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Improving Compost Process Efficiency by Leachates Inoculation and Shredding of the Organic Fraction of Municipal Solid Waste at Bordo Poniente Composting Plant, Mexico City

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Abstract: Management of MSW (Municipal Solid Waste) is a major downside in most of the biggest cities. The composting of the organic fraction of MSW is one of the oldest and simplest ways of organic waste stabilization. It is a self-heating biological conversion that generates appropriate finished merchandise such as soil conditioner or fertilizers. Mexico City generates about 12,500 ton/day of MSW, 44% of it is food scraps and yard trimmings which are the OFMSW (Organic Fraction of Municipal Solid Waste), 2,500 ton/day of it is composted at the BPCP (Bordo Poniente Composting Plant) yielding 500 ton/day of compost. The purpose of this study was to evaluate three treatments to accelerate the composting process, so eventually the city could increase the amount of the OFMSW at BPCP. We compared three different treatments; one of them showed a significant reduction in time of the composting process ($p \leq 0.05$) i.e., it took less time to reach the thermophilic stage, maturity and stabilization phases. Maturity was achieved at 35 days and 60 days to stabilize. We conclude that shredding the feedstock plus leachate inoculum addition at the beginning of the process, reduces the composting time in about 61% with respect to the time it takes at the BPCP, where lasted 90 days.

Key words: Composting, organic fraction, municipal, solid waste, inoculum, leachates, size particle.

1. Introduction

The composting of the OFMSW (Organic Fraction of Municipal Solid Waste) is an economically and environmental opportunity, and an effective method for treating the OFMSW, where the resulting product can be used as soil conditioner [1]. In recent decades various large-scale composting systems have been operating, however, many have failed from economic and environmental issues. In recent years, the overall trend is to control and optimize the process to avoid environmental problems, poor product quality and high production costs [2].

Mexico City generates about 12,500 ton/day of MSW (Municipal Solid Waste), 44% of it is food scraps and yard trimmings. Since 2012 the BPCP (Bordo Poniente Composting Plant) located northeast of Mexico City processes about 2,500 ton/day of food

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scraps and yard trimmings in an area of 37 ha (112.2 ac) yielding 500 ton/day of compost in a process that lasts 90 days [3]. The purpose of this study was to evaluate three treatments to accelerate the composting process, so eventually the city could increase the amount of the OFMSW at BPCP and reduce the amount of waste at landfills.

Accelerating the composting process can be achieved through the addition of specific nutrients (biostimulation) or by inoculation of specific microorganisms (bioaugmentation). However, insufficient quantity or poor ability to biodegrade the indigenous microbial community used may easily lead to low composting efficiency and undesirable compost quality [4].

The use of an external microbial inoculum in composting materials produced a significant acceleration of the composting process and showed that there were no significant differences among the different inoculation levels (10^5, 10^6 and 10^7 CFU/g) during the composting process [5]. The main concern in the composting process is the time required to get compost, so strategies have now been raised to accelerate the process, one of which is microbial inoculation to increase and improve microbial populations that produce the enzymes required for the degradation of organic materials [6, 7].

It has been observed that the leachate generated during the OFMSW aerobic composting process, contains sufficient native microorganisms with the ability to consume the organic material and emphasized that the particle size of the OFMSW is a key in the acceleration of the composting process, since the ratio of oxygen contained in the pores of the mixed materials depends on particle size, since air flow is essential in composting an adequate particle size will provide oxygen and moisture replenishment and carbon dioxide removal bringing about aerobic OFMSW decomposition [8]. Various authors mention that particle size as a physical property plays an important role during the composting process, and between 2 and 3.5 cm in diameter can ensure aerobic compost conditions [9]. Particle size associated with pH and humidity accelerates the OFMSW transformations during the composting process [10].

Therefore, the purpose of this study was to evaluate three treatments to accelerate the composting process with OFMSW leachates as inoculum, and the shredding of the OFMSW to increase the surface area and the reaction rate of the process.

2. Material and Methods

2.1 Organic Waste

Source-selected OFMSWs from the composting plant of Bordo Poniente (BPCP) were used as the main substrate for composting experiments. Food scraps and yard trimming shredding were made with a Vermeer horizontal grinder with a size particle of 1 inch diameter.

