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Evaluation of Co-Composting as an Alternative for the Use of Agricultural Waste of Spring Onions, Chicken Manure and Bio-Waste Produced in Moorland Ecosystems

Edgar Ricardo Oviedo-Ocaña [1], Angelica Hernández-Gómez [1], Isabel Dominguez [1], Brayan Alexis Parra-Orobio [1], Jonathan Soto-Paz [1] and Antoni Sánchez [2,*]

1 Grupo de Investigación en Recurso Hídrico y Saneamiento Ambiental-GPH, Facultad de Ingenierías Fisicomecánicas, Universidad Industrial de Santander, Carrera 27 Calle 9, Ciudad Universitaria Bucaramanga, Bucaramanga 680002, Colombia; eroviedo@uis.edu.co (E.R.O.-O.); angelica2188255@correo.uis.edu.co (A.H.-G.); isabeldr@uis.edu.co (I.D.); brayan.parra@correo.uis.edu.co (B.A.P.-O.); jsotopaz@correo.uis.edu.co (J.S.-P.)

2 Composting Research Group, Department of Chemical Engineering, Universitat Autònoma de Barcelona, 08193 Barcelona, Spain

* Correspondence: antoni.sanchez@uab.cat

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Abstract: Composting is an adequate method for treating and valorizing agricultural waste such as those from spring onion (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 moorland 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; (ii) Treatment B: 52% CM + 32% SO + 16% WC, and (iii) Treatment C: 70% SO + 30% WC. 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%). 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. 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. In summary, we have demonstrated that this waste, in combination with other organic materials, could be a good amendment for the composting process and the end product.

Keywords: agricultural waste; composting; chicken manure; end-product quality; spring onions

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 minimally processed fruit and vegetable crops [1,2]. 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 [3,4]. Thus, the treatment and use of AW is highly relevant for agricultural development and environmental protection [5,6].

The moorland is a high mountain ecosystem located between the upper limit of the Andean forest and, if applicable, the lower limit of the glaciers, located mainly in the Andean countries (Colombia, Venezuela and Ecuador) [7]. This ecosystem is essential for water regulation in addition to its important services ecosystems. However, it is a territory with a high vulnerability to climate change and with strong agricultural activity [8], due to the productivity of its soils, which has altered its physical, chemical, and microbiological properties, leading to the need to incorporate organic fertilizers [9].

The high costs of disposal of agro-industrial waste in the moorland area must be assumed by the farmers themselves and, therefore, makes these become not only an environmental problem but also an economic one [10]. For this reason, the use of this type of waste becomes an environmentally and economically adequate strategy for managing by-products, highlighting co-composting as an option that values these wastes and reduces their environmental impacts in an ecosystem as sensitive as the moorland. It is an option that is rarely applied in moorland contexts due to the low temperatures that occur in these regions [11].

Spring onion (SO) is a typical crop from high-mountain ecosystems such as tropical moorland, where the average temperature is 10 °C, and production varies depending on the geographic region [12,13]. For instance, the Berlin moorland in Colombia has an estimated production of 180,000 t/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 > 3 mS/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. [14] assessed the composting of SO and found that the process was feasible, but the end-product had nutritional deficiencies. Likewise, Rizzo et al. [15] 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. [16] recommend assessing different strategies that increase the composting process's efficiency.

Onion waste is characterized by the presence of sulfurous substances, which can be important for the transformation of animal excreta used as organic fertilizers, especially chicken excreta. However, authors such as Pellejero et al. [17,18] point out that the use of onion residues as a co-substrate in the production of organic fertilizers through biological processes such as composting has been little addressed, considering its significant contribution of P and K to agricultural soils.

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 [3,19]. Woodchips, green waste, and rice straw are common BA; Woodchips (WC) are the most popular due to its TOC contribution and low water content [20,21]. On the other hand, recently, Oviedo-Ocaña et al. [22] 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 [23].

