Management of Agroindustrial Lignocellulosic Wastes through Vermitechnology and Production of Agronomic Valid Vermicompost

K.V. Prashija* and Kasi Parthasarathi

Department of Zoology, Annamalai University, Annamalainagar - 608 002, India

Abstract: We aimed to recycle the agroindustrial waste resources- pressmud(PM), sugarcane trash (ST) and biomethanated distillery effluent(BE) and produced agronomic valid vermicompost using earthworm, *Perionyx excavatus* for maintaining natural soil organic and sustainable agricultural activity. Therefore, a series of studies were carried out to convert PM-ST-BE in different proportion vermibeds (T1-1000g PM+0g ST+790ml BE), (T2- 900g PM+100g ST+740ml BE), (T3-800g PM+200g ST+696ml BE), (T4-700g PM +300g ST+655ml BE), (T5-600g PM+400g ST+625ml BE) and (T6-500g PM+500g ST+542ml BE) into vermicompost. The study was to examine the activity of earthworm- growth, reproduction, vermicompost recovery and its nutrient status. The pronounced and better worm activity was found in all vermibeds, especially more in T1 and T3 vermibeds followed by others. This seems to be due to rich cellulose, OC, N, P, microbial activity, enhanced water holding capacity and palatability of the substrates. Enhanced microbial activity, humic acid content, NPK, normalized pH, declined OC, C-N, and C-P ratio, lignin, cellulose, hemicellulose and phenol in vermicompost than normal compost and control. The increased microbial-enzymatic activities contribute an increase in nutrients through nitrification, phosphate solubilization and mineralization. Reduction of OC, C-N, C-P ratio, lignin, cellulose, hemicellulose and phenol in the vermicompost are due to combined action of gut microflaura and earthworm during the vermicomposting process and utilization of these contents by the worm for their growth and reproduction. Finally, our study recommended for the production and application of vermifertilizer from lignocellulosic wastes using vermitechnology for sustainable activity.

Keywords: Agroindustrial wastes, pressmud, sugarcane waste, biomethanated distillery effluent, vermicompost.

INTRODUCTION

Waste management of organic materials aims to turn animal and other organic wastes into useful materials that could be added to agricultural land to improve soil structure and fertility. The pressing need of today's population explosion and the consequent demand for more food has made enormous pressure on the diminishing areas of agriculture. This has lead to erratic use of synthetic fertilizers, soil sickness, more and more application of inorganic fertilizers to sustain productivity and the increasing accumulation of industrial, agricultural and urban wastes in the name of civilization. When every ecological niche is polluted and the very existence of man was threatened, he resorted to re-cycling and organic farming. The recycling of organic wastes for increasing soil fertility has gained importance in recent year due to the high cost of fertilizers and reduced availability of organic manures. Vermicompost application may be a source of nutrient for organic farming practices with several other options, eg. biofertilizer, compost, VAM(Vesicular Arbuscular Mycorrhiza), BGA(*Blue Green Algae*) etc. Decomposition of complex organic waste resources into odor free humus like substance through the combined action of earthworms and microorganism is called as vermicomposting. The vermicompost of organic wastes results in a product with relatively high content of microbial-enzyme activities, macro-micro nutrients and plant metabolites. Disposal and eco-friendly management of day by day formed organic waste materials from various resources has become a serious global problem. Vermicomposting, a novel technique of converting decomposable organic waste into valuable vermicompost through earthworm activity is a faster and better process when compared to the conventional methods of composting. Vermicomposting of organic waste using epigeic earthworm is one of the recent technique for the recycling of organic wastes and it is a viable, eco-friendly efficient, ecologically sound method for waste management and manure production [1, 2].

India is the largest producer of sugar and during the period of sugar production from the 464 sugar mills and 319 molasses based distilleries large volume of organic waste are produced (pressmud, bagasse, molasses, sugarcane trash and molasses based distillery waste effluent). There are about 10.0 million tones of pressmud per annum, 40 million tones of cane trash and 40.40 x 10^{10} of effluent per annum are produced with more renewable energy sources. These energy resources as wastes are discharged on land or into nearby water – bodies, particularly without any

*Address correspondence to this author at the Department of Zoology, Annamalai University, Annamalainagar - 608 002, India; Tel: +91 9566308211; E-mail: kvprashija@gmail.com, kpguruprasad@rediffmail.com

ISSN: 1927-3037/16 © 2016 Lifescience Global

treatment and serve as a major causes of environmental pollution. In India and several other countries in the southern hemisphere, leaf litter often piled-up and set on fire. The resulting ash returns some of the NPK content of the litter to the soil, but much of N, PM and OC get lost, due to improper waste management technique. The burning of litter also adds to air pollution [3, 4]. Also the formed distillery effluent with more BOD, COD solid content and organic resource is a major problem for disposal and causing environmental pollution problem. To overcome these problems, the agroindustrial wastes – PM, ST and BE can be vermicomposted and the vermicompost could be used as fertilizer or soil conditioner. Therefore, the present study deals with the nutrient quality assessment of vermicompost, at physico-chemical and biological level obtained from the enormously available agroindustrial wastes by using predominantly available indigenous epigeic earthworm, *Perionyx excavatus*. Also the study deals with the earthworm activity – growth, reproductive performances and compost recovery during vermicomposting of agroindustrial wastes.

MATERIALS AND METHODS

Collection and Preparation of Experimental Substrates

In the experimental studies, two months old and cured PM free of foul smell and the BE were collected from E.I.D Parry (I) sugar factory at Nellikuppam, Cuddalore district, Tamil Nadu, India at different times of the year. The dried sugarcane trash was collected from sugarcane experimental farm of Annamalai University, Annamalainagar, Cuddalore district, Tamil Nadu, India. In the present study, six proportions of agro-industrial waste (PM, ST and BE) mixtures were prepared in the following manner (Table **1**).

The PM and chopped ST (>3 cm) were weighed (dry weight) in the above said proportions and mixed well. The substrates (PM and ST) were made in 65-70% moisture content by sprinkling of BE in each treatment and constantly maintained up to 60 days. For making 65-70% moisture content of substrates by adding required ml of BE from each per kg of the substrates are given in the Table **1**. The substrates (PM, ST and BE) (T_1-T_6) were left for 96 hours to stabilize before the experimental animals were inoculated into them. One kg of 96 hour stabilized substrates (T_1-T_6) were taken in a plastic trough (32 cm diameter and 20 cm height) at 31 ± 2°C and 65% relative humidity (Thermo-Hygrometer, Germany). The sides and bottom of the each trough was perforated to facilitate free aeration and to avoid water logging in the trough. The trough was covered with nylon mesh and maintained in the laboratory at aforementioned conditions for 60 days. Also, the chemical composition of the agroindustrial wastes is given in the Table **2**. Experimental bedding was kept in triplicate for each treatment and same another triplicate for each treatment, without earthworms served as the experimental control.

Earthworm Collection and Inoculation

Perionyx excavatus was collected from our stock culture, Department of Zoology, Annamalai University, Annamalainagar, Tamil Nadu. 15 g of sexually immature preclitellate *P. excavatus* (36 numbers, 15-18 days old) were inoculated into each plastic troughs separately. The worms were not fed with additional substrates in the duration of the experiments (60 days).