2.2 Composition and Preparation of the Inoculum

Leachates were released from the feedstock percolated through the windrows; the moisture content of the feedstock was 55%. No coliforms were detected in the leachates that served as inoculum for the composting process. The average concentration of was 10^6 CFU/100 mL of leachates. The inoculum was added at the beginning of the composting process in a ratio of 200 mL per kilogram of feedstock. In Table 1 the results of the physicochemical proprieties of inocula are shown.

2.3 Composting Experiments

We built three 155 kg piles with food scraps and yard trimmings in a relationship 70%:30% (*v*/*v*). The treatments applied to the piles were: A (31 L inoculum with a count of 10^6 CFU/100 mL of leachates and shredded feedstock), B (control) (no leachates inoculum was added; only shredded feedstock) the control represents the used method by the BPCP and C (31 L inoculum with a count of 10^6 CFU/100 mL of leachates and non-shredded feedstock). The particle size of OFMSW shredded was 1 inch^2 (Fig. 1).

Table 1 Physicochemical proprieties of inoculum.

Parameter	Units	Value
pH		6.11 ± 0.01
EC	Mv	49.50 ± 0.00
Moisture	%	90.11 ± 0.45
TS	%	9.89 ± 0.43
FS	%	19.85 ± 0.43
TOM	%	2.35 ± 0.32
OC	%	1.31 ± 0.18
TN	%	3.80 ± 0.02
$N\text{-}NH_4$	mg/kg	12.76 ± 0.01
$N\text{-}NO_3$	mg/kg	0.33 ± 0.04
Total coliforms	MPN/100 mL	Not detected
Fecal coliforms	MPN/100 mL	Not detected

pH: potential hydrogen, EC: electrical conductivity, TS: total solids, FS: fixed solids, TOM: total organic matter, OC: organic carbon, TN: total nitrogen, $N\text{-}NH_4$: ammonium nitrogen, $N\text{-}NO_3$: nitrate nitrogen.

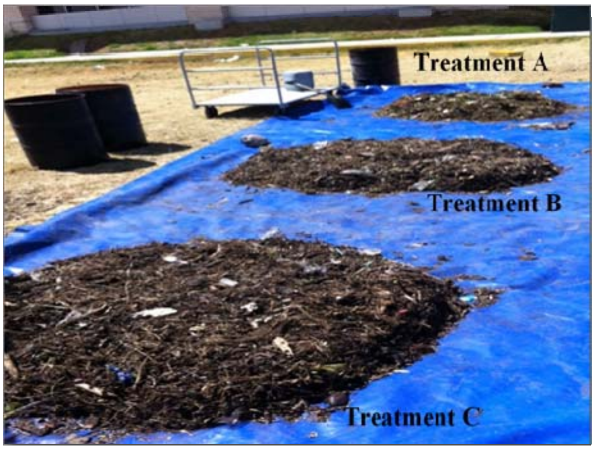

Fig. 1 Experimental piles evaluated during the composting process.

Temperature was measured with a thermocouple sensor type K (FLUKE 51-2) and oxygen and carbon dioxide concentration were measured in interstitial air with a portable O_2 and CO_2 detector (FIRYTE Classic, BACHARACH).

We analyzed other parameters of the composting process in the laboratory from representative double sample quartet of approximately 1 kg in weight in three different points of the pile. Compost samples were collected in sterile plastic containers and kept at 4 °C for microbiological and Solvita® tests [11].

2.4 Analytical Methods

Moisture, TOM (Total Organic Matter), pH, EC (Electrical Conductivity), OC (Organic Carbon), TS (Total Solids), FS (Fixed Solids), TN (Total Kjeldahl Nitrogen), $N\text{-}NH_4$ (Ammonia Nitrogen), $N\text{-}NO_3$ (Nitrate Nitrogen), and the Solvita® test were determined according to standard procedures [12, 13].

2.5 Data Analysis

The analysis was performed in duplicate, and the results were expressed as mean, with standard deviation and coefficient of variation. The samples' differences between physical and chemical parameters were established by one-way analysis of variance, with the software SIGMAPLOT 12, where differences were considered significant at $p \leq 0.05$.

3. Results and Discussion

The goal process temperature was 55 °C (Fig. 2) to eliminate pathogens during the composting [14].

