Improvement of Biowaste Composting by Addition of Sugarcane Filter Cake as an Amendment Material*

Mejora del compostaje de biorresiduos mediante la incorporación de cachaza como material de enmienda

Received: March 18, 2020 | Accepted: January 29, 2021 | Published: November 2, 2021

Laura Moreno-Escandón
Universidad del Valle, Colombia
ORCID: 0000-0002-4317-4030

Daniela Perea-Soto
Universidad del Valle, Colombia
ORCID: 0000-0002-5290-7179

Jonathan Soto-Paz
Universidad del Valle, Colombia
ORCID: 0000-0002-9211-6435

Patricia Torres-Lozada[a]
Universidad del Valle, Colombia
ORCID: 0000-0001-9323-6677

Luis Fernando Marmolejo-Rebellón
Universidad del Valle, Colombia
ORCID: 0000-0001-9993-2841

* Research paper

[a] Corresponding author. E-mail: patricia.torres@correounivalle.edu.co

DOI: https://doi.org/10.11144/Javeriana.iued26.ibca

How to cite this article:
L. Moreno-Escandón, D. Perea-Soto, J. Soto-Paz, P. Torres-Lozada, and L. F. Mermolejo-Rebellón, “Improvement of Biowaste Composting by Addition of Sugarcane Filter Cake as an Amendment Material,” *Ingeniería y Universidad,* vol. 26, 2022. https://doi.org/10.11144/Javeriana.iued26.ibca

Abstract

Objective: The goal of this research was to evaluate the influence of the incorporation of Sugarcane Filter Cake (SFC) as an amendment material (AM) on the process of biowaste (BW) composting and the quality of the final product. *Methods:* In this study the effect (in terms of stability, maturity and agricultural value) of SFC incorporation on four mixture proportions BW: SFC (100:00–control; 90:10; 80:20 and 70:30) was evaluated on a pilot scale. *Results:* The results show that overall, the incorporation of SFC enabled thermophilic temperatures to be achieved in a shorter time than the control treatment and improved the stability conditions (oxygen consumption <1.0 mgO2/gVSh), germination index (GI >80%: mature product) and quality product index (FI >3.5: high soil fertilization potential). The mixing ratio 80:20, showed the best product quality (highest total N content: 2.32%, TP: 1.42%, CEC: 65.5 meq/100 g), lower electrical conductivity (EC) value (0.38 dS/m) and total and fecal coliforms (15.3 and 4.0 NMP/g respectively), complying with technical standards (Colombian and Chilean) for organic products used as fertilizers and amendments or soil conditioners. In addition to demonstrating the best results of GI and FI (123.40% and 4.67 respectively).

Keywords: Agricultural value, Amendment material, Biowaste, Co-composting, Filter cake.

Resumen

Objetivo: Evaluar cómo la incorporación de cachaza (CA) como material de enmienda, afecta la eficiencia del proceso y la calidad del producto final del compostaje de biorresiduos de origen municipal (BOM). *Materiales y métodos:* En este estudio se evaluó a escala piloto y en términos de estabilidad, madurez y valor agrícola, el efecto de la incorporación de CA sobre el compostaje de BOM en cuatro proporciones de mezcla BOM:CA (100:00–control; 90:10; 80:20 y 70:30). *Resultados:* Los resultados mostraron que en general, la incorporación de CA permitió alcanzar temperaturas termofílicas en menor tiempo que el tratamiento control y alcanzar mejores condiciones de estabilidad (consumo de oxígeno <1,0 mgO2/gSVh), Índice de Germinación (IG >80%: indicador de un producto maduro) e Índice de calidad de compost (IF >3,5: indicador de alto potencial de fertilización de suelos), siendo la proporción 80:20 la de mejor calidad del producto (mayor contenido de NT: 2,32%, PT: 1,42%, CIC: 65,5 meq/100g), menor valor de CE (0,38 dS/m) y de coliformes totales y fecales (15,3 y 4,0 NMP/g respectivamente), cumpliendo con normas técnicas como la colombiana y la chilena para productos orgánicos utilizados como fertilizantes y acondicionadores del suelo, además de los mejores resultados de IG e IF (123,40% y 4,67 respectivamente).

Palabras clave: Biorresiduos de Origen Municipal-BOM, Cachaza, Cocompostaje, Material de enmienda, Valor agrícola.

Introduction

World generation of Municipal Solid Waste (MSW) is of the order of 17 billion t/year, and due to population growth and changes in consumption habits, has been predicted to increase up to 27 billion t/year by 2050 [1]. The organic fraction (Biowaste - BW), represents the main flow of MSW in developing countries [2] and is characterized by aspects such as: high moisture (> 70%), low content of Total Organic Carbon and Total Phosphorus (TOC <35%, TP <1%) and medium-low Total Nitrogen content (TN> 1%), as reported by Campuzano y Gonzales [3].