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 wastes like pig manure, cow manure, and food waste [22], reports from the composting of crops such as SO are limited. On the other hand, experiences reported on the composting of CM mixed with different materials include wheat straw [15], biocarbon [24], and vegetable waste [25]. 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. Materials and Methods

2.1. Experimental Units

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

2.2. 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 Calabi-Floody et al. [2], 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) is the predominant fraction of municipal solid waste generated in the town (it makes up more than 60% of the waste generated in that area) 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 were 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. [26], 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 [27].

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 (corresponds to the ratio of each waste); dry weight (dw); SO: Spring Onion; CM: Chicken Manure; BW: Biowaste; WC: Woodchips.

The SO had a high-water content and EC, and also had a low contribution of organic matter. This is possibly due to the fact that one of the usual practices of farmers during the harvest in the moors is to build piles of SO residues to facilitate their subsequent collection. This activity promotes the degradation of a fraction of SO. 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 [15]. On the other hand, BW had typical food waste characteristics: high water content, acidic pH, lack of TP, and low C/N [22,23]. Regarding WC, this co-substrate had high C/N ratios, adequate to be added to TN-rich substrates; likewise, it has low EC and water content.

2.3. Analytical Methods

For the analysis of critical parameters, an integrated sample was made using 200 g of subsamples taken from the centroid and peripheral points in each treatment pile. Samples were stored at 4 °C for up to 24 h before the laboratory analysis to prevent the degradation process. pH was measured using a pH meter (WTW Model 315i, Wissenschaftlich-Technische Werkstatten GmbH, Weilheim, Germany) by taking a solid sample (10 g) 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 when 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 [27]. The self-heating test was carried out using Dewar vessels, according to Lü et al. [28], which measured the increase in temperature produced by the microbial activity of a sample under certain conditions.

2.4. 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 with a length of 70 cm. 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 (Figure A1). 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 of 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)–(3), according to Komilis et al. [29], using radish seeds due to their sensitivity to phytotoxicity. Treatments with a GI lower than 80% were considered indicators of inhibition.

$$RGP\ (\%) = \frac{GS}{GSC} \times 100 \tag{1}$$

$$RRG\ (\%) = \frac{RG}{RGC} \times 100 \tag{2}$$

$$GI\ (\%) = \frac{RGP \times RRG}{100} \tag{3}$$

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.

2.5. 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, and 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 [30]. On the other hand, as a complementary quality indicator, the fertility index proposed by Saha et al. [31] (Equation (4)) was estimated for the end-products. This index uses the parameters TOC, TN, TP, TK, and 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).

$$FI = \frac{\sum_{n}^{i=1}(S_i * W_i)}{W_i} \quad (4)$$

where S_i is a score between 1 and 5, depending on the magnitude of parameters, and 'W_i' is the weight assigned to the parameters on a scale from 1 to 5. Table 2 includes the criteria to assign scores and weights [22].

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 (%)	>20.0	15.1–20.0	12.1–15.0	9.1–12.0	<9.1	5
Total Nitrogen (%)	>1.25	1.01–1.25	0.81–1.00	0.51–0.80	<0.51	3
Total Phosphorus (%)	>0.60	0.41–0.60	0.21–0.40	0.11–0.20	<0.11	3
Total Potassium (%)	>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. [20]. Note: db–dry base % on the dry basis.

2.6. Statistical Processing

To determine the effect of co-composting on product quality, an analysis of variance (ANOVA) and post-ANOVA (Tukey test) were applied with a significance level of $p < 0.05$, where the quality parameters were the variable response using the statistical package R software version 3.6.5® [23].

3. Results and Discussion

3.1. Process Monitoring

Temperature: Temperature is a widely used parameter to describe the composting process behavior [32]. 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.

