in treatments.

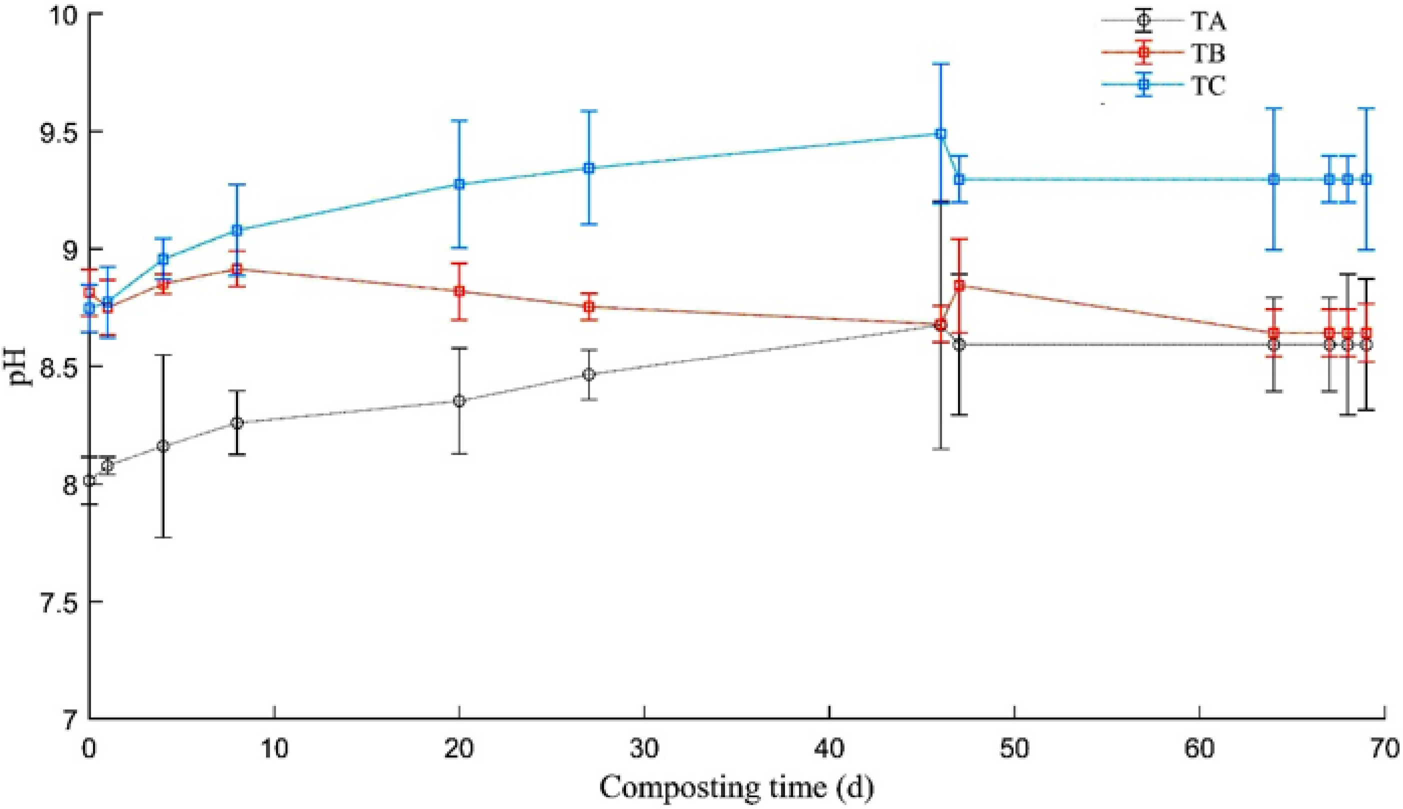

Figure 2

pH behavior in treatments

Note: TA: Treatment A; TB: Treatment B; TC: Treatment C

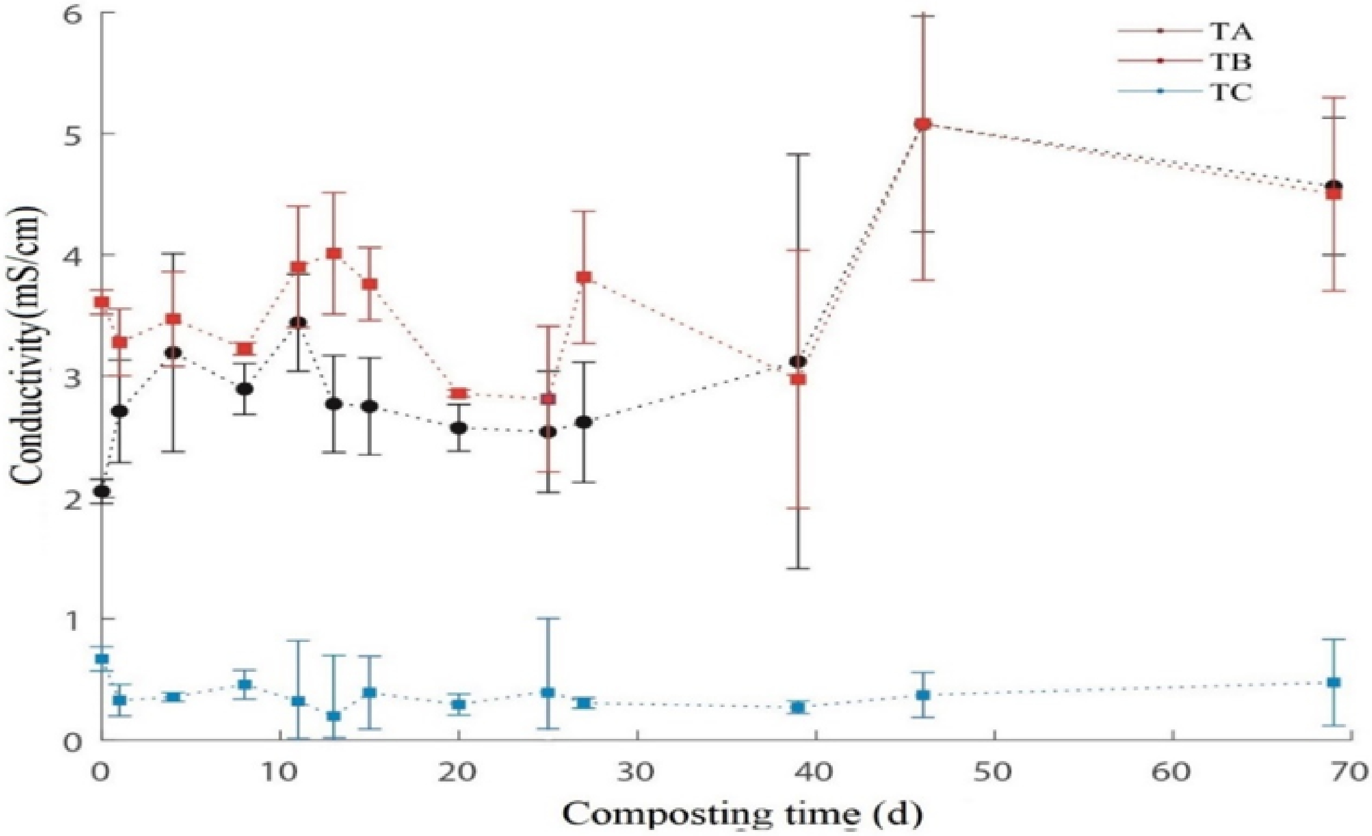