Fig. 2 shows in A treatment the four stages of the composting process: mesophilic, thermophilic cooling and maturing phases, with a short time between mesophilic and the thermophilic phase when the temperature reached the 55 °C, with significant differences ($p \leq 0.05$) with treatment B (control) and C.

Such phenomenon has been described in references [7, 15-17]. According to these authors, this effect is achieved when adding inoculum concentrations

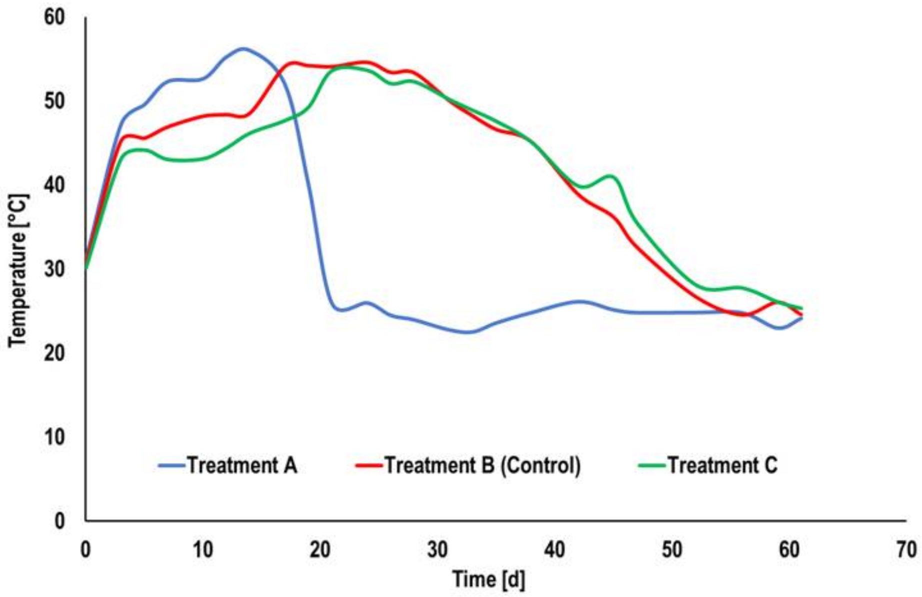

Fig. 2 Temperature profiles (average values) for the treatments studied.

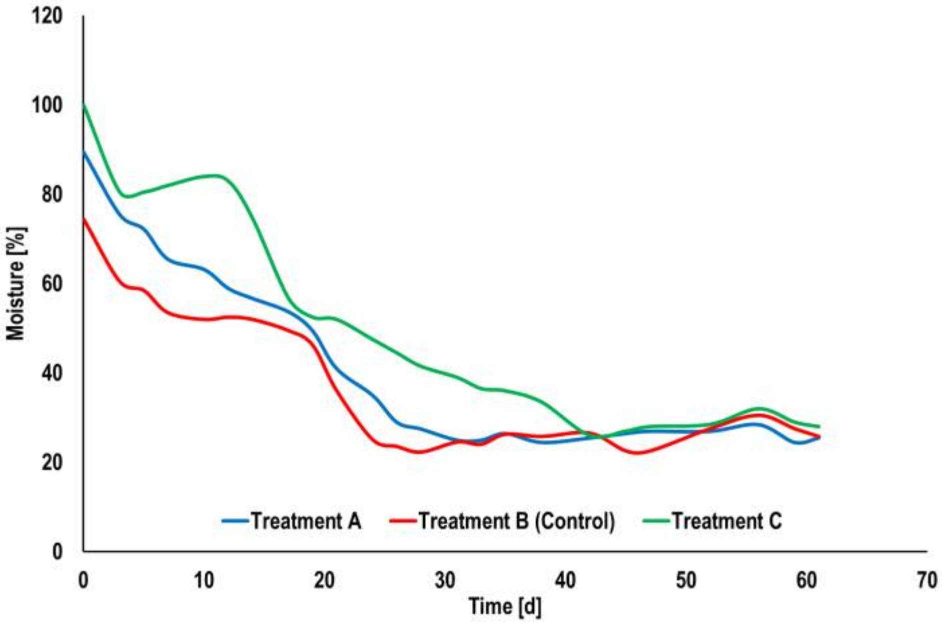

Fig. 3 Moisture profiles (average values) for the treatments studied.

between 10^6 and 10^7 CFU at the beginning of the composting process, conditions happened in A treatment, where in the beginning the leachate inoculum (10^7 CFU) was added and the OFMSW was shredded to a particle size between 2.5 and 3.5 cm^2.