Earthworm Activity in the Vermibeds

The mortality (%) of the worms was observed on every day morning in each treatment up to 60 days. The growth of the worms (biomass in wet weight) was determined before the animals were inoculated into each of the treatment substrates and at the end of the experiment (60th days) by an electronic balance. The

Table 1: Description of Agroindustrial Wastes for Experiment

Treatment	Description	Substrates		
		PM (g)	ST (g)	BE (ml)
T_1	10:0	1000	0	790
T_2	9:1	900	100	740
T_3	8:2	800	200	696
T_4	7:3	700	300	655
T_5	6:4	600	400	625
T_6	5:5	500	500	542

Table 2: Chemical Composition of Agroindustrial Wastes

Parameters	PM	ST	BE
pH	7.85	7.68	7.80
Electrical conductivity (dSm^{-1})	0.84	0.76	19.26
Moisture content (%)	12.14	-	94.55
BOD (mg/L)^x	-	-	5670
COD (mg/L)^x	-	-	37480
Organic carbon (%)	39.06	38.17	14.15
Nitrogen (%)	2.02	0.98	2.26
Phosphorus (%)	1.99	0.85	0.78
Potassium (%)	0.58	0.29	9.46
Magnesium (%)	0.38	0.27	712*
Calcium (%)	2.44	1.93	1920*
Sodium (%)	0.11	0.08	38*
Zinc (ppm)	60	18	1.66*
Iron (ppm)	1175	824	56.22*
Copper (ppm)	18	14	3.12*
Manganese (ppm)	122	120	5.03*
C:N ratio	19:1	39:1	6:1
C:P ratio	20:1	45:1	18:1
Crude protein (%)	12.6	6.1	14.13
Total microbial population (CFU x 10^6 g^{-1})	520	-	111
Dehydrogenase^a	7.76	0.96	2.10
Lignin (mg/g)	41	86	-
Cellulose (mg/g)	153	277	-
Hemicellulose (mg/g)	26	32	-
Phenol (mg/100g)	44	56	-
Humic acid (mg/5g)	21.36	0.18	-

*mg/L, a - μlH/5g substrate, CFU – Colony forming unit, PM – Pressmud, ST – Sugarcane trash, BE – Biomethanated distillery effluent, ^{x} – (APHA, 2005) [81].

reproductive parameters like number of cocoon production and number of hatchlings were counted on the 60th day by hand sorting method [5]. The vermicompost was collected on the 60th day by hand sorting method [6], weighed, and used for determining various quality parameters.

Quality Analysis of Vermicompost

The nutrient contents of the substrates (initial (0-day), worm unworked and worm worked compost) were analyzed by using standard methods. The pH was measured by the method described by ISI Bulletin [7]. Organic carbon was determined by the partially-oxidation method [8]. The total N content of substrates was analyzed according to the method of Jackson [9] by Macro Kjeldhal method and phosphorus [10] and potassium [11] were determined by colorimetrically and flame photometer methods, respectively. The C/N ratio was calculated by dividing the percentage of carbon in the substrates by the percentage of nitrogen in the same substrates. The C/P ratio was calculated by dividing the percentage of carbon in the substrates by the percentage of phosphorus in the same substrates. The total microbial population [12] and microbial activity in terms of dehydrogenase activity [13], lignin and hemicellulose [14], cellulose [15], phenol [16], and humic acid content [17] were estimated by the standard methods.

Statistical Analysis

Two-way ANOVA procedures were applied to the data to determine significant differences. Duncan's multiple – ranged test was also performed to identify the homogenous type of the treatments for the various assessment variables.

RESULTS AND DISCUSSION

The nutrient quality of the initial feed substrates from six different treatments of agroindustrial wastes (T_1 – T_6), worm unworked natural compost and worm worked vermicompost are given in the Tables **3-6**. Vermicomposting process of agroindustrial wastes in different treatments caused significant ($p<0.05$) changes in the chemistry and biochemical levels of the 6 treatments, after 60 days of experimentation. Also, their percentage changes over compost proceed with or without earthworms are depicted in the Tables **3-6**. As compared to initial substrate and worm unworked compost values of 6 treatments, vermicompost showed significantly ($p<0.05$) more reduction in pH, OC, C:N ratio, C:P ratio, lignin, cellulose, hemicellulose and phenol values in all treatments, more being in the T_3 followed by T_1 and T_2 treatments than other treatments. At the end of the experiment, N, P, K, total microbial population, dehydrogenase activity and HA contents in the vermicompost were significantly ($p<0.05$) higher than that in the initial substrate and normal compost. Comparatively, the maximum increase in these values occurred in T_3 treatment followed by T_1 and T_2 treatments than other treatments.

The earthworm activity like mortality, growth, cocoon production, hatchling number and recovery of vermicompost by *P. excavatus* reared on different combination of agroindustrial wastes (T_1 – T_6) up to 60 days are given in the Table **7**. The precomposted

Table 3: Chemical Composition of Compost and Vermicompost of *P. excavatus* Obtained from Agroindustrial Wastes (n=6)

Treatments (vermibeds)	pH			Organic carbon (%)			Nitrogen (%)		
	OD	WU	WW	OD	WU	WW	OD	WU	WW
(PM+BE)*	8.82 ^{a}	7.36 ^{a} $(-17)^x$	7.04 ^{a} $(-20.1)^x(-4.0)^y$	39.02 ^{b}	36.66 ^{b} $(-6.0)^x$	24.14 ^{b} $(-38.1)^x(-34.2)^y$	2.00 ^{ab}	2.10 ^{ab} $(+4.8)^x$	2.33 ^{ab} $(+14.2)^x(+9.9)^y$
(PM+ST+BE)*	8.76 ^{a}	8.45 ^{a} $(-3.5)^x$	7.12 ^{a} $(-18.7)^x(-15.7)^y$	38.06 ^{b}	35.24 ^{b} $(-7.4)^x$	25.42 ^{b} $(-33.2)^x(-27.9)^y$	2.09 ^{bc}	2.14 ^{bc} $(+2.3)^x$	2.47 ^{bc} $(+15.4)^x(+13.4)^y$
(PM+ST+BE)*	8.71 ^{a}	7.38 ^{a} $(-15.2)^x$	7.06 ^{a} $(-20.0)^x(-4.3)^y$	36.05 ^{ab}	33.11 ^{ab} $(-8.2)^x$	23.61 ^{ab} $(-34.5)^x(-28.7)^y$	2.14 ^{c}	2.22 ^{c} $(+3.6)^x$	2.68 ^{c} $(+20.1)^x(+17.2)^y$
(PM+ST+BE)*	8.66 ^{a}	7.51 ^{a} $(-13.3)^x$	7.18 ^{a} $(-17.1)^x(-4.4)^y$	34.11 ^{ab}	30.72 ^{ab} $(-9.9)^x$	26.31 ^{ab} $(-22.9)^x(-14.3)^y$	2.06 ^{ab}	2.11 ^{ab} $(+2.4)^x$	2.31 ^{ab} $(+10.8)^x(+8.7)^y$
(PM+ST+BE)*	8.62 ^{a}	7.78 ^{a} $(-9.7)^x$	7.22 ^{a} $(-16.2)^x(-7.2)^y$	32.14 ^{ab}	29.53 ^{ab} $(-8.1)^x$	25.74 ^{ab} $(-19.9)^x(-12.8)^y$	1.86 ^{ab}	2.10 ^{ab} $(+11.4)^x$	2.25 ^{ab} $(+17.3)^x(+6.7)^y$
(PM+ST+BE)*	8.59 ^{a}	7.85 ^{a} $(-8.6)^x$	7.34 ^{a} $(-14.6)^x(-6.5)^y$	31.61 ^{a}	28.41 ^{a} $(-10.1)^x$	24.82 ^{a} $(-21.5)^x(-12.6)^y$	1.72 ^{a}	2.09 ^{a} $(+17.7)^x$	2.23 ^{a} $(+22.9)^x(+6.3)^y$

Anova (two-way)

Substrates			
Sum of squares	7.221	0.491	0.949
Mean of squares	3.611	0.245	0.475
F-value	58.309	33.613	57.310
P-value	0.000	0.000	0.000
Treatments			
Sum of squares	0.324	0.210	0.221
Mean of squares	0.065	0.042	0.044
F-value	1.046	5.763	5.339
P-value	0.443	0.009	0.012

PM – Pressmud, ST – Sugarcane trash, BE – Biomethanated distillery effluent, *For treatment (bedding) composition see text and Table **1**.
Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, p<0.05); OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without *P. excavatus* (normal compost); WW – chemical composition of compost proceed with *P. excavatus* (vermicompost); x – The figures in parentheses (+/-) indicates the % increase / decrease over OD; y – The figures in parentheses (+/-) indicates the % increase / decrease over WU.