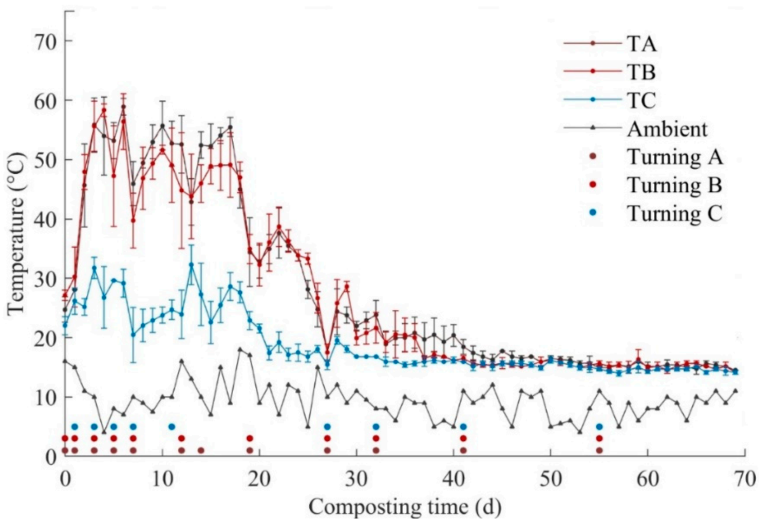

Figure 1. Temperature profiles in treatments. Note: TA: Treatment A; TB: Treatment B; TC: Treatment C.

Table 3. Temperature behavior in each replicate per treatment.

Treatment	Time to the Start of the ThermoPhilic Phase (Days)	T_{MAX} (°C)	Time to T_{MAX} (Days)	Duration of the ThermoPhilic Phase (Days)	Time to $T_{amb} \pm 3$ °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; T_{MAX} Maximum temperature, Tamb ambient temperature.

Treatments A and B had a typical behavior of the composting process, with sequential mesophilic, thermophilic, cooling, and maturation phases. Treatments A and B had a mesophilic phase of three days. Similar results were reported for Zheng et al. [33] in the animal manure windrow composting in cold and warm seasons. This is associated with low temperatures reducing biological activity in the layer of the battery exposed to the atmosphere [34]. According to Soobhany [35], 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. [30] in biowaste composting and Rizzo et al. [15] 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 the 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 [35]. However, treatment A and B showed, for at least three consecutive days, temperatures above 55 °C, which contributes to the pathogen inactivation, as recommended by Hemidat et al. [36]. 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 [37]. 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 [38].

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 a 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. [36] 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 [39]. At the start of the process, pH was alkaline (>8) in all treatments due to the degradation of short-chain fatty acids as intermediate products of the bacterial metabolism of the organic matter degradation [40]. 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 ammonium as a result of protein degradation in the treatments for the presence of BW and CM [15,38,41], the decomposition of organic acids, and the release of CO_2 during pile turning [32].

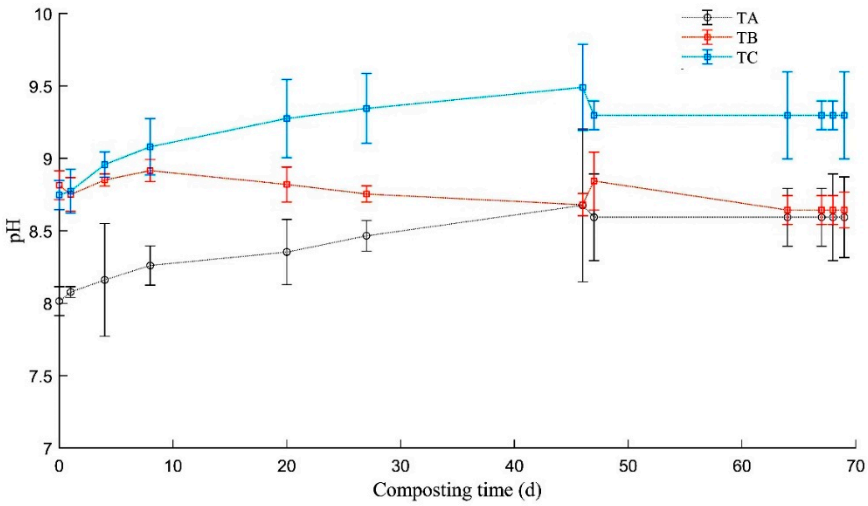

Figure 2. pH behavior in treatments. Note: TA: Treatment A; TB: Treatment B; TC: Treatment C.