In addition, Fig. 3 shows that in A treatment, moisture decreases more than in treatments B and C, condition associated with the higher increment of temperature in the beginning. Moisture decreases when adding the inoculum in the beginning of the OFMSW composting process, because thermophilic stage is reached in a shorter time, when the temperature is incremented [17].

The treatment A showed greater decrease in moisture than treatments B and C, associated with the temperature increment. Related with the oxygen concentration,

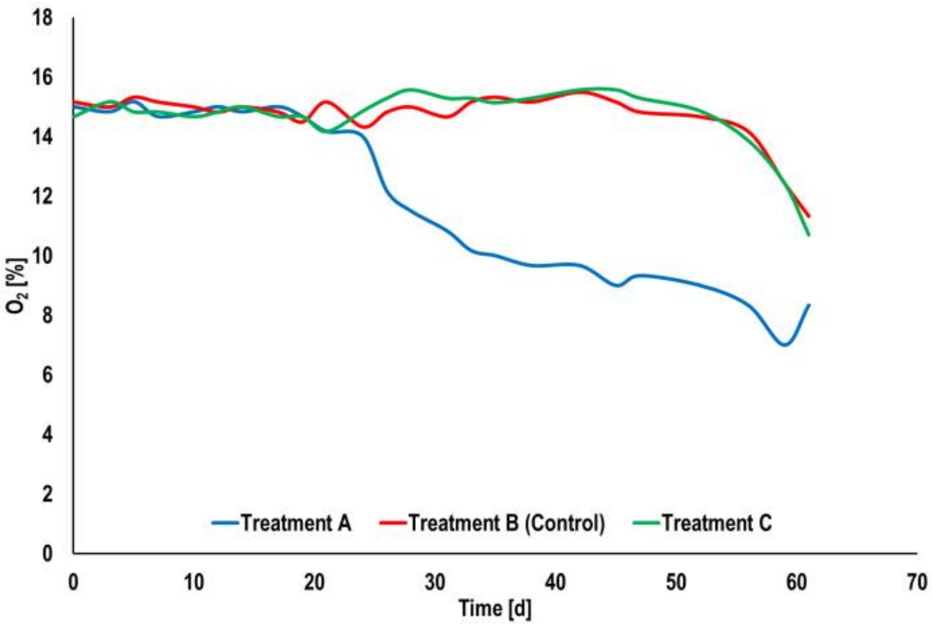

Fig. 4 Oxygen profiles (average values) for the treatments studied.

Fig. 4 shows a decay in treatment A after 26 days, associated with the maturation of the compost. For this behavior in the maturity process there is a decrease in oxygen and is an indicator of stabilization of the final product [9].

Tables 2 and 3 show moisture, TOM, EC pH, Organic Carbon, TS, FS, TN, N-NH_4 and N-NH_3 were determined for the initial sample of OFMSW, day zero for the three treatments, and the final compost obtained for each treatment. As can be seen only slight differences were observed among the treatments applied. The differences were in pH, EC, and nitrogen content in the final products.

In Table 4 we observed in treatment A, a better quality in the final product, indicated by the grade, the maturity and the stability Solvita® index, we observed that the latter was 7, whereas, in treatments B and C, it was 5 in 36 days, this confirms that the leachate inoculum addition and the OFMSW shredding accelerates the composting process. In addition, presence of pathogenic organisms was not detected in any treatment.

Table 2 Physicochemical characteristics of composting process in the treatments A and B.