Table 4: Chemical Composition of Compost and Vermicompost of *P. excavatus* Obtained from Agroindustrial Wastes (n=6)

Treatments (vermibeds)	Phosphorus (%)			Potassium (%)			C-N ratio			C-P ratio		
	OD	WU	WW	OD	WU	WW	OD	WU	WW	OD	WU	WW
(PM+BE)*	2.05^{a}	2.26^{a} (+9.3)^{x}	2.55^{a} (+19.6)^{x}(+11.4)^{y}	3.44^{a}	3.61^{a} (+4.7)^{x}	4.76^{a} (+27.7)^{x}(+24.2)^{y}	20:1^{b}	17:1^{b} (-15.0)^{x}	11 :1^{b} (-45.0)^{x}(-35.2)^{y}	19:1^{b}	16 :1^{b} (-15.8)^{x}	9 :1^{b} (-52.6)^{x}(-43.8)^{y}
(PM+ST+BE)*	2.17^{b}	2.41^{b} (+10.0)^{x}	2.84^{b} (+23.6)^{x}(+15.1)^{y}	3.52^{a}	3.76^{a} (+6.4)^{x}	4.89^{a} (+28.0)^{x}(+23.1)^{y}	18:1^{ab}	16:1^{ab} (-11.1)^{x}	10:1^{ab} (-44.4)^{x}(-37.5)^{y}	17:1^{ab}	15:1^{ab} (-11.8)^{x}	10:1^{ab} (-41.2)^{x}(-33.3)^{y}
(PM+ST+BE)*	2.21^{b}	2.56^{b} (+13.7)^{x}	3.01^{b} (+26.6)^{x}(+15.0)^{y}	3.70^{a}	3.82^{a} (+3.1)^{x}	5.12^{a} (+27.7)^{x}(+25.4)^{y}	17:1^{a}	15:1^{a} (-11.7)^{x}	9:1^{a} (-47.1)^{x}(-40.0)^{y}	16:1^{ab}	13:1^{ab} (-18.8)^{x}	9:1^{ab} (-43.8)^{x}(-30.8)^{y}
(PM+ST+BE)*	2.26^{b}	2.61^{b} (+13.4)^{x}	2.74^{b} (+17.5)^{x}(+4.7)^{y}	3.74^{a}	3.88^{a} (+3.6)^{x}	4.67^{a} (+20.0)^{x}(+17.0)^{y}	17:1^{ab}	15:1^{ab} (-11.7)^{x}	11:1^{ab} (-35.3)^{x}(-26.7)^{y}	15:1^{ab}	12 :1^{ab} (-20.0)^{x}	10 :1^{ab} (-33.3)^{x}(-16.7)^{y}
(PM+ST+BE)*	2.31^{b}	2.66^{b} (+13.2)^{x}	2.77^{b} (+16.6)^{x}(+3.0)^{y}	3.78^{a}	3.91^{a} (+3.3)^{x}	4.62^{a} (+18.2)^{x}(+15.4)^{y}	17:1^{ab}	14 :1^{ab} (-17.6)^{x}	12 :1^{ab} (-29.4)^{x}(-14.3)^{y}	14:1^{a}	11 :1^{a} (-21.4)^{x}	10 :1^{a} (-28.6)^{x}(-9.1)^{y}
(PM+ST+BE)*	2.39^{b}	2.65^{b} (+9.8)^{x}	2.80^{b} (+14.6)^{x}(+5.4)^{y}	3.81^{a}	3.94^{a} (+3.3)^{x}	4.59^{a} (+17.0)^{x}(+14.2)^{y}	18:1^{ab}	14 :1^{ab} (-22.2)^{x}	12.1^{ab} (-33.3)^{x}(-14.3)^{y}	14:1^{a}	11 :1^{a} (-21.4)^{x}	10 :1^{a} (-28.6)^{x}(-9.1)^{y}

Anova (two-way)

Substrates				
Sum of squares	4.336	972690.11	149.778	114.333
Mean of squares	2.162	486345.05	74.889	57.167
F-value	81.295	30.387	64.80	30.088
P-value	0.000	0.000	0.000	0.000
Treatments				
Sum of squares	0.122	177984.27	8.944	23.167
Mean of squares	0.024	35596.85	1.789	4.633
F-value	0.912	2.224	1.548	2.439
P-value	0.511	0.132	0.260	0.108

PM – Pressmud, ST – Sugarcane trash, BE – Biomethanated distillery effluent, *For treatment (bedding) composition see text and Table 1.
Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test,$p<0.05$); OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without *P. excavatus* (normal compost); WW – chemical composition of compost proceed with *P. excavatus* (vermicompost); x – The figures in parentheses (+/-) indicates the % increase / decrease over OD; y – The figures in parentheses (+/-) indicates the % increase / decrease over WU.

Table 5: Biological Composition of Compost and Vermicompost of *P. excavatus* Obtained from Agroindustrial Wastes (n=6)

Treatments (vermibeds)	Total microbial population (CFU x 10^6 g^{-1})			Dehydrogenase (µlH / 5 g substrate)			Lignin (mg/g)			Cellulose (mg / g)		
	OD	WU	WW	OD	WU	WW	OD	WU	WW	OD	WU	WW
(PM+BE)*	548^{a}	610^{a} $(+10.2)^{x}$	946^{a} $(+42.1)^{x}(+35.5)^{y}$	7.73^{ab}	8.42^{ab} $(+8.2)^{x}$	10.61^{ab} $(+27.1)^{x}(+20.6)^{y}$	40.6^{a}	38.3^{a} $(-5.7)^{x}$	33.5^{a} $(-17.5)^{x}(-12.5)^{y}$	153.4^{a}	150.5^{a} $(-1.9)^{x}$	142.3^{a} $(-7.2)^{x}(-5.4)^{y}$
(PM+ST+BE)*	572^{ab}	676^{ab} $(+15.4)^{x}$	1212^{ab} $(+52.8)^{x}(+44.2)^{y}$	7.81^{ab}	8.65^{ab} $(+9.7)^{x}$	11.83^{ab} $(+46.5)^{x}(+26.9)^{y}$	43.3^{b}	41.5^{b} $(-4.2)^{x}$	34.2^{b} $(-21.0)^{x}(-17.6)^{y}$	196.1^{b}	192.3^{b} $(-1.9)^{x}$	184.6^{b} $(-5.9)^{x}(-4.0)^{y}$
(PM+ST+BE)*	606^{b}	705^{b} $(+14.0)^{x}$	1549^{b} $(+60.9)^{x}(+54.5)^{y}$	7.92^{b}	9.02^{b} $(+12.2)^{x}$	12.77^{b} $(+38.0)^{x}(+29.4)^{y}$	49.8^{c}	46.5^{c} $(-6.6)^{x}$	42.4^{c} $(-14.9)^{x}(-8.8)^{y}$	213.5^{c}	205.6^{c} $(-3.7)^{x}$	181.2^{c} $(-15.1)^{x}(-11.9)^{y}$
(PM+ST+BE)*	555^{ab}	626^{ab} $(+11.3)^{x}$	975^{ab} $(+43.1)^{x}(+35.8)^{y}$	7.65^{ab}	8.53^{ab} $(+10.3)^{x}$	10.82^{ab} $(+29.3)^{x}(+21.2)^{y}$	53.5^{d}	51.7^{d} $(-3.4)^{x}$	47.8^{d} $(-10.7)^{x}(-7.5)^{y}$	228.2^{d}	213.4^{d} $(-6.5)^{x}$	205.4^{d} $(-10.0)^{x}(-3.7)^{y}$
(PM+ST+BE)*	536^{a}	605^{a} $(+11.4)^{x}$	931^{a} $(+42.4)^{x}(+35.0)^{y}$	7.59^{a}	8.21^{a} $(+7.6)^{x}$	10.26^{a} $(+26.0)^{x}(+20.0)^{y}$	56.7^{e}	53.2^{e} $(-6.2)^{x}$	49.5^{e} $(-12.7)^{x}(-7.0)^{y}$	236.5^{e}	231.3^{e} $(-2.2)^{x}$	211.6^{e} $(-10.5)^{x}(-8.5)^{y}$
(PM+ST+BE)*	523^{a}	589^{a} $(+11.2)^{x}$	893^{a} $(+41.4)^{x}(+34.0)^{y}$	7.44^{a}	8.14^{a} $(+8.6)^{x}$	9.72^{a} $(+23.5)^{x}(+16.3)^{y}$	60.4^{f}	57.4^{f} $(-5.0)^{x}$	51.3^{f} $(-15.1)^{x}(-10.6)^{y}$	241.8^{e}	237.5^{e} $(-1.8)^{x}$	217.2^{e} $(-10.2)^{x}(-8.5)^{y}$

