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# Influence of Substrate Particle Size on Vermicomposting of Pre-processed Vegetable Waste

**Senthilkumar Palaniappan†, Murugappan Alagappan and Senthilkumar Rayar**
Department of Civil Engineering, Annamalai University, 608 002, Chidambaram, India
†Corresponding author: Senthilkumar Palaniappan

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## ABSTRACT

Past studies report that pre-composting of waste is highly required and 10-15 cm of substrate depth is optimum for conventional vermicomposting, which leads to encroachment of large land area and long time in the process. Keeping this as a core problem, an attempt was made to accelerate and digest the high volume of waste by modifying the conventional vermicomposting to engineered vermicomposting. In the engineered process, the substrate depth was raised to a maximum of 30 cm and elimination of pre-composting by pre-processing (chopping, pulverizing, stocking and drying) the waste. The study also aims in determining the ideal substrate particle size distribution for vermicomposting by experimenting with five different substrate particle mix. Pre-processed waste was sieved through IS sieves for extracting the substrate particles of different sizes (less than 1.7 mm, between 2.36 mm and 1.7 mm, between 4.75 and 2.36 mm, and between 6.30 mm and 4.75 mm). Then the sieved particles were mixed at six different combinations (T1, T2, T3, T4, T5 and T6) and then vermicomposted by *Eisenia fetida*. Results revealed that vermi bin loaded with T3 and T4 combinations produced good volume reduction and biomass growth.

## INTRODUCTION

Unceasing and high volume of organic waste generated treks year by year. The core reason for the high volume of waste generated is population growth and change in life style of the public. It is estimated that developing countries like India alone produce 42 million tonnes of solid waste every year, of which around 50-60% is biodegradable (Senthilkumar & Kavimani 2012). In most of the developing countries the generated solid waste is open dumped without any treatment, which leads to environmental pollution in multidimensions (soil, air and water). Very fewer fractions of organic wastes undergo biological treatment for energy generation and manure production. The reason behind this is awesome maintenance cost and the time elapsed in the biological treatment process like composting or vermicomposting. Out of these two biological treatment options, vermicomposting is proven to be a better option, since it consumes less time and produces quality by-products (vermiwash and vermicast) (Cristina et al. 2008).

In conventional vermicomposting, adult earthworms are inoculated into the pre-composted waste heap (windrow) with a depth not more than 10-15 cm. Past studies report that approximately 1 kg of worms is required to digest 0.5 $m^3$ of pre-composted waste (Foo 1999). In this process, regular monitoring of pile temperature and moisture is highly required. It has been reported that high temperature (>35 °C) of waste mass will inhibit the worms digestion process and lead to the death of worms (Neuhauser et al. 1988). The other disadvantage of higher temperature is reduction of substrate moisture content in the waste.

The optimum moisture required for vermicomposting ranges between 55 and 60 percent and it varies according to the species of worms used (Bansal et al. 2000). From the literature reviewed, it was identified that conventional vermicomposting requires large land area and long waste digestion duration. Senthilkumar & Murugappan (2016) reported that pre-processing and stocking of vegetable waste would eliminate the pre-composting process in vermicomposting and save 30 percent of total time elapsed in the process. Still, a higher percent of waste digestion is required, which would occupy more land area for windrow formation and prove to be not a viable way.

The only option is to accelerate the conventional vermicomposting process and increase the waste digestion rate. Sing et al. (2004) reported that ideal soil structure would contain 30% macro pores and 70% micro pores for effective vermi mobilization and reproduction. Even though in-depth studies on vermicomposting had been done earlier, only little scientific information is available about substrate particle size and its influence on vermicomposting (Senthilkumar et al. 2016). Keeping this in mind, this study was carried out to identify the ideal substrate particle size on vermicomposting process. The results obtained demonstrate the influence of substrate particle size on vermicomposting.

## MATERIALS AND METHODS

### Processes Involved in Pre-processing of Vegetable Waste

Fig. 1 shows the schematic of the various processes involved in pre-processing of vegetable waste. The vegetable wastes (40 kg) collected from the local vegetable market were screened to remove inorganic and inert materials. In order to ease the pulverizing process, the waste was chopped to 20-30 mm size. After chopping, pulverization was done mechanically to make the organic wastes into a paste form. Then, to this waste paste, binding (fresh cow dung-20% of waste volume) and bulking agents (sawdust-5% of waste volume) were added. Adding cow dung and saw dust will increase the proportion of air space or air voids in the waste (Barrington et al. 2003). This aids to increase the aeration in the waste mass. Using sawdust as the bulking agent will boost the pH from 5.5 to 6.8 and help to maintain moisture content and provide integrity to the physical structure by increasing the porosity of the substrate. Drying is the last process, which will remove the excess moisture content that causes foul smell during vermicomposting. Further, it removes volatile toxic gases that upset the vermicomposting. Drying is done by keeping the waste mixture under the sun (30°C to 40°C) for a maximum of 4 to 5 days. Once the waste mixture is well dried, it is stocked in airtight container for vermicomposting. Fig. 2 shows the picturization of the different stages involved in pre-processing of waste.

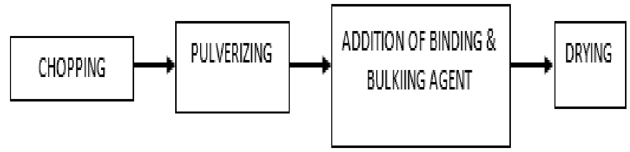


Fig. 1: Pre-processing of vegetable waste.

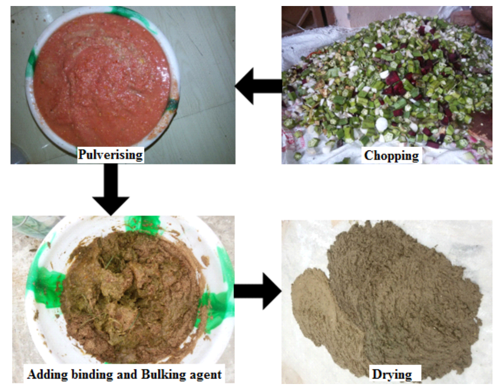


Fig. 2: Stages involved in pre-processing of waste.