Composting is often considered a clean and ecological technology, as it represents a transformation of organic waste into nutrient-rich fertilizers through two phases, the mineralization and humification phases [4]. During the mineralization phase, organic matter (OM) is degraded, mainly by the action of microorganisms, whilst during degradation, TOC and TN transformations are often used to characterize the composting process [5]. Composting is a highly applicable technology for the management of BW in developing countries, due to aspects such as low investment costs, simple operation, and the generation of a value-added product (compost), whose physicochemical and biological properties contribute to improving the availability of organic matter and nutrients in the soil. However, due to its limiting characteristics, the composting process and the quality of the product are affected, by requiring between two and six months to complete the process and to obtain a product that often presents limitations compared to normative standards [6], [7].

To reduce these limitations, it is common to incorporate co-substrates as amendment and/or bulking agents, such as green waste, and agro-industrial waste such as Sugarcane Filter Cake (SFC) or sugarcane bagasse [1]-[8]. SFC is an amendment material that can be defined as the residue that is eliminated during the decanting process of the cane juice, during the treatment stage, and in the production of sugar and/or alcohol. After the decanting stage of the juice treatment, the resulting suspension is sent to the filtration sector where residual sugar is eliminated, resulting in an SFC whose composition depends on several factors: soil type, sugar cane variety, harvesting method (manual or mechanized), juice extraction, dosage of lime and other products used for clarification, filtration methods, among others [9].

These clarification products typically have no value and are placed directly in crops, but in some cases can lead to environmental problems such as Greenhouse Gas (GHG) emission and nutrient leaching [10].

In Brazil, India, and China 1.9 million tons of sugarcane are produced, on average generating 85.5 million tons of SFC [10]. Authors such as Meunchang et al. [11], have evaluated the co-composting of SFC with other substrates such as sugarcane bagasse and poultry manure in a

2:1 ratio, managing to reduce the loss of TN between 83 and 85%. Bohórquez et al. [12], evaluated different proportions of a mixture of SFC with bagasse, with the 50:50 mixture being the treatment that presented the best quality in nutritional terms.

Although SFC has traditionally been used in composting with agro-industrial waste, it has been little considered in composting with BW. In this research, the effect of incorporating SFC as an amendment material was evaluated, on a pilot scale, on the improvement of both, the BW composting process and the quality of the final product. The following characteristics were analyzed, nutritional: total nitrogen (TN), total potassium (TK) and total phosphorus (TP); agronomic: cation exchange capacity (CEC), electrical conductivity (EC), stability, maturity; and microbiological: total and fecal coliforms.

Materials and methods

Substrate characteristics

The materials evaluated in the composting process were: *i*. BW obtained from a municipality in the Department of Valle del Cauca - Colombia where source separation and selective collection are practiced [13] and *ii*. SFC from the processing of sugar cane in a sugar mill in a rural area of the same municipality. The variables measured for the two co-substrates were: humidity (%, gravimetry), pH (potentiometric), TOC (%, spectrophotometry) TN (%, Kjeldahl titre), C/N ratio, TP (%, colorimetry), TK (%, atomic absorption) according to ICONTEC [14]; lignin (%) and cellulose (%) measured according to PJ Van Soest & Wine [15]. All measurements were taken in triplicate.

Description of the Experimental Design

The composting piles were formed in duplicate, with 150 kg and conical geometry. To determine the incidence of the incorporation of the SFC in BW composting, a unifactorial experimental design was carried out by considering the mixing ratio BW:SFC to be the only factor defined considering that *i*. BWs were the main substrate and, consequently the material in the highest proportion (> 60%) and *ii*. the C/N ratio should be in the recommended range ($15<C/N<30$) [16]. Thus, the BW:SFC ratios evaluated were 100:00 (control treatment), 90:10 (B1), 80:20 (B2) and 70:30 (B3).

Process monitoring and experimental conditions

Process monitoring was carried out by monitoring the behavior of the variables temperature, moisture, pH, TOC, and TN. Temperature was monitored daily by using a 70 cm dial thermometer and the mean value recorded for the perimeter points and the centroid of each treatment was recorded as well. Moisture was measured every three days by gravimetry, while pH was determined daily by diluting 10g of sample in 50 mL of distilled water, using a WTW Model 315i meter. The TOC and TN were determined twice a week.

The aeration of the piles was carried out by manual turning, with a twice-a-week frequency during the first four weeks of the process, during which time, there is a greater microbial activity. Once this active (mesophilic and thermophilic) phases of the process had been completed, according to the temperature profiles in the treatments, the frequency of the tumbling was reduced to once a week [17].

Product quality

At the end of the composting process, a manual sieving (1.25 cm sieve) of the products of each treatment [18] was carried out, from which the moisture, pH, CEC and EC were determined according to ICONTEC [14]; TN, TOC, TP and TK were measured based on the methods described in section 2.1. The concentration of total (TC) and fecal (FC) coliforms was measured according to ICONTEC [14].