Anova (two-way)

Substrates				
Sum of squares	35.797	178.881	1416.108	105.708
Mean of squares	17.899	89.441	708.054	52.854
F-value	67.825	121.012	29.045	82.944
P-value	0.000	0.000	0.000	0.000
Treatments				
Sum of squares	4.210	858.064	13969.838	134.169
Mean of squares	0.842	171.613	2793.968	26.834
F-value	3.191	237.947	114.611	42.111
P-value	0.056	0.000	0.000	0.000

PM – Pressmud, ST – Sugarcane trash, BE – Biomethanated distillery effluent, *For treatment (bedding) composition see text and Table 1.
Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, $p<0.05$); OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without *P. excavatus* (normal compost); WW – chemical composition of compost proceed with *P. excavatus* (vermicompost); x – The figures in parentheses (+/-) indicates the % increase / decrease over OD; y – The figures in parentheses (+/-) indicates the % increase / decrease over WU.

Table 6: Biological Composition of Compost and Vermicompost of *P. excavatus* Obtained from Agroindustrial Wastes (n=6)

Treatments (vermibeds)	Hemicellulose (mg/g)			Phenol (mg/100g)			Humic acid (mg/5g)		
	OD	WU	WW	OD	WU	WW	OD	WU	WW
(PM+BE)*	25.8 ^{a}	24.2 ^{a} (-6.2)^{x}	21.5 ^{a} (-16.7)^{x}(-11.2)^{y}	44.2 ^{a}	42.6 ^{a} (-3.6)^{x}	40.3 ^{a} (-9.0)^{x}(-5.4)^{y}	2.15 ^{ab}	23.21 ^{ab} (+90.7)^{x}	31.42 ^{ab} (+93.2)^{x}(+26.1)^{y}
(PM+ST+BE)*	28.6 ^{b}	26.3 ^{b} (-8.0)^{x}	23.3 ^{b} (-18.5)^{x}(-11.4)^{y}	46.5 ^{a}	43.4 ^{a} (-6.7)^{x}	41.7 ^{a} (-10.3)^{x}(-3.9)^{y}	2.05 ^{b}	25.44 ^{b} (+91.3)^{x}	33.17 ^{b} (+93.8)^{x}(+23.3)^{y}
(PM+ST+BE)*	31.4 ^{b}	27.5 ^{b} (-12.4)^{x}	22.6 ^{b} (-28.0)^{x}(-17.8)^{y}	48.0 ^{a}	44.1 ^{a} (-8.1)^{x}	40.6 ^{a} (-15.4)^{x}(-7.9)^{y}	2.01 ^{ab}	24.63 ^{ab} (+91.8)^{x}	35.46 ^{ab} (+94.3)^{x}(+30.5)^{y}
(PM+ST+BE)*	32.5 ^{c}	30.6 ^{c} (-5.8)^{x}	26.5 ^{c} (-18.5)^{x}(-13.4)^{y}	52.2 ^{b}	46.8 ^{b} (-10.3)^{x}	44.7 ^{b} (-14.4)^{x}(-4.5)^{y}	1.96 ^{ab}	24.61 ^{ab} (+92.0)^{x}	34.21 ^{ab} (+94.3)^{x}(+28.1)^{y}
(PM+ST+BE)*	33.1 ^{cd}	31.4 ^{cd} (-5.1)^{x}	27.8 ^{cd} (-16.0)^{x}(-11.5)^{y}	53.8 ^{b}	47.4 ^{b} (-11.9)^{x}	45.2 ^{b} (-16.0)^{x}(-5.6)^{y}	1.93 ^{ab}	23.34 ^{ab} (+91.7)^{x}	32.49 ^{ab} (+94.1)^{x}(+28.2)^{y}
(PM+ST+BE)*	33.8 ^{d}	32.3 ^{d} (-4.4)^{x}	28.3 ^{d} (-16.3)^{x}(-12.4)^{y}	55.6 ^{c}	49.8 ^{c} (-10.4)^{x}	48.42 ^{c} (-12.9)^{x}(-2.8)^{y}	1.90 ^{ab}	23.17 ^{ab} (+91.8)^{x}	31.28 ^{ab} (+93.9)^{x}(+25.9)^{y}

Anova (two-way)

Substrates			
Sum of squares	133.766	3056.12	79.440
Mean of squares	66.883	1528.106	39.720
F-value	56.436	1864.091	61.528
P-value	0.000	0.000	0.000
Treatments			
Sum of squares	177.561	9.668	42.789
Mean of squares	35.512	1.934	14.263
F-value	29.966	2.359	22.094
P-value	0.000	0.116	0.001

PM – Pressmud, ST – Sugarcane trash, BE – Biomethanated distillery effluent, *For treatment (bedding) composition see text and Table **1**.
Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, $p<0.05$); OD – chemical composition of raw materials used in different vermibed (initial 0-day); WU – chemical composition of compost proceed without *P. excavatus* (normal compost); WW – chemical composition of compost proceed with *P. excavatus* (vermicompost); x – The figures in parentheses (+/-) indicates the % increase / decrease over OD; y – The figures in parentheses (+/-) indicates the % increase / decrease over WU.

T_1 – T_6 agroindustrial waste treatments during vermicomposting process when inoculated with *P. excavatus* it was found that there is no mortality of worms in all the treatments. As summarized in Table **7** the rate of growth (biomass), reproduction (cocoon production and hatchlings) and recovery of vermicompost of *P. excavatus* were highest in T_1 followed by T_3 and T_2 treatments and then the values obtained from other treatments (T_4, T_5 and T_6). In general, regarding vermicomposting of agroindustrial wastes by using *P. excavatus*, biomass of earthworms had increased significantly ($p<0.05$) in all treatments (T_1-T_6), but the overall rate of biomass production was maximum in the T_1 treatment followed by T_3 and T_2 than other treatments. Like the growth of earthworms, the mean cocoon production rate also varies in different treatments. Among the 6 treatments earthworm reared on T_1 treatment, followed by T_3 and T_2 treatments were shown significantly ($p<0.05$) increased cocoon production than other treatments. Also, significantly ($p<0.05$) highest rates of hatchling number were observed in the T_1 treatment, followed by T_3 and T_2 treatments than other treatments. Similar to growth and reproductive performance of *P. excavatus* cultured on the 6 different treatments, recovery of vermicompost was significantly ($p<0.05$) higher in T_1 treatment, followed by T_3 and T_2 treatments, than other treatments.