### Characterization of Vegetable Waste

Fig. 3 shows the various parameters determined in the proximate and ultimate analyses in characterising the vegetable waste.

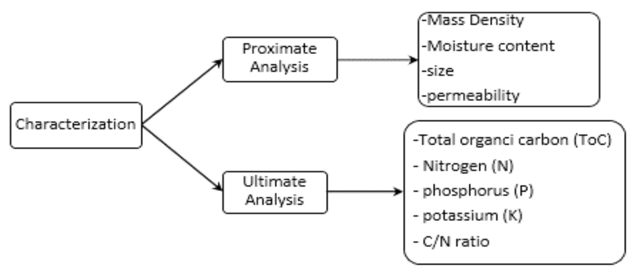


Fig. 3: Characterization of pre-processed waste.

Characterization of pre-processed waste will provide necessary information about the physical and chemical properties of it. Moreover, it is essential in determining the efficiency of any treatment process. The analysis was divided in two phases: (1) Proximate analysis and (2) Ultimate analysis. All the analyses were done as recommended in "Manual on Municipal Solid Waste Management, First edition, India (May 2000) and Manual of Soil Testing in India, New Delhi (January 2011). The results of proximate analysis and ultimate analysis are presented in Tables 1 and 2 respectively.

Volume reduction is the fundamental requirement in any solid waste treatment process. From Table 1, it is very clear that approximately 60% waste volume reduction was achieved by pre-processing it. In addition, during vermicom posting, the pre-processed waste will not produce odorous gases (Senthilkumar & Murugappan 2016) and it eliminates the menace caused by flies. Moreover, considerable increase (nearly 60%) in bulk density leads to reduction in area requirements for treating the waste. Ranganathan (2006) reported that 30% macro pore space in soil is suitable for worm's mobilisation and less pore percent will create water logging, which leads to the suffocation of worms. The pore space available in the pre-processed substrate is approximately 40%, which might be attributed to the addition of cow dung and sawdust and it satisfies the basic requirement of substrate porosity. The above discussion reveals that pre-processing the waste provides more advantages than pre-composting. For any biological treatment process, organic carbon and nitrogen levels play a significant role. Ramamoorthy (2004) reported that the energy nutrient balance of the substrate is indicated by the carbon to nitrogen ratio (C: N) and the ideal ratio lies between 25:1 and 35:1. Too low C:N ratio shows insufficient nutrient level and too high ratio will hold less nitrogen content in it.

Table 1: Proximate analysis of vegetable waste.

| Processing of vegetable waste | Bulk density ($kg/m^3$) | Moisture content (%) | Size(mm) | Permeability *k* (cm/sec) | Volume reduction (%) | Porosity *n*(%) |
|---|---|---|---|---|---|---|
| Raw waste | 91.00 | 61 | 100-300 | NR | 00 | NR |
| Chopped | 109.20 | 63 | 20-30 | NR | 20 | NR |
| Pulverized | 127.40 | 98 | >0.20 | NR | 40 | NR |
| Dried | 145.60 | 00 | 6 to >1.7 | $2.2297 \times 10^{-3}$ | 60 | 40.72 |

NR- Not recorded

Table 2: Ultimate analysis of vegetable waste.

| Processing of vegetable waste | pH | Total Organic Carbon 'C'(mg/g) | Nitrogen 'N' (mg/g) | Phosphorus 'P' (mg/g) | Potassium 'K' (mg/g) | C:N ratio |
|---|---|---|---|---|---|---|
| Chopped | 7.30 | 38.62 | 1.12 | 4.85 | 28.96 | 34.48 |
| *Pulverized | 8.65 | 40.12 | 1.36 | 4.98 | 31.32 | 29.50 |
| *Dried | 8.95 | 46.35 | 1.63 | 5.32 | 33.26 | 28.43 |

*The vegetable was pulverized with binding (cow dung) and bulking (sawdust) agent and then dried.

Table 3: Geophysical properties of the pre-processed vegetable waste.

| Mix trails | Permeability 'k' ($\times 10^{-3}$)(cm/sec) | Voids ratio 'e' | Porosity 'n' | Seepage velocity 'cm/sec' | Rate of Flow 'cm/sec' |
|---|---|---|---|---|---|
| T1 | 2.0153 | 0.6870 | 0.4072 | 0.0120 | 1.0329 |
| T2 | 1.9190 | 0.5190 | 0.3417 | 0.0099 | 0.8177 |
| T3 | 1.6638 | 0.4520 | 0.3113 | 0.0085 | 0.7155 |
| T4 | 1.4087 | 0.3850 | 0.2780 | 0.0071 | 0.6133 |
| T5 | 1.3828 | 0.3712 | 0.2705 | 0.0071 | 0.6101 |
| T6 | 1.3570 | 0.3574 | 0.2630 | 0.0070 | 0.6070 |

It is inferred from Table 2 that the total organic carbon (TOC) level rose from raw to processed waste and this could be attributed to addition of fresh cow dung and saw dust in the waste. The purpose of using binding and bulking agents (fresh cow dung and saw dust) is to increase the proportion of air space or air voids in the substrate (Barrington et al. 2002) and to stabilize the C: N ratio (Ranganathan 2006). Using sawdust as the bulking agent helps to shift the pH from acidic to alkaline and maintains optimum moisture content in the substrate. Adding cow dung shows high microbial community, which helps to boost the conversion performance. Dan Xie et al. (2016) reported combining of organic wastes with cow dung will avoid odour and prevents the breeding of insects and flies. Moreover, using cow dung as the binding agent provides a better environment for the fecundity of earthworms, which results in better degradation of organic waste (Ranganathan 2006).