The stability of the products was quantified with the Dynamic Respirometric Index (RI) [19], [20], by taking 130 grams of sample incubated at 35°C in 500 mL reactors where air was supplied at incubation temperature, at a rate 20 $mL*min^{-1}$; The oxygen concentration at the inlet and outlet of each reactor was measured with the GFM406 Multichannel Portable Gas Analyzer, United Kingdom. Additionally, the degree of maturity was measured by following the methodology proposed by Zucconi et al. [21] (See Table 1) through germination bioassays with radish seeds (*Raphanus sativus*) at 25°C, determining the relative germination percentage (RGP), relative root growth (RRG) and the Germination Index (GI).

Table 1. Equations used to determine the degree of maturity.

Name	Parameter	Expression	Equation number
RGP	SG: Number of germinated seeds in the compost extract. SGC: Number of germinated seeds in the control	$RGP = \frac{SG}{SGC} \times 100$	Eq. (1)
RRG	RG: Radicle growth in compost extract RGC: Radicle growth in control	$RRG = \frac{RG}{RGC} \times 100$	Eq. (2)
GI	RGP: Relative germination percentage RRG: Relative Root Growth	$GI = \frac{RGP \times 100}{100}$	Eq. (3)

Source: Zucconi et al. [21]

As a complementary quality indicator, the fertility index (FI) was determined. Saha et al. [22] propose a fertility index that considers parameters TOC, TN, TP, TK, C/N. Each of these parameters had a weighting factor from 1 to 5 (the latter being the most important), assigned according to their relative importance from an agricultural point of view. In this sense, the TOC had the highest value (5), followed by TN, TP (3) and to a lesser degree the C/N ratio (1). With the data obtained from the characterization of the product, each parameter is weighted with the measured value and the fertility index was determined. The FI calculation form is presented in Equation. 1.

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

Where S_i is the score value of the analytical data (*i.e.*, 1 to 5) and "W_i" is the weighting factor of the "i" fertility parameter (1 to 5) [22].

Finally, the characteristics of the products obtained were analyzed and compared with the Colombian technical standards NTC 5167 [14] and Chilean regulation [23] for organic products used as fertilizers and soil amendments or conditioners.

Results and discusion

Characteristics of the co-substrates and treatments

Table 2 shows the main characteristics of the co-substrates (BW and SFC) and the treatments. Moisture in BWs is characteristic of this type of substrate in developing countries [15]; however, it was higher than indicated (60%) by authors such as Li et al. [1] and Onwosi et al. [24]. Acid pH is associated with the MSW storage period in homes and the presence of citrus residues [18].

Regarding the BW, it was found that the TOC is lower than that reported in other studies (TOC <35%) and the TN is higher (> 1%) [5]. Their C/N ratio was low (21.4 ± 5.42) and it is associated with a low TOC content. Likewise, the TP content of BW was lower than that reported by Parra-Orobio et al. [13] in the same studied municipality. Lignin and cellulose provide insight into the degradability of the substrate, since lignin is considered a difficult component to breakdown. Generally, its content is between 10-15%, while cellulose is found in a higher proportion, between 40-60% [25]. In this study, BW presented lignin and cellulose values of the order of 1.1 ± 0.2% and 1.4 ± 0.2%, which are similar to those obtained by Parra-Orobio et al. [13], who report values of 1.20 and 1.47% respectively.

Regarding SFC, it presented a C/N ratio of 30.37 ± 2.58 due to the high TOC content and is similar to the value reported by Meunchang et al. [11]. This allowed an increase in the TOC content of the BW:SFC treatments, improving the C/N ratio. In this study, treatment B2 (80:20) had an initial C/N ratio close to 25, a value recommended in the literature [1]. On the other hand, the most critical condition in the treatments corresponded to B1 (90:10) which presented a C/N ratio close to 21.1 and acid pH.

Table 2. Physicochemical characterization of the co-substrates (BW and SFC) and of the treatments.

Parameter	Method	BW*	SFC*	B1+ (90:10)	B2+ (80:20)	B3+ (70:30)
Moisture (%, hb)	Gravimetry	77.3 ± 2.6	65.5 ± 2.1	75.4 ± 1.7	71.1 ± 0.5	69.7 ± 0.7
pH	Potenciometric	5.5 ± 0.3	5.4 ± 0.2	5.1 ± 0.1	5.2 ± 0.1	5.2 ± 0.3
TOC (%, db)	Walkley method	31.0 ± 2.5	48.6 ± 3.4	31.7 ± 0.3	40.6 ± 3.2	44.1 ± 1.2
TN (%, db)	Macro Kjendhal	1.5 ± 0.1	1.6 ± 0.8	1.5 ± 0.2	1.5 ± 0.3	1.5 ± 0.8
C/N	—	21.4	30.4	21.1	25.4	29.2
TP (%, db)	Acid Digestion	0.4 ± 0.2	0.9 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	0.7 ± 0.2
TK (%, db)	Atomic Absorption	1.8 ± 0.2	0.2 ± 0.1	1.6 ± 0.3	1.7 ± 0.5	1.5 ± 0.5
Cellulose (%, db)	VanSoest	1.4 ± 0.2	0.6 ± 0.1	—	—	—
Lignin (%, db)	VanSoest	1.1 ± 0.2	2.1 ± 0.9	—	—	—