Finally, in our present experimental observation, T_3 treatment alone was found to show prolonged and sustainable earthworm activity and nutrient quality of vermicompost even though better growth, reproduction and more recovery of vermicompost, and nutrient quality of vermicompost i.e., increased N, P, K, total microbial population, dehydrogenase activity and humic

Table 7: Earthworm (*P. excavatus*) activity during vermicomposting of agroindustrial wastes (n=6)

Treatments (vermibeds)	Mortality (%)		Biomass (g)		Cocoon production (number)		Hatchling (number)		Recovery rate of vermicompost (g)	
	Initial (0 days)	Final (after 60 day)	Initial (0 days)	Final (after 60 day)	Initial (0 days)	Final (after 60 day)	Initial (0 days)	Final (after 60 day)	Initial (0 days)	Final (after 60 day)
(PM+BE)*	-	-	15.2^{a}	38.6^{c}	0	142^{c}	0	184^{c}	0	692^{c}
(PM+ST+BE)*	-	-	15.5^{a}	35.2^{c}	0	116^{b}	0	172^{b}	0	677^{b}
(PM+ST+BE)*	-	-	15.4^{a}	36.4^{c}	0	131^{c}	0	179^{c}	0	683^{c}
(PM+ST+BE)*	-	-	15.6^{a}	33.1^{b}	0	104^{b}	0	164^{b}	0	612^{b}
(PM+ST+BE)*	-	-	15.0^{a}	30.2^{b}	0	88^{a}	0	148^{a}	0	555^{a}
(PM+ST+BE)*	-	-	15.1^{a}	26.4^{b}	0	67^{a}	0	121^{a}	0	442^{a}

Anova (Two-way)

Substrates					
Sum of squares	-	81970.28	34992.00	78085.33	1116910.08
Mean of squares	-	6985.18	615.50	243.50	1901.58
F-value	-	486.87	90.983	283.80	233.68
P-value	-	0.000	0.000	0.000	0.000
Treatments					
Sum of squares	-	1851.94	1923.00	1375.66	23897.41
Mean of squares	-	168.359	384.60	275.13	4779.43
F-value	-	1.000	1.000	1.000	1.000
P-value	-	0.500	0.500	0.500	0.500

PM – Pressmud, ST – Sugarcane Trash, BE – Biomethanated distillery effluent.
*For treatment (bedding) composition see text and Table **1**.
Mean value followed by different letters is statistically different (ANOVA; Duncan multiple - ranged test, $p<0.05$).

acid content and reduced pH, OC, C:N ratio, C:P ratio, lignin, cellulose, hemicellulose and phenol were found to observed in the other treatments.

Vermicomposting is an earthworm – microbe symbiotic process where the conversion of organic waste into organic manure – vermicompost take places. Earthworms are very sensitive to pH and in general are neutrophilic in nature [18]. Vermicomposting of agroindustrial waste seems to be advantageous over conventional process of composting. Lowering of pH, in the present study, in the worm-worked vermicompost at the end of experimentation in all the treatments (T_1 – T_6) (60^{th} day) was probably due to mucus secretion by the earthworms that had a 'priming effect' on microbial activity [19] and CO_2 and organic acids produced during microbial metabolism [20]. It is likely that comparatively lower pH (towards neutral) during vermicomposting was due to additional contribution made by the earthworms. Elvira.*et. al* [21] suggested that production of CO_2, ammonia, NO^{-3} and organic acids by microbial decomposition during vermicomposting lowers the pH of substrate. Similarly, Ndegwa *et al*. [22] and Suthar [23] pointed out that shifting of pH could be related to the mineralization of the nitrogen and phosphorus into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of the organic acids.

The value of organic matter is very important for soil health. The deficiency in OC reduces storage capacity of soil nitrogen, phosphorus, sulphur and leads to reduction in soil fertility. Further, microbial biomass in soil is mainly related to the OC content [24]. Vermicomposting refers to the breakdown of organic matter by earthworm and subsequent microbial degradation. Earthworm modify substrate conditions, which consequently affects carbon losses from substrates through microbial respiration in the form of CO_2 and even through mineralization of OC. Body fluids and excreta, secreted by earthworms (e.g.

mucous, high concentration of organic matter, ammonia and urea) promote microbial communities in vermicomposting sub-system. OC content of vermicompost in the present study indicated that during the process of vermicomposting the level of OC was reduced in the vermicompost obtained from the all treatments (T_1 – T_6) when compared to worm-unworked compost and initial substrates. The results revealed that during the process of vermicomposting the level of OC was reduced to lesser extent in the vermicompost obtained from various treatments and retained the quantity of OC ranging between 20%-35%. Many earlier investigators have reported and confirmed the reduction of OC content in organic wastes after converted in to vermicompost [6, 23, 25]. The obtained reduction in the level of OC in the present study falls in line with the earlier reported results. Drop in the level of OC due to the combined action of earthworm and microbes during vermicomposting revealed that earthworm accelerate the decomposition of organic matter.

The main index to assess the rate of organic matter decomposition is the reduction of C-N and C-P ratio during vermicomposting. Carbon to nitrogen ratio is one of the criteria to assess the rate of decomposition of organic wastes and a reduction in the ratio indicates increased rate of decomposition [18, 26, 27]. A similarly reduction in carbon to phosphorus ratio indicates enhanced rate of decomposition [28]. Further, plants cannot assimilate mineral nitrogen unless the C:N ratio is 20:1 or lower [18]. Hence the NPK and OC analysis of vermicompost is essential and inevitable to confirm its manural maturity and quality. Many earlier investigators have reported and confirmed the reduction of OC, C:N and C:P ratios and increase in NPK content in organic wastes after converted in to vermicompost [5, 26, 27, 29-32]. The C:N ratio is considered as an important indicator of compost maturity. The parameters traditionally considered to determine the degree of maturity of compost and to define its agronomic quality is the C:N ratio. According to Morais and Queda [33] and Jordening and Winter [34], a C:N ratio below 20 is indicative of acceptable maturity, while a ratio of 15 or lower is being preferable for agronomic use of compost. The vermicompost obtained in the present study in all the treatments (T_1-T_6) showed the C:N ratio within the acceptable limit and agronomic preferable as described by Morais and Queda [33] and Jordening and Winter [34].

The significant reduction and narrow range of C:N ratio below 20:1 and reduction in C:P ratio recorded in the vermicompost obtained from all treatments compared to worm-unworked initial substrates and natural compost reflected the high rate of organic matter decomposition, and mineralization thereby resulting in mature and nutrient rich and agronomic value added vermicompost. The observed significant reduction in the levels of C:N and C:P ratio in the vermicompost obtained from all the treatments were in accordance with the work of Mba [35], who found that in *E. eugeniae* worked cassava peel compost C:N and C:P ratios decreased. In most of earlier reports a decrease and narrow down of C:N and C:P ratios were recorded in the vermicompost produced from different types of organic wastes [23, 26, 36-39]. The reduction in OC and lowering C:N ratio and C:P ratio in the vermicompost could be achieved on one hand by the combustion of carbon or loss of C as CO_2 during respiration and worm gut microbial utilization [18] and on the other hand simultaneously enhancement of higher proportion of total N and ionic protein content in the vermicompost due to loss of dry matter [40] coupled with the addition of earthworm's activities (i.e., production of mucus, enzymes and nitrogenous excrements [41, 42]. The decrease in C:N ratio over time might also be attributed to increase in the earthworm population which led to rapid decrease in OC due to enhanced oxidation of the organic matter [22]. Acid production during organic matter decomposition by the micro-organisms is the major mechanism of solubilization of P and K content [43].

Also, the presence of large number of microflora in the gut of earthworms [44] might play an important role in increasing P and K content during the process of degradation of organic wastes thereby decreasing C:P ratio [27, 45]. Enhancement of P and K content during vermicomposting is probably due to the mineralization, solubilization and mobilization of phosphorus and potassium because of earthworm – microbial activity [5, 27, 31]. Parthasarathi and Ranganathan's [31]; Suthar's [46]; Parthasarathi's [5, 27] investigation support the hypothesis that earthworms can enhance the NPK content during their inoculation in waste system. So from the present finding it can be concluded that the reduction in C:N and C:P ratios of vermicompost indicated enhanced biodegradation process of the organic matter in the agroindustrial wastes. Further, reduction in C:N and C:P ratios of vermicompost are the indices for the effective biodegradation of agroindustrial wastes – PM, ST and BE and production of good quality vermicompost with enriched nutrients such as NPK from them.