### Effect of Substrate Particle Size on Airflow and Earthworm's Mobility

Table 3 shows the geophysical properties of the waste with different particle mix. The geophysical properties were tested under 100 percent saturation limit and the test performed until maximum consolidation was reached.

The test results imply that maintaining 60% substrate moisture (optimum moisture content for vermi bins) with proper drain will not allow the substrate mass to consolidate and ensure the airflow and mobility of worms in the substrate. Particle size and geophysical properties of substrate play an effective role in the distribution of air in the substrate mass (Felix & Emilio 2009). High percent of bigger size particles will drain the moisture and air faster, while smaller size particles will obstruct the movement of air and restrict the movement of worms. The other disadvantage of smaller size particles is bed consolidation and retention of high bed moisture for longer duration.

### Experimental Setup

**Vermi bins specification:** Seven vermi bins made of poly vinyl chloride (PVC) pipes each having dimensions of 40 cm height and 15.24 cm diameter were used (Fig. 4). In each bin, top 5 cm and bottom 5 cm were left as free board and drain bed respectively. Providing free board on top of the

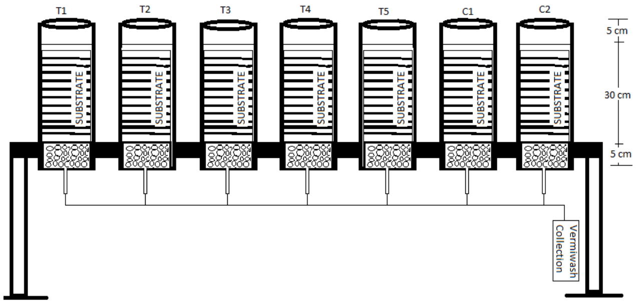


Fig. 4: Schematic representation of the vermi bins.

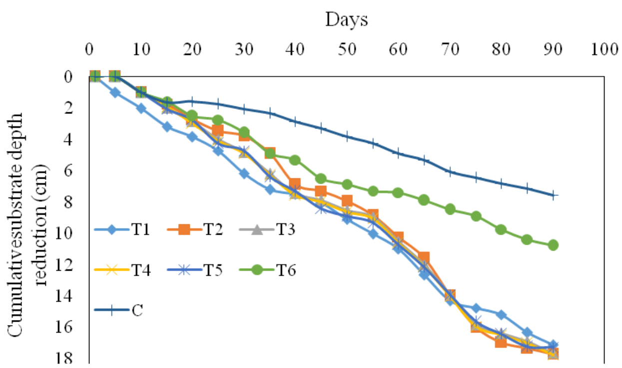


Fig. 5: Cumulative substrate depth reduction ($d_{cr}$) in cm.

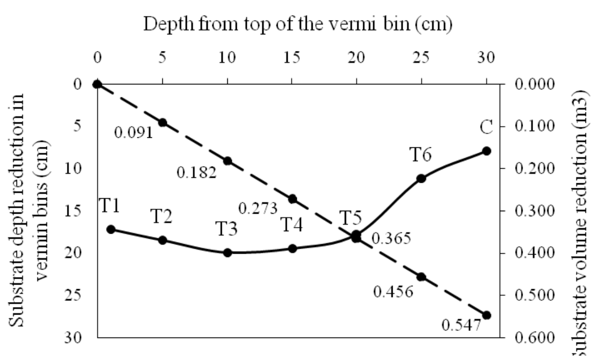


Fig. 6: Volume of waste digested with respect to substrate depth in vermi bins.

bin will prevent the escape of earthworm from the bins. The drain bed at the bottom of the bin was filled with pebbles of size 6-8 mm. An outlet was provided at the bottom of each vermi bin to collect the vermi wash as excess moisture if not drained will form a discomfort zone to worms by suffocation. Out of seven bins, six were with different particle size mix. The bins were named T1, T2, T3, T4, T5, T6 and C as control unit.

**Preparation of mix trials:** Table 4 represents the substrate trial mix used for the study. Initially the pre-processed waste was sieved and particles with different sizes were extracted (sizes less than 1.7 mm, between 2.36 mm and 1.7 mm, between 4.75 and 2.36 mm, and between 6.30 mm and 4.75 mm). Then the extracted substrates with different particle sizes were mixed together in different proportions. The mix proportions percentage with its weight are given in Table 4.

**Filling the substrate and inoculating the earthworms:** All the bins (T1, T2, T3, T4, T5, T6) filled with processed vegetable waste (1.2 kg each) were kept for 2 days before inoculating the earthworms. This will drain the presence of unwanted organic gases and stabilize the fluctuations of control parameters like moisture, temperature and pH in the substrate. On weight basis each bin was inoculated with worms (*E. fetida*) weighing 100 ± 10g. In parallel, a conventional unit and a control unit were also maintained for comparing the consolidation and volume reduction of substrate mass in the bins.

## Statistical Analysis

The significant difference, if any, between the cumulative substrate depth reduction ($d_{cr}$) of any two trial bin were tested by Student's *t*-distribution at significance levels of 0.1 and 0.5. If $\mu_1$ and $\mu_2$ denote the population mean cumulative substrate depth reduction in any two vermi bins, respectively the null hypotheses and alternate hypothesis are stated as herein:

$H_0$: $\mu_1 = \mu_2$ and there is no difference between the two groups.

$H_1$: $\mu_1 \neq \mu_2$ and there is a significant difference between the two groups.

Under hypotheses $H_0$ the test statistic Student's *t* is defined by

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma\sqrt{\frac{1}{N1}+\frac{1}{N2}}} \quad ...(1)$$

Where, $\bar{X}_1$ and $\bar{X}_2$ are the mean cumulative substrate depth reduction in two vermi bins.