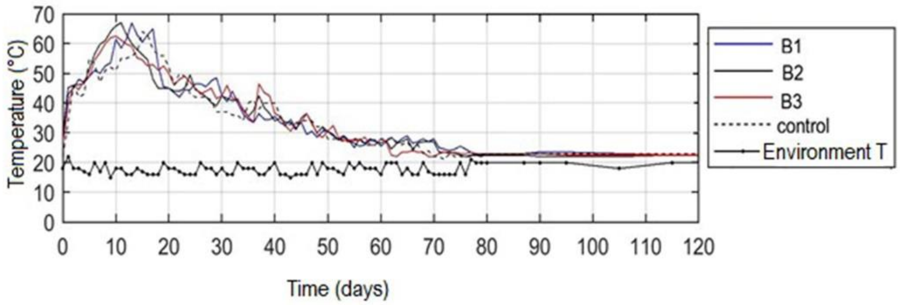
Mean values; *sample size (n): 5. + simple size (n):3. hb: Humid base, db: Dry base, BW: Biowaste, SFC: Sugarcane Filter cake, (BW:SFC)

Source: own source.

Process monitoring

Figure 1 shows the average temperature profile of the two replicates of each treatment in the process.

Figure 1. Temperature profiles of the treatments.



Source: Own elaboration.

The treatments with the incorporation of SFC reached the thermophilic phase in less time (between 1 and 2 days) compared to the control treatment (3 days), which shows the synergistic effect of incorporating SFC in BW composting. The statistical analysis confirmed the existence of significant differences between the treatments with SFC ($p=0.022$) compared to the control (only BW). The time to reach thermophilic temperatures coincides with the results of authors such as Ogunwande et al. [26] and Bryndum et al. [27], who concluded that the high proportion of easily degradable compounds favors the metabolism of different trophic groups that increase the reaction rates and consequently the generation of heat inside the pile.

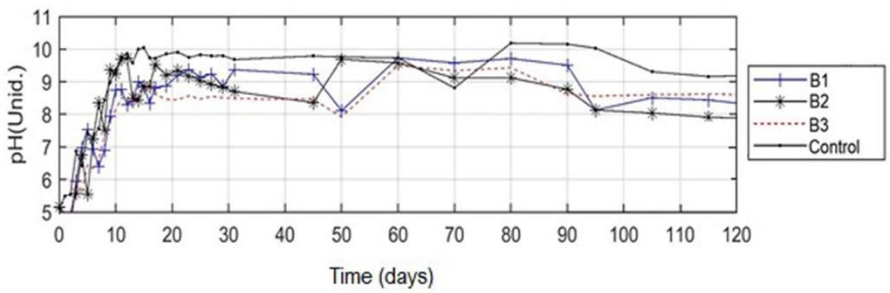
The highest temperature (67°C) was reached in treatment B2; however, all the treatments achieved hygienic conditions since they sustained temperatures equal to or greater than 55°C for at least four consecutive days [28], [29]. During the cooling and maturation phases (temperature <45°C and after day 40), the same behavior was maintained (existence of significant differences between the treatments with incorporation of SFC compared to the control ($p = 0.031$); however, the temperature profiles for treatments B2 and B3 declined more rapidly (33-35 days) compared to treatment B1 (day 39) and the control (day 42).

The aforementioned is associated with a shorter duration of the cooling phase in B2 and B3, which confirms that the incorporation of SFC decreases the process time with respect to the control treatment, which coincides with that reported by Meunchang et al. [11] in the composting of SFC with cane bagasse, who indicate that as the proportion of SFC was higher, the reaction speed of the process increased and the cooling phase was shorter since the process of biodegradation of slow-moving compounds biodegradation like lignin and hemicellulose started faster.

The initial pH values for all the treatments ranged between 5.13 and 5.54 units (Figure 2), however alkaline conditions (between 7.72 and 9.53) were reached after 10 days. Several authors associate this behavior with the degradation of organic nitrogen, CO_2 emissions and the volatilization of ammonia [30], [24]. pH values higher than 8.0 may also be associated with the predominance of residues such as banana and plantain peels in the BW, which contribute TK and together with water, form a strong base (KOH) [31].