The significantly enhanced levels of NPK in the vermicompost obtained from all the treatments (T_1 – T_6) especially in T_3, T_2 and T_1 over worm unworked initial substrates and natural compost indicated effective decomposition of PM-ST-BE by the combined action of earthworm – microbes. Earthworms enrich the vermicompost with N through excretory products, mucous, enzymes and growth stimulating hormones and even by decaying earthworm tissue after their death. Studies revealed that decomposition of organic material by earthworms accelerates the N mineralization process and subsequently changes the N profile of the substrate [21, 26, 27, 47]. In general, earthworm contains about 60-70% (of dry mass) protein in their body tissue, and this pool of N returned to the soil upon mineralization. Satchell [48] reported that over 70% of the N in the tissues of dead earthworm was mineralized in less than 20 days. However, decomposition activities and N enrichment by earthworms also depend upon the quality of the substrate material.

After vermicomposting of different proportions of agroindustrial wastes PM-ST-BE, all treatments showed significantly higher concentration of available P in the vermicompost than normal compost and initial substrates. According to Lee [49] the passages of organic residue through the gut of earthworms, results in phosphorus converted to forms, which are more available to plants. The release of phosphorus in forms available to plants is mediated by phosphatases, which are produced in earthworm's gut [27, 42, 50]. Further, release of P may occur by the presence of P-solubilizing microbes in the vermicompost [44]. Recently, Parthasarathi [27] reported about 6-8 fold increment in available P content in the vermicasts, after inoculation of wastes-pressmud, cowdung and sawdust with earthworms – *E. eugeniae, E. fetida, L. mauritii* and *P. excavatus.* Earthworm gut flora provides enzymes required for PM metabolism and these enzyme release phosphorus form ingested waste material [5, 27, 42, 44, 50].

After 60 days of vermicomposting, K content increase for different vermibeds was recorded in the order: $T_3 > T_2 > T_1 > T_4 > T_5$ and $> T_6$ treatment. K content in the vermicompost was higher significantly than initial substrate material and normal compost. However, when organic waste passes through the gut of earthworm the some quantity of organic minerals are then converted in to more available forms through the action of enzymes produced by gut associated microorganisms. The vermicomposting plays an important role in microbial - mediated nutrient mineralization in wastes. The results of this study agree with previous reports that the vermicomposting process accelerates the microbial populations in the waste and subsequently enriches the vermicompost with more available forms of plant nutrients. Also the present result is similar to those by Parthasarathi and Ranganathan [31], Parthasarathi [5, 27] and Suthar [23], whose reported enhancement of K content in the vermicompost.

The significantly increased levels of NPK in the vermicompost obtained from the treatments T_1 - T_6 especially in T_3, T_2 and T_1 over worm unworked normal compost and initial substrates indicated effective decomposition of agroindustrial wastes by the combined action of earthworm and microbes. The increased levels of NPK in the vermicompost are in conformity with the result of earlier workers. Edwards *et al.* [51] stated that by the combined action of earthworms and microorganisms on the waste materials most of the N, P, K, Mg were converted in to available form. Kale [30] reported an increase in the available N, P, K in worm worked cowdung and sawdust vermicompost. Haimi and Huphta [52] have demonstrated that the feeding activity of worm significantly mineralization of macronutrients of brich litter. Parthasarathi and Ranganathan [31, 42] and Parthasarathi *et al.* [44] reported a significant increase in the level of NPK in *E. eugeniae, E. fetida, P. excavatus* and *L. mauritii* worked pressmud vermicompost. Karmegam and Daniel [53] reported a significant hike in the level of N, P, K in *E. fetida* worked leaf litters. Suthar [26, 46] reported an increase in the level of N, P, K contents during vermicomposting process.

On the basis of above discussion and literature evidences cited it can be concluded that the significantly increased levels from T_3, T_2 and T_1 treatments (PM-ST-BE) and other treatments (T_4, T_5 and T_6) (T_1-T_6) could be due to the combined action of microorganisms and *P. excavatus* increased the mineralization of organic matter when it passes through the worm gut. Microbial and enzyme activity also contributes to increase the mineral nutrients in the vermicasts through nitrification, phosphate solubilization and mineralization [18, 27, 31]. Parthasarathi and Ranganathan [42]; Vinotha *et al*. [50]; Parthasarathi [27] reported increased microbial and enzyme activity during the passage of organic matter through the gut of earthworms. Thus, vermicompost obtained from T_3 treatment (PM-ST-BE) by the action of *P. excavatus* evidenced with increased levels of NPK and drastically reduced C:N and C:P ratios and hence can be considered as quality rich vermicompost.

Lignin is the most resistant form of plant products of photosynthesis in nature and accounts for 25 to 50% of the plant biomass generated. Pressmud and sugarcane trash consists of (41 and 86 mg/g) of lignin, 153 and 277 mg/g of cellulose and 44 and 56 mg/g of phenol. So requires long time for natural decomposition. Meentemeyer [54] stated that many studies on the decomposition of leaf litter lack information on the lignin, cellulose, hemicellulose, phenol and humic acid. No study is available regarding the levels of these content in the sugar industrial wastes particularly pressmud and sugarcane trash after vermicomposting process. In the present study, the comparison of lignin, cellulose, hemicellulose content between T_1-T_6 treatments indicated that among the 6 treatments significantly maximum reduction of these contents were recorded in the T_3>T_2>T_1 treatments than other treatments $T_4 > T_5 > T_6$ when compared to normal compost and initial substrates. This is due to the combined action of gut lignocellulolytic microflora and earthworm in the decomposition process. This finding was supported by Parthasarathi *et al.* [55] during vermicomposting of cashew leaf litter admixed with different animal dungs. Parthasarathi *et al.* [44] and Parthasarathi [27] reported the presence more cellulolytic, amylolytic, proteolytic and phosphate solubulizing microbes in the gut and casts of *E. eugeniae, E. fetida*, *L. mauritii* and *P. excauatus* and also the presence of cellulosic degrading enzymes as well as enzyme producing microbes in the gut of earthworms [27, 42]. Also, Loquet *et al*. [56] reported that the combined activity of microflora in the gut of worm and inoculated lignocellulolytic fungi might have intensified cellulolysis and lignolysis. From the present observed decrease of cellulose, hemicellulose, lignin and phenol content in the treatments containing sugar industrial wastes (PM+ST+BE) especially more in T_3 treatment confirmed the fact that it is necessary to inoculate suitable lignocellulolytic microbes and nitrogen rich boosters for the quick degradation of the lignocellulolytic material like sugarcane trash as suggested by Tiwari *et al*. [57], Makhija [3] and Parthasarathi *et al.* [55].

The enhancement of HA in the casts is mainly due to the large number of microbial population, their activity and also due to the gut associated process of the earthworm. Earthworm gut is known to stimulate biological activity, modify the composition of microbial communities and speed up the humification of organic matter [29]. Now, it is well established that the earthworm gut harbours specific symbiotic microflora [18, 27, 44]. Earthworms are known to accelerate humification process and vermicompost were shown to contain HA [27, 44, 58, 59]. Numerous earlier studies have shown that the guts of earthworms and vermicasts have enhanced microbial population and their activity than the ingested food material or the surrounding soil [5, 18, 27, 31, 44]. The humus will hold on the nutrients such as P and S and prevent their ready leaching. This fact has been proved in the field experiments conducted by Parthasarathi and Ranganathan [60], Parthasarathi *et al.* [61], Suthar [62] and Jayanthi *et al.* [63] where vermicompost was supplemented with 50% NPK applied to black grams, ground nut, beans, garlic and chilli, the yield was more than that of the NPK or vermicompost alone.