$N_1$ and $N_2$ represents sample size (that is the total number of measured cumulative substrate depth reduction) in the two bins. The sample size for all the bins is same ($N_1$=$N_2$).

$$\sigma = \frac{\sqrt{N1.S1^2 + N2.S2^2}}{N1 + N2 - 2} \quad ...(2)$$

Using a two tailed test at 0.05 significance level we would reject $H_0$, if the value of *t* lies outside the range $-t_{0.995}$ to $+t_{0.995}$ which for (N1+N2-2) degrees of freedom. Similarly, at 0.01 significance level we would reject $H_0$, if *t* lies outside the range $-t_{0.975}$ to $+t_{0.975}$ for (N1+N2-2) degrees of freedom.

Table 4: Substrate mix trials.

| Substrate particle size (mm) | Proportion of substrate particle size in mix (%) | | | | | | Weight of substrate with respectparticle size (grams) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T5 | T6 | T1 | T2 | T3 | T4 | T5 | T6 |
| < 1.70 | 10 | 20 | 30 | 40 | 25 | 60 | 140 | 280 | 420 | 560 | 350 | 840 |
| 1.70 to 2.36 | 20 | 30 | 40 | 10 | 25 | 20 | 280 | 420 | 560 | 140 | 350 | 280 |
| 2.36 to 4.75 | 30 | 40 | 10 | 20 | 25 | 10 | 420 | 560 | 140 | 280 | 350 | 140 |
| 4.75 to 6.30 | 40 | 10 | 20 | 30 | 25 | 10 | 560 | 140 | 280 | 420 | 350 | 140 |

## RESULTS AND DISCUSSION

Table 5 shows the depth reduction and temperature of substrate in the vermi bins during the experimental duration.

**Influence of particle size on substrate depth reduction:** Fig. 5 represents the cumulative substrate depth reduction with respect to time. The cumulative substrate depth reduction $d_{cr}$, at a particular time is worked out as the difference between the initial depth of the substrate $d_i$, at the beginning of experimentation and the depth of substrate $d$, at the particular time. The initial depth of substrate in all the bins at the beginning of experimentation was kept at 30 cm.

It is well evinced from Fig. 5 that high substrate depth reduction was achieved in the bins T1 to T5 except T6 and the control unit C. During the first week of experimentation, no major difference was identified in the substrate depth in all trial units. This may be attributed to the slow acclimatization of worms in the new environment and due to the consolidation of the substrate self-weight, or disintegration of waste material due to microbial decomposition (Atiyeh et al. 2002). The maximum substrate depth reduction, at the end of 90 days, was recorded in T3 (19.92 cm) followed by T4 (19.43 cm) and the minimum in T6 (11.18 cm), which demonstrates that substrate particle size in the vermi bins play a vital role in waste digestion rate. Ranganathan (2006) reported that in any vermi digestion activity, soil texture and particle size play an important role. Further, he added that 30 percent macro pore and 60-70 percent micro pore in the soil would enhance the worm mobility and reproduction activity. Moreover, the proper substrate particle size will aid the flow of oxygen inside the vermi beds, which will enhance the oxygen uptake rate by microorganisms for their growth and reproduction. As the particle size distribution in the vermi bins T3 and T4 is compatible for sufficient airflow and moisture content compared to other bins, it has resulted in enhanced substrate depth reductions. From the second week of experimentation, different trial units (T1 to T6) show good progression and very particularly the bin T3 and T4 show consistent progress in substrate depth reduction. Fig. 6 shows the waste volume reduction achieved in various trial bins. The dotted line represents the digested waste volume corresponding to the depth in vermi bin. The solid curve represents the cumulative depth reduction achieved in various bins and corresponding volume reduction at the end of the experimental period.

The locomotion of worms happens by contracting and relaxing their physiques in waves, interchanging between circular and long muscles. Shrinkage of the circular muscles militaries the worm's body advancing, then the long muscles contraction pull the tail end of the worm toward the skinny anterior end. When the long muscles contract, the circular muscles reduce the muscular stress causing the worm to become thick. To keep from slipping during the drive, tiny spines called setae act as a support to hold worm's body against the surface (Ranganathan 2006). The porosity of vermi bin T3 (0.31) and T4 (0.28) provides suitable environment for the worms movement; hence these bins achieved high volume reduction respectively (66.67% and 64.76%). The main disadvantage of bigger size particles is quick draining of moisture in the vermi bed and that with smaller diameter particles is they retain high temperature in the vermi bins and restrict the flow of air in the bin. This might be the reason for the low volume reduction in trial bins T1, T5 and T6. The very low waste volume reduction (42%) achieved in trial bin T6 could be attributed to the high percent (60%) of smaller sized particles (<1.70 mm). Hence, the high proportion of smaller sized particles will restrict the worm's mobility inside the bed, increase the bed temperature, force the worm into a quiescent stage, and hinder the biomass growth.

During the final stages of the experiment, the substrate depth reduction slowed during the final duration of the experiment (70 to 90 days) and this may be due to the fall in the TOC in the substrate. Suthar (2007) reported that the body fluid and excreta secreted by worms (e.g., mucus, high concentration of organic matter, ammonia and urea) promote microbial growth in vermicomposting, which may also contribute in the reduction of TOC in the substrate. The low depth reduction in control set C, is due to the absence of earthworms and this proves that vermicomposting is an ideal

Table 5: Variations of substrate depth, temperature and moisture content in various trail units.