The pH values at the end of the process ranged between 7.53 and 9.5 units. The most alkaline value was found in B1, a condition that could hinder the release of nutrients in the soil and plants [32] and can be associated with the volatilization of ammonia nitrogen due to the high content of TN at the beginning of the experiment [26]. The lowest value was obtained with treatment B2.

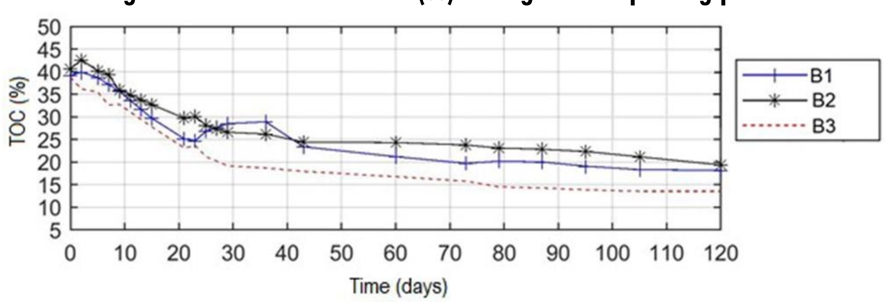
Figure 2. pH profiles of each treatment during the composting process.



Source: Own elaboration.

In relation to TOC and TN, Figure 3 shows the behavior during the composting process. In Figure 3A it is observed that the SFC treatments began with a similar TOC content (between 40 and 45%), higher than that of the BW (31%), which subsequently decreased in the active (mesophilic and thermophilic) phase of the process, a product of the oxidation reactions in organic matter and consequent release of carbon dioxide [33].

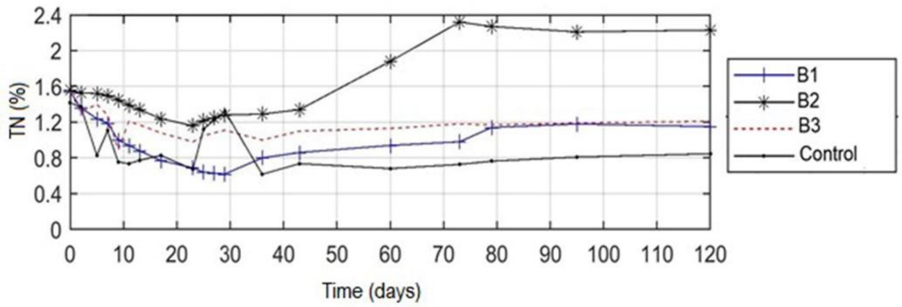
Figure 3A. Evolution of TOC (%) during the composting process.



Source: Own elaboration.

After day 40, the biodegradation of TOC tended to stabilize, which is associated with a probable decrease in biological activity, due to the easily degradable substrate being broken down during the active phase of the process. Waqas et al. [29] also attribute this behavior to the degradation of structurally complex compounds such as lignin and cellulose, present in both BW and SFC. At the end of the process, the treatments with the highest TOC content were B2 (20%) and B1 (18%), followed by B3 (14%).

Figure 3B. Evolution of TN (%) during the process.



Source: Own source.

Figure 3B presents the TN profiles for all treatments. The initial TN of the BW and the SFC was 1.45% and 1.5% respectively. During the mesophilic and thermophilic stages, a rapid decrease in TN is observed in all treatments, associated with the volatilization of ammoniacal nitrogen at temperatures above 45°C and pH values above 8.0 [27]. This behavior coincides with that observed by other authors in the composting of food waste [29], [30].

From day 43 to day 79, there was a marked increase in TN, during which time the cooling phase occurred. This increase is associated with the mineralization of organic matter and the effect of concentration [33]. At the end of the process (120 days), treatment B1 had the lowest total NK content (0.99%), while B2 and B3 had the highest content (2.27% and 1.59% respectively), indicating that the incorporation of SFC presented a synergistic effect in the process. In all treatments, the TN content was higher than that of the BW showing significant statistical differences ($p = 0.019$).

In summary, the analysis of the effect of the different variables on the process shows that the incorporation of SFC had a favorable effect on the composting of BW, with the proportion B2 (BW: SFC - 80:20) being the most favorable, presenting improved characteristics such as pH, higher content of nutrients and TOC.

Product Quality

Table 3 presents the physicochemical and agricultural characteristics of the final products and their contrast with the Colombian Technical Standards - NTC 5167 [14] and Chilean Composting Standards [23]. In general, the treatments which incorporated SFC showed better characteristics than the control treatment (BW).

Table 3. Quality of the products obtained in the treatments.