The analysis of results in the present study indicated that HA, MP and MA contents were significantly higher in the vermicompost obtained from the treatments (T_1-T_6) especially more in T_3, T_2 and T_1 than the initial substrate and normal compost. The increase of HA contents in vermicompost could mainly due to the activity of large number of microbes and also due to the gut associated process of earthworm [27, 64]. Clark and Paul [65], Mulongoy and Bedoret [58] and Muscolo *et al.* [66] have also reported that microbial population and their activity play a significant role in HA synthesis and also exhibit positive correlation with HA and FA content. In accordance with these reports in the present also in all the treatments (T_1-T_6) maximum enhancement of microbial activity especially in treatments T_3, T_2 and T_1 over initial substrates and normal compost were recorded. In general, increased microbial population and activity and more availability of nutrient content especially nitrogen content that support and stimulate the quick decomposition of organic matter. In the present study, increased nitrogen availability due to the different proportions of sugar industrial wastes - PM-ST-BE in all treatments (T_1-T_6) might have enhanced microbial activity and earthworm activity in one hand and speed up the decomposition of sugar industrial wastes on the other hand. This conclusion is in accordance with the suggestion of Berg and Matzner [67] and Manyuchi and Phiri [1]. They have stated that increasing nitrogen availability influenced the decomposition rates of plant litter and organic matter.

During the process of vermicomposting the stability of the tested substrate mainly depends on fold increase in essential plant nutrients, lowering of toxicants, earthworm biomass as well as reproductive performances, and even less or no mortality in tested earthworm species. In the present study, no mortality of earthworms were found during vermicomposting of agroindustrial wastes (PM-ST-BE) using predominantly available indigenous epigeic earthworm, *P. excavatus* in all the treatments of vermibeds (up to 60 days). This indicates the favourable and acceptable biochemical and micro environment of the vermibeds and absence of any toxic chemicals in the vermibeds. This present result is similar to those by Suthar and Singh [68] who reported no mortality of earthworm during vermicomposting of distillery industry sludge admixed with cowdung using *P. excavatus*. Vermicomposting is also considered in terms of production patterns of earthworm biomass, numbers of cocoon, numbers of hatchling and vermicompost. The dependency of earthworm on soil moisture for their survival and activity and organic matter rich in N for growth and reproduction is well known [18]. Quality of the organic waste is also one of the factors determining the onset and rate of reproduction [69] and recovery rate of vermicompost [27]. Murchie [70] proved experimentally the existence of a significant relationship between weight increase and susbtrate type, which may reasonably be attributed to nutritional quality of the susbtrate. Growth and reproduction in earthworms require OC, N and PM [71] which are obtained from litter, grit and microbes [18, 27, 72, 73]. Earlier studies of Ranganathan and Parthasarathi [74] and Parthasarathi and Ranganathan [42] have shown the higher nitrogen (1.6%) and phosphorus (2.5%) content of pressmud to support better growth (length and biomass) and bring about earlier maturation, earlier differentiation of the clitellum, lobulation in the ovary and release of cocoons in *L. mauritii* and *E. eugeniae* than worms fed with cowdung or clay loam soil. In the present study, the biomass, number of cocoon production, number of hatchling and recovery of vermicompost were highest in T_1, T_3 and T_2 followed by other treatments. *P. excavatus* exhibited highest biomass, more cocoon, hatchling and vermicompost production, very particular in the T_3 treatment.

The reasons for the enhanced growth and reproduction in T_1 and T_3 treatments followed by other treatments in the present study seems to be due to: rich cellulose content, microbial population and activity and enhanced water holding capacity (39-41%) which enable the T_3 treatment to maintain good and ideal moisture. The dependency of earthworm on soil moisture for their survival and activity and on organic matter rich in N for growth and reproduction is well known [18, 27]. The physical structure of the T_3 treatment substrate depends on the chemical composition of the constituents, particularly organic matter rich in N; it is only in such type of substrate (vermicomposting medium) that earthworm could reproduce. The T_3 treatment provides such ideal physico-chemical conditions suitable for better growth and maximum reproduction. Hence, it may be concluded that through PM-ST-BE are nutritionally inferior and slow degrading, the presence of high cellulose in the T_3 treatment develop better water holding capacity and become more palatable and nutritive (rich OC, N, P and microbial population) supporting better growth, reproduction and more compost recovery. Earlier studies of Ranganathan and Parthasarathi [74], Parthasarathi and Ranganathan [31, 42, 75]and Parthasarathi [27] have shown the higher N, P, OC, microbial content of pressmud to support better growth, reproduction and more vermicompost production of *L. mauritii, P. excavatus, Eudrilus eugeniae* and *Eisenia fetida*. This was supported by Kale [37] Edwards and Bohlen [18], Suthar [76] who reported that the factors relating to the growth, reproduction and compost production of earthworms may also be considered in terms of physico-chemical and nutrient characteristics of waste feed stocks.

Organic waste palatability for earthworms is directly related to the chemical nature of the waste material that consequently affects the earthworm growth, reproduction and compost production parameters. Garg *et al.* [39], Suthar [76] and Parthasarathi [27, 77] concluded that growth and reproductive performance of *E. fetida, P. sansibaricus* and *P. excavatus* was directly related to the quality of the feed stock. Edwards *et al*. [78] and Suthar [46] concluded that the important difference between the rates of cocoon production in the two organic wastes must be related to the quality of the waste. The variability in the earthworm biomass gain and reproduction rate in different treatments was probably related to the palatability, microbiology as well as the chemistry of the feeding stuff. The difference in cocoon production patterns among different treatment suggest a physiological trade-off [79] related to N-limitations. Recently, Suthar [76], Ranganathan [80] and Parthasarathi [27, 77] demonstrated that earthworm growth, reproduction (cocoon production and hatchling) and vermicompost production is related to initial N-content of the substrate. Our present experimental results are confirmatory of above hypothesis. Finally, from our experimental observations it is recommended that the agroindustrial wastes-pressmud, trash and biomethanated distillery effluent combination could be better vermicomposted by *P. excavatus* and used for vermiculture and vermicomposting practices.

Thus, vermicompost produced from T_3 treatment (800 g PM: 200 g ST: 696 ml BE) evidenced with increased level of NPK, MP, MA and HA, drastically reduced C:N and C:P ratio, lignin, cellulose, hemicellulose, phenol content coupled with increased microbial and earthworm activity (better and more earthworm growth and reproductive performance and vermicompost recovery). The present study proved beyond doubt that sugar industrial wastes can be serve as feed stock for earthworm and converted in to nutrients and microbial rich organic manure/vermicompost by the action of *P. excavatus* and other species of earthworms, particularly indigenous earthworms. Hence, from the present study observation T_3 treatment could be recommended for vermicompost and production of quality rich vermicompost for sustainable agricultural activity in an eco-friendly way besides abating environmental pollution.

It is evident from the results of the present study that agroindustrial wastes either in different combination (PM-ST-BE) was highly supportive of growth, reproduction, compost recovery and quality vermicompost production of *P. excavatus* whereas in the other treatments, *P. excavatus* showed lesser growth and reproductive performance and vermicompost recovery with quality. This may be due to the combined effect of various factors such as exhaustion of available food (since food is not renewed between treatment periods), population density pressure, speeded up microbial degradation and humification of organic wastes etc. Finally, this study paves a way for effective utilization of sugar industrial wastes using *P. excavatus* and lays foundation for the further planning of large scale vermicomposting program using various other indigenous earthworm species. Further study is needed to use various animal dung as bulking material for vermicomposting and develop the integrated system of vermicompostiing method by enhancing the efficiency of indigenous earthworm to overcome the problem of lignocellulosic waste degradation of organic wastes with bioinoculants and produce quality vermicompost.

ACKNOWLEDGEMENTS

We thank the authorities of Annamalai University for providing facilities and financial assistance from the DST (SERB) (SB/SO/AS-082/2013), New Delhi.

REFERENCES

[1] Manyuchi MM, Phiri A. Vermicomposting in solid waste management: a review. International Journal of Scientific Engineering and Technology 2013; 2(12): 1234-1242.

[2] Parthasarathi K, Jayanthi L, Soniya MA, Sekar J, Ameer Basha S. Efficiency of *Perionyx excavatus* (Perrier) in litter (*Anacardium occidentale* L.) decomposition and nutrient mineralization. Int J Modn Res Revs 2014; 2(10): 453-458.