Figure 3

EC behavior in treatments

Note: TA: Treatment A; TB: Treatment B; TC: Treatment C

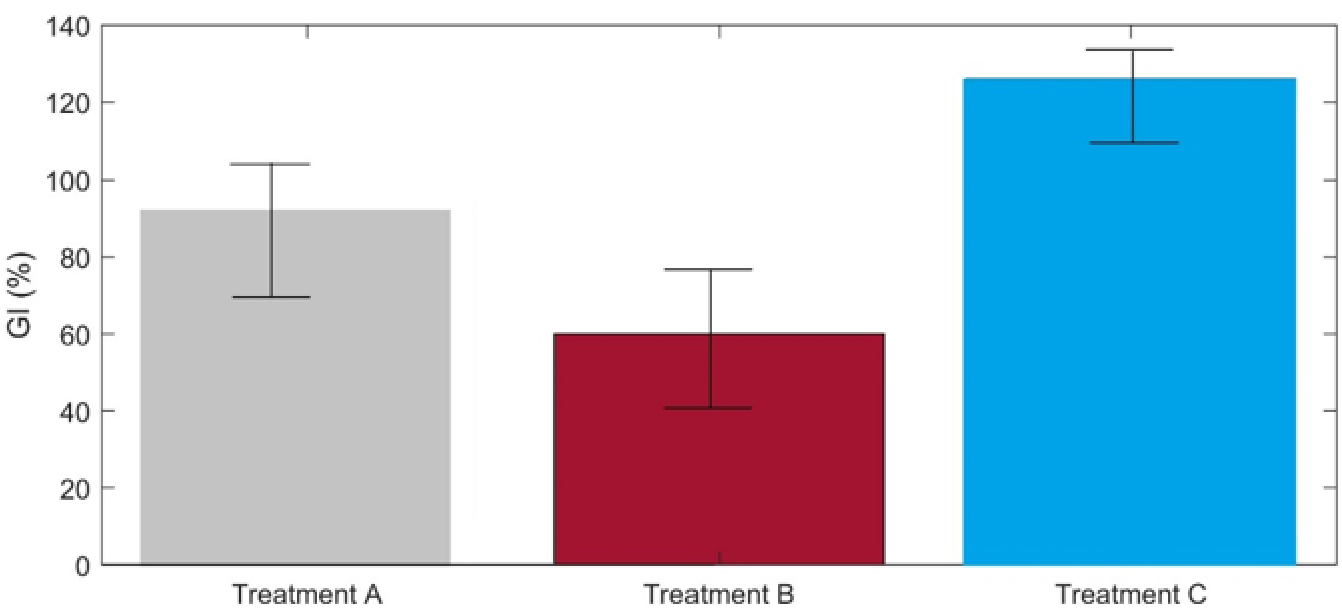

Figure 4

IG in the treatments