Parameters	Unit	Control (BW)	B1 (90:10)	B2 (80:20)	B3 (70:30)	NTC 5167	NCh 2880
pH	Units	8.9 ± 0.5	8.5 ± 0.6	7.7 ± 0.4	7.8±0.1	4 – 9	5 – 8.5
Moisture	%	35.4 ± 18.2	25.9 ± 5.8	19.1 ± 4.9	24.6±5.5	≤30	30 – 45
CEC	meq/100 g	22.4 ± 2.2	45.1 ± 3.6	36.3 ± 2.2	46.1 ± 2.5	≥30	-
EC	dS/m	0.4 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.6±0.1	-	< 3.5
TN	%	0.8 ± 0.3	1 ± 0.2	2.32 ± 0.1	1.8± 0.1	>1	≥0.5
TOC	%	12.8 ± 2.4	13.2 ± 2.5	20.3 ± 3.8	15.3±1.9	≥15	≥20
TP	%	0.6 ± 0.3	1 ± 0.1	1.4 ± 0.6	1.2±0.5	>1	-
TK	%	2.2 ± 1.2	1.9 ± 0.8	2.1 ± 0.8	2.3±0.8	>1	-
Stability	$mgO_2/gSVh$	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.4	0.9±0.1	-	8
GI	%	62.7 ± 1.9	85.4 ± 3.6	122.4 ± 4.2	112±2.8	-	>80
FI	-	3.53	3.9	4.67	4.33	-	-
FC	NMP/g	35 ± 3	10 ± 0	3 ± 0	4±0	<1	<1
TC	NMP/g	59 ± 11	48.2 ± 3.4	15.3 ± 8.4	314±2,9	<1	-

Source: Own elaboration.

Regarding pH, the products presented alkaline values (pH> 7.5). According to Lasaridi et al. [32], the pH of the product must fluctuate between 6.0 and 8.5 so that the process can be applied to a wide variety of plants, therefore treatments B2 and B3 show greater potential to stimulate plant activity. Moisture, in general, complies with the provisions of NTC 5167 (≤35) and the Chilean standard (30 - 45%), being lower in treatments with the incorporation of SFC.

All the treatments presented a CEC greater than 20 meq/100 g, that indicates that they would stimulate biological activity by the exchange of bases with the soil. The EC values are low in comparison with the limit proposed in the regulations and indicate little presence of salts, which is important to reduce phytotoxicity problems in plants [32].

Regarding the content of TOC, TNK, TP and TK, treatment B2 shows the highest potential for agricultural use, since it presents better nutrient content and agronomic characteristics such as CEC and EC. Consideringthe biological quality, all the SFC treatments presented stable conditions since they had an oxygen consumption lower than 1.0 $mgO_2\ gSV^{-1}$ [19]. The most stable products were those resulting from treatments B2 and B3, which confirms the synergistic effect of the incorporation of sugarcane filter cake in the composting of BW.

The final product obtained (compost) from each of the evaluated treatments is considered mature (not phytotoxic) and with high fertilization potential according to the GI obtained during the germination tests with *Raphanus sativus* and with the FI values obtained. However, the BW:SFC ratio (80:20) was the one that presented the best performance, both from the point of view of the process (the initiation and duration of the thermophilic phase was reduced and at the same time a maximum temperature was reached 67°C) as well as the final product (medium-high concentrations (w / w) of organic matter (> 20%), TN (2.32%), TP (1.42%) and TK (> 2%) and alkaline pH values (7.7)), promoting radicle growth and / or the number of germinated seeds.

In contrast, the BW composting product (control) and the B1 treatment had a lower GI and FI, indicating that these products can inhibit plant growth. Regarding microbiological quality, the products of all the treatments are Class A because the density of TC and FC is less than 1000 NMP / g.

Conclusions

BW are a substrate with high potential for composting; however, they are often deficient in nutrients such as phosphorus TP, TN and TOC. This deficiency can be compensated through the incorporation of an amendment material such as SFC, increasing both the amount of TOC and the amount of nutrients (TN and TP) and at the same time improving parameters such as CEC.

The performance of BW composting improved in the three treatments in which SFC was incorporated, reaching temperatures higher than 55°C and reducing the duration of the process when compared to the control treatment.

The treatment that complied with all the guidelines established by NTC 5167 was B2 (80% BW: 20% SFC), achieving medium-high concentrations (w/w) of organic matter (> 20%), TN (2.32%), TP (1.42%), TK (> 2%) and alkaline pH values (7.75), promoting radicle growth and/or the number of germinated seeds. Which gives it potential as an organic fertilizer in acid soils.

From the point of view of the final quality, the product (compost) obtained from each of the treatments is considered a mature product (not phytotoxic), according to both the GI and FI obtained during the germination tests carried out with *Raphanus sativus*, and the regulations established by NCh 2880. This confirms that the incorporation of SFC improves the quality of the composting product.

Acknowledgments

The authors would like to thank Universidad del Valle for funding the C.I. 2985. Conflicts of interest: This article was prepared and reviewed with the participation of all authors. We declare that there is no conflict of interest that puts the validity of the results presented at risk.