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 [39]. However, at the process end, all treatments had pH in the alkaline range (higher to 8.0), with 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 [32].

Electric conductivity: Electric conductivity reflects the concentration of water-soluble inorganic ions in the compost [42]. 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. [43], the EC increase is due to microbial mineralization of organic matter and the release of mineral ions such as phosphates, ammonium, and potassium during this process. Similar results are reported in other investigations with some of the substrates used here indicating an increase in EC, although the concentration of salts can generate a potential phytotoxic effect [44]. In contrast, treatment C showed the lowest EC values related to the low EC from both SO and WC in 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 values compared with treatment C (EC > 4.5 mS/cm).

Germination and Stability test: Germination indexes (GI) were used to determine the maturity (non-phytotoxic) or phytotoxicity of a product, as outlined by Komilis et al. [29]. The GI was different in each treatment. The highest GI was achieved for TA (117%) followed by TB (115%). There were no significant differences between both treatments for the IG ($p = 0.089$). The high GI values are due to the greater degradation of organic matter and environmental conditions generated by the mixture of substrates. The values obtained are similar to those found by Oviedo-Ocaña et al. [22] in the composting of BW with other co-substrates and higher than the lower limit suggested in the literature (IG > 80%). In contrast, treatment C had the lowest GI value of 66%. This suggested that there is a presence of phytotoxic compounds that can limit seed germination and plant growth. Therefore, treatments A and B show better characteristics to be comfortable at paramo temperatures.

On the other hand, the self-heating test evidenced that treatments A and B had a stability degree of V, indicating that end products were stable. In contrast, the degree of stability for treatment C was IV, indicating that there was organic matter still to be degraded, showing consistency with the low GI value obtained for this treatment.

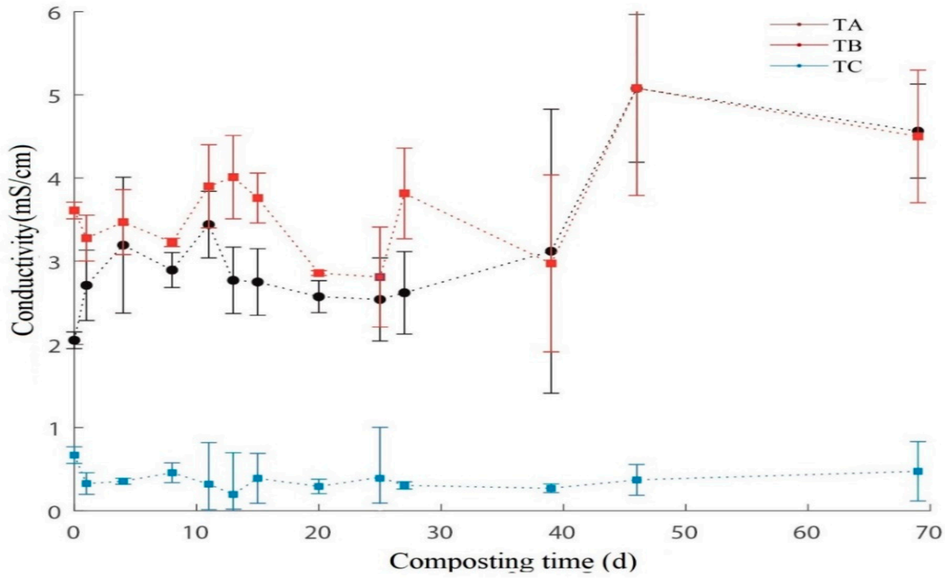

Figure 3. EC behavior in treatments. Note: TA: Treatment A; TB: Treatment B; TC: Treatment

3.2. 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 than 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 [32,45]. 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 [46].