| | | T1 | | | T2 | | | T3 | | | T4 | | | T5 | | | T6 | | | C | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | Ta | d | T | MC | d | T | MC | d | T | MC | d | T | MC | d | T | MC | d | T | MC | d | T | MC |
| 0 | 30.4 | 30.00 | 32.2 | 48 | 30.00 | 32.0 | 48 | 30.00 | 31.9 | 54 | 30.00 | 32.8 | 54 | 30.00 | 31.6 | 62 | 30.00 | 34.3 | 68 | 30.00 | 34.1 | 69 |
| 5 | 30.2 | 29.00 | 31.3 | 47 | 29.00 | 31.5 | 46 | 29.00 | 31.65 | 53 | 29.00 | 31.7 | 56 | 29.00 | 32.6 | 61 | 29.00 | 33.9 | 67 | 29.00 | 33.8 | 67 |
| 10 | 27.9 | 27.97 | 31.4 | 48 | 28.27 | 30.2 | 45 | 28.00 | 31.45 | 51 | 28.12 | 29.9 | 55 | 27.95 | 31.9 | 62 | 28.43 | 31.7 | 68 | 28.37 | 31.5 | 68 |
| 15 | 31.0 | 26.80 | 33.7 | 46 | 27.28 | 33.2 | 45 | 27.15 | 32.15 | 53 | 27.05 | 32.5 | 52 | 27.23 | 34.1 | 60 | 27.50 | 32.9 | 66 | 28.42 | 31.6 | 66 |
| 20 | 29.6 | 26.15 | 31.4 | 44 | 26.52 | 31.7 | 44 | 26.02 | 31.5 | 52 | 25.92 | 32.3 | 57 | 25.72 | 31.1 | 59 | 27.25 | 31.7 | 64 | 28.24 | 31.7 | 63 |
| 25 | 30.7 | 25.28 | 31.9 | 46 | 26.20 | 31.7 | 43 | 25.18 | 32.9 | 53 | 25.08 | 32.9 | 56 | 25.28 | 32.7 | 58 | 26.43 | 32.3 | 63 | 27.95 | 32.7 | 62 |
| 30 | 32.2 | 23.8 | 33.7 | 48 | 25.10 | 33.4 | 49 | 23.80 | 32.2 | 55 | 23.70 | 33.9 | 56 | 23.60 | 33.6 | 59 | 25.12 | 33.6 | 62 | 27.65 | 33.6 | 61 |
| 35 | 30.1 | 22.8 | 31.7 | 45 | 23.12 | 31.3 | 48 | 22.55 | 31.7 | 51 | 22.45 | 31.8 | 54 | 22.67 | 31.4 | 60 | 24.70 | 32.9 | 66 | 27.15 | 32.3 | 65 |
| 40 | 31.9 | 22.5 | 33.9 | 46 | 22.70 | 34.6 | 48 | 22.10 | 32.65 | 52 | 22.00 | 34.9 | 53 | 21.60 | 33.9 | 58 | 23.50 | 32.9 | 65 | 26.68 | 32.4 | 64 |
| 45 | 30.4 | 21.97 | 31.5 | 43 | 22.05 | 31.2 | 48 | 21.45 | 31.7 | 54 | 21.35 | 31.9 | 54 | 21.10 | 31.4 | 59 | 23.15 | 32.3 | 66 | 26.15 | 33.1 | 65 |
| 50 | 29.9 | 20.90 | 31.3 | 45 | 21.13 | 30.9 | 47 | 21.03 | 30.9 | 53 | 20.93 | 30.6 | 55 | 20.68 | 30.7 | 58 | 22.70 | 30.9 | 67 | 25.75 | 30.9 | 66 |
| 55 | 28.5 | 19.95 | 30.4 | 48 | 19.76 | 29.3 | 47 | 19.51 | 29.5 | 54 | 19.41 | 30 | 54 | 19.25 | 28.9 | 59 | 22.60 | 29.3 | 68 | 25.10 | 29.7 | 67 |
| 60 | 29.3 | 19.00 | 30.5 | 47 | 18.40 | 30.1 | 46 | 18.00 | 30.7 | 56 | 17.90 | 30.9 | 57 | 17.82 | 29.9 | 58 | 22.10 | 30.5 | 65 | 24.70 | 30.7 | 64 |
| 65 | 30.5 | 17.33 | 31.6 | 49 | 16.00 | 31.9 | 46 | 16.07 | 31.7 | 57 | 15.97 | 31.4 | 58 | 16.08 | 31.6 | 60 | 21.50 | 31.6 | 64 | 23.95 | 31.8 | 63 |
| 70 | 30.1 | 15.67 | 31.7 | 51 | 14.00 | 31.7 | 50 | 14.15 | 31.9 | 57 | 14.05 | 31.6 | 56 | 14.35 | 31.8 | 59 | 21.10 | 31 | 65 | 23.55 | 31.2 | 64 |
| 75 | 29.2 | 15.24 | 28.9 | 50 | 13.00 | 29.1 | 51 | 13.61 | 29 | 52 | 13.51 | 28.7 | 54 | 13.55 | 29 | 58 | 20.25 | 30.4 | 63 | 23.20 | 30.8 | 62 |
| 80 | 28.7 | 14.8 | 28.4 | 51 | 12.65 | 28.3 | 50 | 13.07 | 28.1 | 55 | 12.97 | 28.3 | 57 | 12.75 | 28.1 | 58 | 19.62 | 29.6 | 64 | 22.85 | 29.9 | 63 |
| 85 | 28.3 | 13.65 | 27.9 | 52 | 12.25 | 28.0 | 52 | 12.34 | 27.9 | 56 | 12.24 | 28.1 | 56 | 12.73 | 28.2 | 57 | 19.22 | 29.5 | 62 | 22.45 | 29.9 | 61 |
| 90 | 28.9 | 12.85 | 28.7 | 52 | 11.55 | 28.4 | 52 | 10.08 | 28.6 | 54 | 10.57 | 28.5 | 55 | 12.25 | 28.7 | 56 | 18.82 | 29.3 | 60 | 22.10 | 29.6 | 59 |

Note: d: Depth of the substrate with respect to time, cm; T: Substrate temperature, °C; Ta: Ambient (room) temperature, °C, MC: Moisture content (%).

process than composting for treating organic wastes. From the above discussion, it is concluded that substrate depth reduction is directly proportional to the geophysical properties of the waste.