References

[1] Z. Li, H. Lu, L. Ren, and L. He, "Experimental and modeling approaches for food waste composting: A review," *Chemosphere,* vol. 93, no. 7, pp. 1247-1257, 2013. https://doi.org/10.1016/j.chemosphere.2013.06.064

[2] N. Thi, G. Kumar, and C.-Y. Lin, "An overview of food waste management in developing countries: current status and future perspective," *Journal of Environmental Management,* vol. 157, pp. 220-229, 2015. https://doi.org/10.1016/j.jenvman.2015.04.022

[3] R. Campuzano and S. Gonzáles-Martínez, "Characteristics of the organic fraction of municipal solid waste and methane production: A review," *Waste Management,* vol. 54, pp. 3-12, 2019. https://doi.org/10.1016/j.wasman.2016.05.016

[4] D. Kulikowska and E. Klimiuk, "Organic matter transformations and kinetics during sewage sludge composting in a two-stage system," *Bioresource Technology,* vol. 102, no. 23, pp. 10951-10958, 2011.

[5] L. Y. Lim, C. P. C. Bong, C. T. Lee, J. J. Klemeš, M. R. Sarmidi, and J. S. Lim, "Review on the current composting practices and the potential of improvement using two-stage composting," *Chemical Engineering Transactions,* vol. 61, pp. 1051-1056, 2017. https://doi.org/10.3303/CET1761173

[6] J. Faverial, M. Boval, J. Sierra and D. Sauvant, "End-product quality of composts produced under tropical and temperate climates using different raw materials: A meta-analysis," *Journal of environmental management,* vol. 183, no. 3, pp. 909-916, 2016. https://doi.org/10.1016/j.jenvman.2016.09.057

[7] R. Götze, A. Boldrin, C. Scheutz, and T. F. Astrup, "Physico-chemical characterisation of material fractions in household waste: Overview of data in literature," *Waste Management,* vol. 49, pp. 3-14, 2016. https://doi.org/10.1016/j.wasman.2016.01.008

[8] L. Zhang and X. Sun, "Improving green waste composting by addition of sugarcane bagasse and exhausted grape marc," *Bioresource Technology,* vol. 218, pp. 335-343, 2017. https://doi.org/10.1016/j.biortech.2016.06.097

[9] N. J. Smallwood, "Environmental Concerns in Soybean Processing," in *Practical Handbook of Soybean Processing and Utilization*, D. Erickson, Ed. Champaign, IL: AOCS Press, 1995, pp. 504-518. https://doi.org/10.1016/b978-0-935315-63-9.50029-2

[10] R. D. M. Prado, G. Caione, and C. N. S. Campos, "Filter cake and vinasse as fertilizers contributing to conservation agriculture," *Applied and Environmental Soil Science,* vol. 2, 2013. http://dx.doi.org/10.1155/2013/581984

[11] S. Meunchang, S. Panichsakpatana, and R. W. Weaver, "Co-composting of filter cake and bagasse; by-products from a sugar mill," *Bioresource Technology,* vol. 96, no. 4, pp. 437-442, 2005. https://doi.org/10.1016/j.biortech.2004.05.024

[12] A. Bohórquez, Y. Puentes, J. C. Menjivar, "Evaluación de la calidad del compost producido a partir de subproductos agroindustriales de caña de azúcar," *Corpoica. Ciencia y Tecnología agropecuaria,* vol. 15, no. 1, pp. 73-81, 2014. https://doi.org/10.21930/rcta.vol15_num1_art:398

[13] B. Parra, *Producción de metano a partir de la digestión anaerobia de biorresiduos de origen municipal,* Thesis, Área de Énfasis Ingeniería Sanitaria y Ambiental, Universidad del Valle, 2014.

[14] ICONTEC, *Norma técnica colombiana NTC 5167. Productos para la industria agrícola, productos orgánicos usados como abonos o fertilizantes y enmiendas de suelo,* Bogotá, Colombia: ICONTEC, 2011.

[15] P. J. van Soest and R. Wine, "Uso de detergentes en el análisis de alimentos fibrosos. IV. Determinación de permanganato," *Association of Official Analytical Chemists,* vol. 50, no. 1, p. 6, 2020.

[16] C. W. Acosta, P. Franco and M. Ivan, *Elaboración de abonos orgánicos a partir del compostaje de residuos agrícolas en el municipio de Fusagasugá,* Thesis, Universidad de Cundinamarca, Bogotá, Colombia, 2015.

[17] T. Getahun, A. Nigusie, T. Entele, T. Gerven, and B. Bruggen, "Effect of turning frequencies on composting biodegradable municipal solid waste quality," *Resources, Conservation and Recycling,* vol. 65, pp. 79-84, 2012. https://doi.org/10.1016/j.resconrec.2012.05.007

[18] C. Sundemberg, I. Franke-Whittlw, S. Kauppi, S. Yu, M. Romantschuk, H. Insam, and H. Jonsson, "Characterisation of source-separated household waste intended for composting," *Bioresource technology,* vol. 102, no. 3, pp. 2859-2867, 2010.