Parameter	Time (days)									
	Treatment A (inoculum + shredded feedstock)					Treatment B (Control, shredded feedstock)				
	0	9	18	27	36	0	9	18	27	36
pH	4.72±0.01	4.72±0.01	8.02±0.24	4.79±0.07	8.23±0.09	8.17±0.12	8.23±0.09	9.20±0.05	8.18±0.19	8.27±0.05
EC (mS/cm)	4.63±0.44	2.64±1.34	2.78±1.75	2.70±1.28	4.86±0.25	5.80±0.08	5.39±0.44	4.66±0.59	3.01±0.66	35.00±2.83
TS (%)	55.58±1.15	55.71±0.77	72.29±0.43	58.93±1.03	74.04±0.81	67.13±1.15	57.13±0.71	69.40±0.77	78.59±0.54	78.59±0.45
FS (%)	0.64±0.04	0.60±0.02	0.62±0.03	0.42±0.03	0.54±0.03	0.54±0.03	0.53±0.04	0.52±0.04	0.67±0.04	0.73±0.03
TOM (%)	36.71±3.94	40.66±1.52	38.74±3.15	58.14±2.80	46.32±3.42	46.65±2.96	46.98±3.63	48.13±3.72	33.20±2.45	27.65±3.09
OC (%)	20.40±2.19	19.59±0.85	15.36±1.71	22.30±1.56	26.10±2.02	25.92±1.42	26.10±2.02	26.74±2.07	18.44±1.24	15.36±1.71
TN (%)	0.91±0.14	0.63±0.06	0.63±0.05	0.89±0.13	0.93±0.11	0.96±0.04	1.06±0.04	1.07±0.25	0.67±0.24	0.70±0.04
N-NH_4 (mg/kg)	0.39±0.04	0.39±0.04	0.26±0.04	0.33±0.04	0.12±0.04	0.07±0.00	0.06±0.01	0.03±0.01	0.23±0.04	0.21±0.07
N-NO_3 (mg/kg)	0.08±0.02	0.081±0.02	0.68±0.10	0.04±0.02	1.03±0.08	0.06±0.01	0.04±0.01	0.03±0.01	0.70±0.00	0.75±0.04

pH: potential hydrogen, EC: electrical conductivity, TS: total solids, FS: fixed solids, TOM: total organic matter, OC: organic carbon, TN: total nitrogen, N-NH_4: ammonium nitrogen, N-NO_3: nitrate nitrogen.

Table 3 Physicochemical characteristics of composting process in the treatment C.

Parameter	Time (days)				
	Treatment C (Only inoculum and non-shredded feedstock))				
	0	9	18	27	36
pH	8.14±0.09	8.09±0.18	8.28±0.18	8.51±0.06	7.47±0.02
EC (mS/cm)	4.18±0.25	5.09±0.16	4.20±3.84	2.65±0.43	3.57±0.54
TS (%)	87.32±0.56	80.49±0.78	78.61±0.95	76.74±0.55	87.09±0.83
FS (%)	0.66±0.03	0.57±0.04	0.64±0.03	0.71±0.02	0.60±0.04
TOM (%)	26.91±3.38	43.65±3.77	36.40±2.85	29.14±1.69	29.83±3.74
OC (%)	16.30±1.88	16.19±0.94	20.22±1.24	16.19±0.94	21.13±2.08
TN (%)	0.63±0.06	0.92±0.15	0.94±0.17	1.04±0.15	1.06±0.05
$N-NH_4$ (mg/kg)	0.21±0.07	0.12±0.04	0.11±0.04	0.23±0.28	0.39±0.04
$N-NO_3$ (mg/kg)	0.82±0.08	1.03±0.08	1.02±0.04	1.00±0.15	1.03±0.04

pH: potential hydrogen, EC: electrical conductivity, TS: total solids, FS: fixed solids, TOM: total organic matter, OC: organic carbon, TN: total nitrogen, $N-NH_4$: ammonium nitrogen, $N-NO_3$: nitrate nitrogen.

Table 4 Indexes of maturity and stability and microbiological parameters.

Parameter	Units	Finished product		
		Treatment A	Treatment B	Treatment C
Stability	Stability Index ®Solvita.	7	5	5
Maturity	Maturity Index ®Solvita	7	5	5
	Anaerobic conditions and pH ≥ 6.5	7.48 ± 0.04	6.35 ± 0.19	6.20 ± 0.43
Fecal coliforms	MPN/g TS	230.98	340.77	540.22
Salmonella and *Shigella*	MPN/4 g TS	Not detected	Not detected	Not detected

MPN: most probable number, TS: total solids.

4. Conclusions

The leachates generated from the OFMSW are an effective inoculum to accelerate the composting time if it is added at the beginning of the process.

In the treatment A, with a concentration 10^6 CFU/100 mL of leachates and shredded feedstock is optimal in terms of reducing the composting time by approximately 20% faster, with respect to treatments B and C.