**Influence of particle size on substrate temperature:** Fig. 7 depicts the difference of substrate temperature and ambient temperature (T-Ta) with respect to time and Fig. 8 illustrates the average bin temperature recorded in various bins during experimentation.

The earthworms are soft-bodied, muscular, slow moving invertebrates without any external protection to defend them against environmental impacts such as temperature, moisture, aeration and pH, which distresses their growth, reproduction and mobilization (Hala & Harold 2008). Moreover, continuous respiration through the thin, moist body surface and excretion of nitrogenous substances, earthworm lose as much as 10-20% of its water content and this must be replaced to prevent the worms from death due to desiccation (Grant 1955). This insists that a proper percentage of pore size in substrate mass plays a vital role. From Fig. 7, the bin temperature in T6 and C was initially higher than the ambient temperature, which ensured the microbial decomposition during the first week of the experimentation (Hala & Harold 2008) and it might also be due to improper air flow across the substrate mass. Edwards & Bohlem (1996) reported that the substrate temperature above 33°C is lethal for many varieties of earthworms. This was proven in the bins T1 and T6, as both the bins recorded death of two to three worms at the initial stage of the experiment. The average temperature noted in the trial bins (T1 to T5) was higher than the ambient temperature up to 70 days of experimentation period and this might be associated with the depth of substrate. On the other hand, improper pore size of substrate reduces the water holding capacity of the substrate mass and drain the moisture in the vermi beds, and this might be the reason for high temperature in T1 and T6.

To overcome this problem, periodical moistening of bed was carried out to reduce the fall of bin moisture and because of this the temperature profile shows a falling trend after the initial few weeks of the experimentation. However, during most of the experimental period, the temperature stood up than the ambient level. This may due to the enhancement of substrate depth (above 15 cm) and microbial activities in the bins. Subsequently, after a period of 60 days, the temperature in bins showed less variation (±2°C) and this may due to the particle size in the substrate mass. The control unit holds maximum temperature until the end of experimentation because of boosting microbial action after lag time and the availability of simple forms of nutrients during the decomposition of waste (Sing et al. 2004). This shows that bin temperature is influenced by substrate particle size.

**Influence of particle size on substrate moisture content:** Fig. 8 illustrates the moisture recorded in the vermi bins. The respiration activity of worms completely differs with humans. Worms breathe through their skin, the oxygen avail-

Table 6: Chemical composition of substrates after 90 days of experimentation.

| Bin | pH | Total Organic Carbon (TOC)(mg/g) | Nitrogen N (mg/g) | Phosphorus P (mg/g) | Potassium K (mg/g) | C:N ratio |
|---|---|---|---|---|---|---|
| T1 | 8.09 | 24.65 | 1.36 | 2.36 | 20.36 | 18.13 |
| T2 | 7.95 | 22.56 | 1.35 | 2.48 | 17.58 | 16.73 |
| T3 | 7.85 | 22.68 | 1.31 | 2.42 | 18.45 | 17.32 |
| T4 | 7.80 | 24.56 | 1.45 | 2.51 | 16.48 | 16.94 |
| T5 | 7.85 | 25.32 | 1.48 | 2.35 | 16.36 | 17.11 |
| T6 | 8.12 | 24.68 | 1.48 | 2.45 | 19.72 | 16.45 |
| C | 8.15 | 32.25 | 1.52 | 3.56 | 28.69 | 21.27 |

Table 7: Basic statistical of cumulative substrate depth reduction in different vermi bins.

| | T1 | T2 | T3 | T4 | T5 | T6 | C |
|---|---|---|---|---|---|---|---|
| Mean x □ s | 9.61 | 10.00 | 10.35 | 10.40 | 10.32 | 6.83 | 4.46 |
| | 4.84 | 5.81 | 5.62 | 5.57 | 5.35 | 3.00 | 2.23 |

Table 8: Computed t-statistic for testing significance in difference of mean cumulative substrate depth reduction ($d_{cr}$)of different vermi bins.

| | T1 | T2 | T3 | T4 | T5 | T6 |
|---|---|---|---|---|---|---|
| T1 | - | -0.208 | -0.398 | -0.429 | -0.393 | 1.956 |
| T2 | -0.208 | - | -0.171 | -0.198 | -0.160 | 1.943 |
| T3 | -0.398 | -0.171 | - | 0.011 | 0.074 | 0.786 |
| T4 | -0.429 | -0.198 | 0.011 | - | 0.057 | 0.696 |
| T5 | -0.393 | -0.160 | 0.074 | 0.057 | - | 0.660 |
| T6 | 1.956 | 1.943 | 0.786 | 0.696 | 0.660 | - |

*Critical value of $t_{0.975}$ to $+t_{0.975}$,which for 32 degrees of freedom is the range -2.036 to +2.036*
*Critical value of $t_{0.995}$ to $+t_{0.995}$,which for 32 degrees of freedom is the range -2.740 to +2.740*

able in the substrate bed moisture will be taken up by the worm's skin and transfer into the bloodstream. As less bed moisture will suffocate the worms, and excess moisture will drown them, optimum bed moisture is required for the worm growth (Grant 1955).

It is clear from Fig. 8 that the substrate moisture in trial units T1 and T2 was found to be less than 50% during most of the experimental duration. This could be attributed to the high percentage of bigger size particles in T1 and T2 (T1 with 40 % of particle size varies between 4.75 and 6.30, and T2 with 40% of particle size between 2.36 and 4.75), hence the waste holding capacity of the substrate mass. The bins T6 and control unit C hold high bed moisture content; this might be due to the presence of high proportion (more than 60% of smaller size particles < 1.70 mm). The optimum moisture content (50 to 60%) was recorded in bins T3, T4 and T5. This emphasises that substrate particle size and percentage of pores play a significant role in maintaining optimum moisture content. Ranganathan (2006) reported that 30:70 (macro: micro pores) will highly influence the water holding capacity of the soil. Moreover, Ganesh et al. (2009) reported that medium loamy soil is suitable for high worm's reproduction rate than the dense clay soil. The moisture content in all the bins converged to optimum level (50 to 60 %) during the final stages (after 80 days) of experimentation period.