[19] R. Barrera, F. Vásquez, and A. Sánchez, "The use of respiration indices in the composting process: a review," *Waste management & research,* vol. 24, no. 37, pp. 37-47, 2006. https://doi.org/10.1177/0734242X06062385

[20] S. Ponsa, E. Pagans, A. Sánchez, "Composting of dewatered wastewater sludge with various ratios of pruning waste used as a bulking agent and monitored by respirometer," *Biosystems Engineering,* vol. 102, no. 4, pp. 433-443, 2009. https://doi.org/10.1016/j.biosystemseng.2009.01.002

[21] F. Zucconi, A. Pera, M. Forte, and M. de Bertoldi, "Evaluating toxicity of immature compost," *Biocycle (USA),* vol. 22, no. 2, pp. 54-57, 1981.

[22] H. Saha , N. Panwar, and M. Singh, "An assessment of municipal solid waste compost quality produced in different cities of india in the perspective of developing quality control indices," *Waste Management,* vol. 30, no. 2, pp. 192-201, 2010. https://doi.org/10.1016/j.wasman.2009.09.041

[23] Gobierno de Chile, *Norma chilena de compost 2880-2004. Compost: Clasificación y requisitos,* Santiago de Chile: Gobierno de Chile, 2015.

[24] C. O. Onwosi, V. C. Igbokwe, J. N. Odimba, I. E. Eke, M. O. Nwankwoala, I. N. Iroh, and L. I. Ezeogu, "Composting technology in waste stabilization: on the methods, challenges and future prospects," *Journal of Environmental Management,* vol. 190, pp. 140-157, 2017. https://doi.org/10.1016/j.jenvman.2016.12.051

[25] J. P. Juanga, *Optimizing dry anaerobic digestion of organic fraction of municipal solid waste,* Bangkok, Thailand: Asian Institute of Technology, 2005.

[26] G. Ogunwande, J. Osunade, K. Adekalu, and L. Ogunjimi, "Nitrogen loss in chicken litter compost as affected by carbon to nitrogen ratio and turning frequency," *Bioresource Technology,* vol. 99, no. 16, pp. 7495-7503, 2008. https://doi.org/10.1016/j.biortech.2008.02.020

[27] S. Bryndum, R. Muschler, A. Nigussie, J. Magid, and A. De Neergaard, "Reduced turning frequency and delayed poultry manure addition reduces n loss from sugarcane compost," *Waste Management,* vol. 65, pp. 169-177. https://doi.org/10.1016/j.wasman.2017.04.001

[28] N. Rich and A. Bharti, "Assessment of different types of in-vessel composters and its effect on stabilization of msw compost," *International Research Journal of Engineering and Technology,* vol. 2, no. 3, pp. 37-42.

[29] M. Waqas, A. S. Nizami, A. S. Aburiazaiza, M. A. Barakat, M. I. Rashid, and I. M. I. Ismail, "Optimizing the process of food waste compost and valorizing its applications: A case study of saudi arabia," *Journal of Cleaner Production,* vol. 176, pp. 426-438, 2018. https://doi.org/10.1016/j.jclepro.2017.12.165

[30] A. Nigussie, S. Bruun, T. W. Kuyper, T. W. and A. De Neergaard, "Delayed addition of nitrogen-rich substrates during composting of municipal waste: Effects on nitrogen loss, greenhouse gas emissions and compost stability," *Chemosphere,* vol. 166, pp. 352-362, 2017. https://doi.org/10.1016/j.chemosphere.2016.09.123

[31] F. Kalemelawa, E. Nishihara, T. Endo, Z. Ahmad, R. Yeasmin, M. M., Tenywa and S. Yamamoto, "An evaluation of aerobic and anaerobic composting of banana peels treated with different inoculums for soil nutrient replenishment" *Bioresource Technology,* vol. 126, pp. 375-382, 2012. https://doi.org/10.1016/j.biortech.2012.04.030

[32] K. Lasaridi, I. Protopapa, M. Kotsou, G. Pilidis, T. Manios, and A. Kyriacou, "Quality assessment of composts in the Greek market: the need for standards and quality assurance," *Journal of Environmental Management,* vol. 80, no. 1, pp. 58-65, 2006. https://doi.org/10.1016/j.jenvman.2005.08.011

[33] N. Soobhany, "Assessing the physicochemical properties and quality parameters during composting of different organic constituents of municipal solid waste," *Journal of Environmental Chemical Engineering,* vol. 6, no. 2, pp. 1979-1988, 2008. https://doi.org/10.1016/j.jece.2018.02.049