Only temperature is statistically different among the treatments studied, indicating that the addition of the inoculum and shredding of the raw material at the beginning of the process has an accelerating effect on reaching the thermophilic stage and therefore the total time of composting.

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References

[1] Hubbe, M. A., Nazhad, M., and Sánchez, C. 2010. "Composting as a Way to Convert Cellulosic Biomass and Organic Waste into High-Value Soil Amendments: A Review." *BioResources* 5: 2808-54.

[2] Bongochgetsakul, N., and Ishida, T. 2008. "A New Analytical Approach to Optimizing the Design of Large-Scale Composting Systems." *Bioresour. Technol.* 99: 1630-41.

[3] Secretaría de Obras y Servicios del Distrito Federal. 2011. *Inventario de Residuos Sólidos del Distrito Federal*. (in Spanish)

[4] Xi, B. D., Huang, G. H., Zhang, G. J., Wei, Z. M., Qin, X. S., and Liu, H. L. 2007. "A Temperature Guided Three-Stage Inoculation Method for Municipal Solid Wastes Composting." *Environ. Eng. Sci*. 24: 745-54.

[5] Barrena, R., Pagans, E., Faltys, G., and Sanchez, A. 2006. "Effect of Inoculation Dosing on the Composting of Source-Selected Organic Fraction of Municipal Solid

Wastes." *J. Chem. Technol. Biotechnol*. 81: 420-5.

[6] Ohtaki, A., Akakura, N., and Nakasaki, K. 1998. "Effects of Temperature and Inoculums on the Degradability of Poly-ε-Caprolactone during Composting." *Polym. Degrad. Stabil*. 62: 279-84.

[7] Ming, L., Xuya, P., Youcai, Z., Wenchuan, D., Huashuai, C., Guotao, L., and Zhengsong, W. 2008. "Microbial Inoculum with Leachate Recirculated Cultivation for the Enhancement of OFMSW Composting." *J. Hazard. Mater*. 153: 885-91.

[8] Richard, T. L., Veeken, A., de Wilde, V., and Hamelers, H. 2004. "Air-Filled Porosity and Permeability Relationships during Solid-State Fermentation." *Biotechnol. Progr*. 20: 1372-81.

[9] Ruggieri, L., Gea, T., Artola, A., and Sánchez, A. 2009. "Air Filled Porosity Measurements by Air Pycnometry in the Composting Process: A Review and a Correlation Analysis." *Bioresour. Technol*. 100: 2655-66.

[10] Zaho, S., Liu, X., and Duo, L. 2012. "Physical and Chemical Characterization of Municipal Solid Waste Compost in Different Particle Size Fractions." *Pol. J. Environ. Stud*. 21: 209-15.

[11] Solvita® Test Quick Guide. 2012. *Official Solvita Guideline Compost Emissions Test*, V. 6.0. Woods End Laboratories, Inc..

[12] Mexican Standard. NADF-020-AMBT-2011.

[13] Sadzawka, R. A., Carrasco, M. A. R., Grez, R. Z., and Mora, M. L. G. 2005. *Métodos de análisis de compost.* Instituto de Investigaciones Agropecuarias, Serie Actas Nº 30, Santiago, Chile. (in Spanish)

[14] Tognetti, C., Mazzarino, M. J., and Laos, F. 2007. "Improving the Quality of Municipal Organic Waste Compost." *Bioresour. Technol*. 98: 1067-76.

[15] Xi, B. D., He, X. S., Wei, Z. M., Jiang, Y. H., Li, M. X., Li, D., and Dang, Q. L. 2012. "Effect of Inoculation Methods on the Composting Efficiency of Municipal Solid Wastes." *Chemosphere* 88: 744-50.

[16] Ghaffari, S., Sepahi, A. A., Razavi, M. R., Malekzadeh, F., and Haydarian, H. 2011. "Effectiveness of Inoculation with Isolated *Anoxybacillu* ssp. MGA110 on Municipal Solid Waste Composting Process." *Afr. J. Microbiol. Res.* 5: 5373-8.

[17] Schloss, P. D., and Walker, L. P. 2000. "Measurement of Process Performance and Variability in Inoculated Composting Reactors Using ANOVA and Power Analysis." *Process Biochem*. 35: 931-42.