**Biomass growth:** Fig. 9 illustrates the biomass growth in vermi bins. The growth of earthworms, in different vermi units, was determined by finding the difference between the initial and final biomass weight. The difference in biomass growth shows the influence of substrate particle size on worms.

*E. fetida* shows different growths in different vermi bins during the experimentation. All the bins show good progression in the vermi growth and reproduction, but the highest biomass growth was recorded in bin T3 (83%) followed by T4 (76%). This might be because of the availability of adequate oxygen flow in the vermi beds, which had favoured vermi growth and reproduction (Felix & Emilio 2009). Apart from aeration, the nature of the substrate also plays a

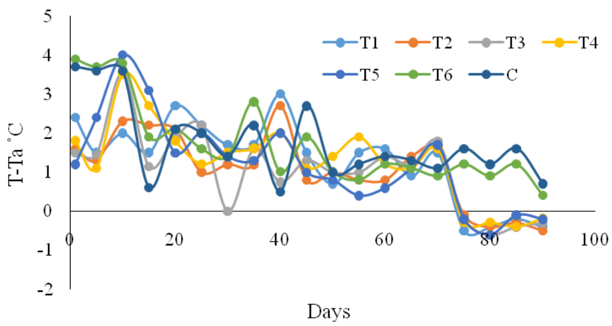


Fig. 7: Temperature variations in vermi bins.

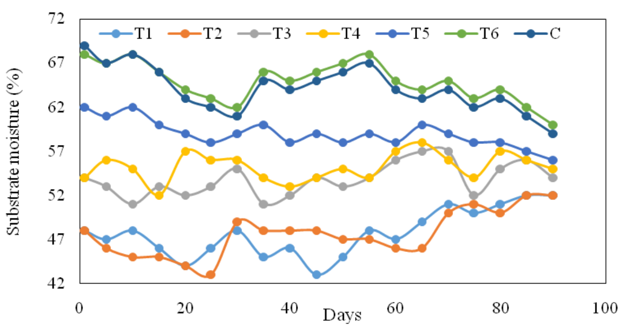


Fig. 8: Substrate moisture variations in vermi bins.

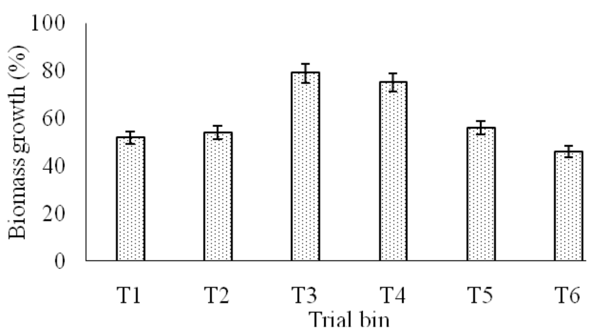


Fig. 9: Biomass growth in vermi bins.

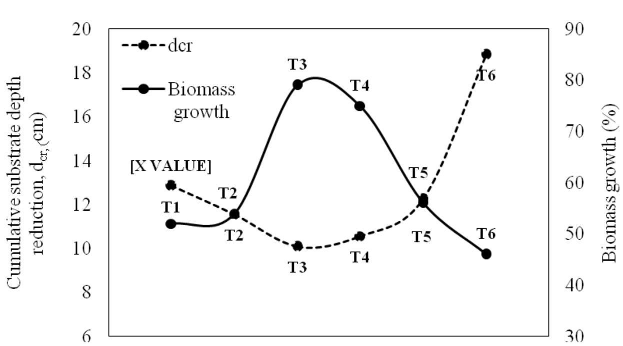


Fig. 10: Biomass growth and cumulative substrate depth reduction.

predominant role. Suthar (2010) reported that healthier worm growth pattern of *E. fetida* was recorded when the substrate possessed easily metabolizable organic waste and non-assimilated carbohydrates. On the other hand, Ganesh et al. (2009) reported that the vegetable market waste possess different C:N ratios, particle size, protein, crude fibre and even some concentration of special plant metabolites substances which will affect the earthworm digestion habit. This problem was eliminated in the present study by pre-processing the organic waste. Pre-processing will break complex organic proteins and crude fibre into simple form. In addition, blending fresh cow dung with waste will enhance the microbial population growth, and this aids in breaking down the complex organic substances in to the simple form (Sing et al. 2010). Kale (1998) reported that *E. fetida* showed better performance when the organic waste was blended with 20-40% of cow dung. As the worms are invertebrate in nature, they move by muscular contraction and expansion (Ranganathan 2006) and this action is purely associated with the bed porosity. Low porosity (less than 30%) will hinder the worm mobilisation activity, hence, ideal porosity plays a significant role in biomass growth and the same was witnessed in Fig. 10.

The experimentation was concluded after 90 days, since the vermicast production rate in all the bins reduced largely. It was also noted that the vermi cast production started to slow down after 70 days of the experimentation. The rate of vermi cast generation is proportional to the biomass growth rate and reproduction (Suthar 2012). This falling trend may be due to the following reasons: (1) shortage of organic content in the waste mass, (2) reduction of biomass growth rate, and (3) stabilisation of substrate depth. In trial bin T6, low biomass growth was recorded. The high substrate depth with high proportion of smaller sized particles would have induced anaerobic condition in the vermibin in bin T6 resulting in low growth rate. Hence, it can be concluded from the experimental results that better worm growth pattern in *E. fetida* was due to the optimum particle size distribution and bed porosity in the substrate.

**Chemical composition of substrates**: Table 6 shows the chemical composition of vermicomposted waste obtained in various trial units.