According to Ravindran et al. [47], the final pH of compost is highly dependent on substrates, the composting process, and the addition of amendments. Bernal et al. [42] 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 [38,48].

Regarding density, all treatments had values lower than 0.6 g/cm^3, which is the value recommended by the NTC 5167, with treatment C being higher (0.30 g/cm^3), 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%, with 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 [49].

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/cm^3)	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.

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 negatively charged surfaces [36,50]. This parameter tends to increase through the process due to the mineralization of organic matter [32]. 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. [42] for agricultural use (CE < 3.0 dS/cm), and Cesaro et al. [30] 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 of 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 [42]. The end products from all treatments had an ash concentration lower than 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%, the minimum value recommended by the NTC 5167 and higher than that reported by Rizzo et al. [15] in the composting of CM and by Soto-Paz et al. [50] 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 [37,51]. 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 lower concentration of TN at the end of the process than in other research addressing composting municipal solid waste and poultry manure through co-composting amending sawdust and coffee husks sawdust (i.e., >3%) [52]. The differences between the studies are associated with the different mixing ratios used in the substrates. On the other hand, treatment C had lower concentrations of TN compared to the other 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 ammonium in equilibrium between the water and gas phase.

The C/N ratio has been extensively used to indicate maturity and stability during composting [42]. However, Bernal et al. [42] 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 [53]: <25. There were no statistically significant differences for C/N ($p = 0.16$) between treatments A and B, and both fulfilled this requirement. In contrast, treatment C had a slightly high value (57.7 ± 2.9), which may be because it was the only treatment with a higher quantity of WC, 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 [51]. 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 [37]. Treatments A and B were statistically different with respect to 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 by the microorganisms in the soil, thus stimulating assimilation of macronutrients and their availability for the plants [37,51].

The Fertility Index (FI) values were above 4.2 in treatments A and B, making them more appropriate for use in the soil. This indicates a high fertilization potential, according to the limits set by Saha et al. [31]. This result indicates that the CM and WC had a positive effect on the agronomical quality of the final product. 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 [42].

4. Conclusions

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 a 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. Finally, the scale used in this study makes these results easily applied to full-scale composting.

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Abbreviations

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

Appendix A

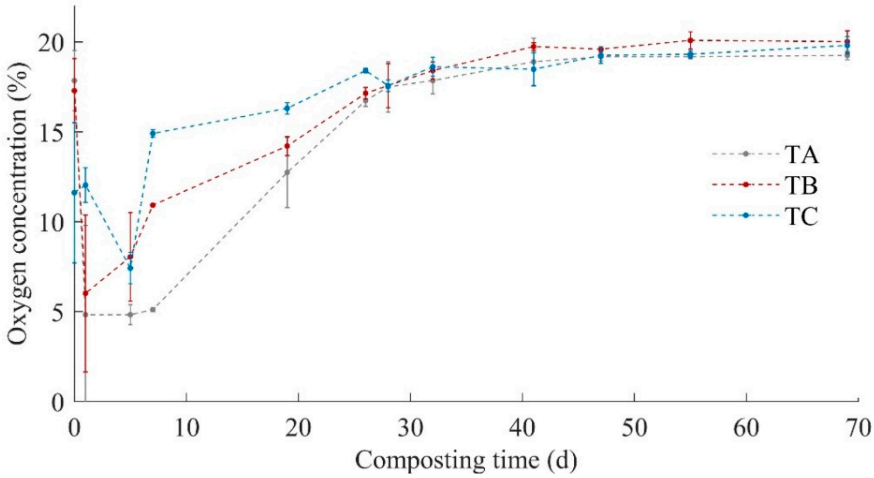

Figure A1. Oxygen concentration for treatments A, B, and C. Note: TA: Treatment A; TB: Treatment B; TC: Treatment C.

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