For the survival of any living organism, carbon is a prime source. Carbon plays a significant role in cell synthesization and reproduction activity of the living organisms. It is inferred from Table 6 that the TOC declined to 45% (at an average of 25) of its initial level (46.36 mg/g) in all vermi bins. This might be due to the following reasons: (1) Microorganisms in the pile consume organic carbon from the substrate for its in metabolic activity and evolve $CO_2$ at end of the action (Loren & Janet 1998) and (2) Consumption of organic carbon by earthworms for reproduction and respiration activity (Elvira et al. 1998). The C:N ratio of vermicomposted substrate in all bins varied in a narrow range (16:1 to 17:1), while it was 21.27:1 in control. In the high level of C:N in control unit, C implies the availability of carbon source for further digestion. Ranganathan (2006) reported that C:N of less than 20:1 is ideal level in organic manure. The other nutrients, nitrogen (N), phosphorus (P) and potassium (K) show significant reduction at the end of experimentation. The reduction in the nitrogen level could be attributed to the respiration activity of microorganisms, which are involved in lignin breakdown process (Crawford 1985). Decrease in phosphorus and potassium levels might be due the earthworm fecundity process. The results also revealed that there was no significant difference in the chemical composition of digested substrate at the end of experimentation in all the aerated trial units. As the same kind of substrate was used in all the aerated bins, the chemical composition of digested substrate did not show significant difference. The decrease in pH in all the vermi bins (7.80 to 8.15) might be due to the production of $CO_2$ and organic acids during microbial metabolic activity. Hartenstein & Hartenstein (1981) reported that the decrease in pH during vermicomposting could be attributed to the mineralization of nitrogen and phosphorus into nitrates/ nitrites and ortho-phosphates, respectively, and due to the conversion of organic matter into $CO_2$ and humic substances by microorganisms. From the above discussion, it can be concluded that substrate particle size will only influence the volume reduction and biomass growth, and not the quality or chemical composition of the substrate.

**Statistical inference:** Table 7 shows the basic statistic of cumulative substrate depth reduction in various vermi bins. The mean of cumulative substrate depth reduction varies between a maximum of 10.40 (T4) and minimum of 6.83 (T6). The standard deviation varies between a maximum of 5.57 (T4) and minimum of 3.0 (T6).

Table 8 shows the computation of significance of mean cumulative substrate depth reduction between different vermi bins.

On comparison of mean $d_{cr}$ observed in any bin with every other bin, its found from Table 8 that the computed *t*-statics in all cases lie within the range of -2.036 to +2.036 and -2.740 to +2.740 at 0.05 and 0.01 significance levels respectively. This shows there is no significant difference in cumulative substrate depth reduction statistically between the different vermi bins. However, the cumulative substrate depth reduction, which is indicative of the volume reduction of the substrate mass in the vermi bins varied in the range of 11.18 cm (T6) to 19.92 (T3) at the end of experimental period (90 days). The percentage difference in volume reduction of substrate mass between T3 (maximum volume reduction) and T6 (minimum volume reduction) works out to be 78.20%, which is phenomenal. The second highest volume reduction of substrate occurred in T4 with $d_{cr}$ equal to 19.43 cm, which works out to be 73.80% higher than T6. In addition, the biomass growth at the experimentation period was found to be the highest at 83% in vermi bin T3, followed by 78% in T4. Even though there is no significant difference shown statistically in the performance of the vermi bins but considering the substrate volume reduction and biomass growth the vermi bins T3 and T4 have performed much better than the other vermi bins. Hence, it can be concluded that the substrate size has played a key role in effecting the vermi composting process. The percentage of substrate with particle size less than 1.70 mm and between 1.70 mm and 2.36 mm were respectively 30 and 40 for T3 and 60 and 20 for T6. As the proportion of the minimum sized particles (<1.70 mm) was maximum at 60% for T6, aeration would have been much less resulting in for poor performance of the process in the bin. The vermi bin T3 has performed the best, as the aeration during the vermicomposting process would have been adequate since the proportion of substrate with particle size between 1.70 mm and 2.36 mm was 40% and the proportion of substrate with particle size less than 1.70 mm was 30%. This provides better natural aeration during the vermicomposting process resulting in effective volume reduction, the optimal size of particles in the substrate should be such that the proportion of particles with size less than 2.36 mm should be more than 50% and less than 70%. Ranganathan (2006) reported that for an effective worm growth 70% micro pore and 30% macro pore is required. Further, the proportion of particles with size less than 1.70 mm should be less compared to the particles with size between 1.70 mm to 2.36 mm.

## CONCLUSION

The outcome of this bench scale experimental study reveals that substrate particle size distribution and bed porosity will influence the waste digestion rate in vermicomposting. In addition, pre-processing the waste will eliminate the pre-composting process in vermicomposting and save considerable time. High percent of volume reduction was achieved in the bin T3 (67%), and the low in T6 (38%). Even though there is no significant difference in cumulative substrate depth reduction statistically between the different vermi bins, but the volume reduction of the substrate mass in the vermi bins varied in a wide range of 11.18 cm (T6) to 19.92 (T3) at the end of the experimental period (90 days). The percentage of the substrate with particle size less than 1.70

mm was ≥ 40 in vermi bins T2, T3, T4 and T5, and it was nearly 60% in T6. As the high proportion of lower sized particles had hindered the natural airflow and worm's mobility in the bin, it resulted in the poor performance of the bin T6; hence the substrate particle size distribution plays a significant role in vermicomposting process. Further cumulative substrate depth reduction in the bins T3, T4 and T5 at the end of the experimentation period was uniform with minor differences but, the highest biomass growth was recorded in T3 (83%) followed by T4 (78%). Hence, the proportions of substrate particle size in bin T3 proves to be ideal in enhancing the waste digestion rate and influencing the biomass growth in vermicomposting process.

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