[3] Makhija M. Vermicomposting of solid waste: Leaf litter, Ipomoea, and used paper. Ph.D Thesis in Environmental Technology, Centre for Pollution Control and Environmental Engineering, Pondicherry (Central) University, Pondicherry, India 2012.

[4] Pandit NP, Maheswari SK. Optimization of vermicomposting technique for sugarcane waste management by using *Eisenia fetida*. International Journal of Biosciences 2012; 2(10): 143-155.

[5] Parthasarathi K. Influence of moisture on the activity of *Perionyx excavatus* (Perrier) and microbial – nutrient dynamics of pressmud vermicompost. Iran J Environ Health Sci Eng 2007a; 4(3): 147-156.

[6] Parthasarathi K. Vermicompost produced by four species of earthworms from sugar mill wastes (pressmud). National Journal of Life Sciences 2004; 1(1): 41-46.

[7] ISI Bulletin Manak Bahavan, Bhadur Shah Zafar Mark, New Delhi 1982.

[8] Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci 1934; 37: 29-38. https://doi.org/10.1097/00010694-193401000-00003

[9] Jackson ML. Soil Chemical Analysis. Asia Publishing House, Bombay 1962.

[10] Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA Circ No. 939. 1954.

[11] Standford D, English L. Use of flame photometer in rapid soil tests of K and Ca. Agron J 1949; 4: 446-447. https://doi.org/10.2134/agronj1949.00021962004100090012x

[12] Baron JE, Peterson RL, Fineglod MS. Cultivation and Isolation of Viable Pathogen in: Diagnostic Microbiology 9th ed, Chap 1. 79-96, Mosby, London 1994.

[13] Stevenson IL. Dehydrogenase activity in soils. Canadian J Microbiol 1959; 5: 229-235. https://doi.org/10.1139/m59-026

[14] Goering HK, Vansoest PJ. Forage fibre analysis. Department of Agriculture. Agriculture Research Service, Washington 1975.

[15] Updegroff DM. Semimicro determination of cellulose in biological materials. Ann Biochem 1969; 32; 420-444. https://doi.org/10.1016/S0003-2697(69)80009-6

[16] Malick CP, Singh MB. Plant Enzymology and Histoenzymology, Kalyani Publisher, New Delhi 1980.

[17] Schnitzer M. Humus substances: chemistry and reaction. In: Soil Organic Matter. (Schnitzer M, Khan SU. Eds). Elsevier, Amsterdam 1978.

[18] Edwards, CA, Bohlen PJ. Biology and Ecology of Earthworms, Chapman and Hall, London 1996.

[19] Trigo D, Barois I, Garvin MH, Huerta E, Soraida I, Lavelle P. Mutualism between earthwroms and microflora. Pedobiologia 1999; 43: 866-873.

[20] Hartenstein R, Hartenstein F. Physico-chemical changes effected in activated sludge by earthworm *Eisenia fetida*. J Env Quality 1981; 10: 377-382. https://doi.org/10.2134/jeq1981.00472425001000030027x

[21] Elvira C, Sampedro L, Benitez E, Nogales R. Vermicomposting of sludge from paper mill and dairy

industries with *Eisenia andrei*: A pilot scale study. Bioresource Technology 1998; 63: 211-218. https://doi.org/10.1016/S0960-8524(97)00145-4

[22] Ndegwa PM, Thompso SA, Das KC. Effects of stocking density and feeding rate on vermicomposting of biosolids. Bioresour Technol 2000; 71: 5-12. https://doi.org/10.1016/S0960-8524(99)00055-3

[23] Suthar S. Production of vermifertilizer from guar gum industrial wastes by using composting earthworm, *Perionyx sansibaricus* (Perrier). Environmentalist 2007; 27: 329-335. https://doi.org/10.1007/s10669-007-9032-9

[24] Schneuer J, Clarholm M, Rosswall T. Microbial biomass and activity in an agricultural soil with different organic matter contents. Soil Biol Biochem 1985; 17: 611-618. https://doi.org/10.1016/0038-0717(85)90036-7

[25] Satchell JE, Martin K. Phosphatase activity in earthworm faeces. Soil Biol Biochem 1984; 16: 191-194. https://doi.org/10.1016/0038-0717(84)90111-1

[26] Suthar S. Growth and fecundity of earthworms: *Perionyx excavatus* and *Perionyx sansibaricus* in cattle waste solids. Environmentalist 2009a; 29: 78-84. https://doi.org/10.1007/s10669-008-9185-1

[27] Parthasarathi K. Earthworms – Life cycle, Compost and Therapy. Lap Lambert Academic Publishing AG & Co., Germany 2010.

[28] Pore MP, Charan AS, Talashikar SC. Effects of fungal cultures on composting of rural residues. Proc Nat Sem Org Coimbatore 1992; 60-61.

[29] Lee KE. Earthworms: Their Ecology and Relationship with Soil and Land Use. Academic Press. Sydney 1985.

[30] Kale RD. Annelids (Terrestrial Oligocheates). In: Applied Soil Biology and Ecology (Veeresh GK, Rajagopal D. (eds), Oxford and IBH Publ. Co. Pvt. Ltd. 1988; pp. 90-110.

[31] Parthasarathi K, Ranganathan LS. Longivity of microbial and enzyme activity and their influence on NPK content in pressmud vermicasts. Eur J Soil Biol 1999; 35: 107-113. https://doi.org/10.1016/S1164-5563(00)00114-X

[32] Aira M, Monroy F, Dominquez J. Earthworms strongly modify microbial biomass and activity triggering enzymatic activities during vermicomposting independently of the application rates of pig slurry. Science of the Total Environment 2007; 385: 252-261. https://doi.org/10.1016/j.scitotenv.2007.06.031

[33] Morais FMC, Queda CA. Study of storage influence on evaluation of stability and maturity properties of MSW composts. In: Proceeding of the Fourth International Conference of ORBIT Association on Biological Processing of Organics: Advances for a Sustainable Society part II, Perth, Australia 2003.

[34] Jordening HJ, Winter J. Environmental Biotechnology – Concepts and Applications, Weinheim: Wiley-VCH, Germany 2008.

[35] Mba CC. Utilization of *Eudrilus eugeniae* for disposal of cassava peel. In: Earthworm Ecology from Darwin to Vermiculture (Satchell JE eds), Chapman and Hall, London 1983. https://doi.org/10.1007/978-94-009-5965-1_27

[36] Syers JK, Sharpley AN, Keeney DR. Cycling of nitrogen by surface casting earthworms in a pasture ecosystem. Soil Biol. Biochem 1979; 11: 181-185. https://doi.org/10.1016/0038-0717(79)90098-1

[37] Kale RD. Earthworms: Nature's gift for utilization of organic wastes In: Earthworm Ecology (Eds. CA Edwards). Ankeny, Lowast. Lucie Press, New York 1998.

[38] Bhattacharjee G. Earthworm resources and waste management through vermicomposting in Tripura, Ph.D Thesis in Zoology Department, Tripura University, Tripura, India 2002.

[39] Garg VK, Kaushik P, Dilbaghi N. Vermiconversion of waste water sludge from textile mill mixed with anaerobically digested biogas plant slurry employing *Eisenia fetida*. Ecotoxic and Environ Safe 2005; 65: 412-419. https://doi.org/10.1016/j.ecoenv.2005.03.002

[40] Viel M, Sayas D, Andre L. Optimization of agricultural industrial waste management through in-vessel composting in: De Bertoldi M, Ed. Compost: Production, Quality and Use. Elsevier Appl. Sci. Essex 1987; pp. 230-237.

[41] Curry JP, Byrne D, Boyle KE. The earthworm population in winter cereal field and its effects on soil and nitrogen turnover. Biol Fertil Soils 1995; 19: 166-172. https://doi.org/10.1007/BF00336154

[42] Parthasarathi K, Ranganathan LS. Aging effect on enzyme activities in pressmud vermicasts of *Lampito mauritii* (Kinberg) and *Eudrilus eugeniae* (Kinbger). Biol Fertil Soils 2000a; 30: 347-350. https://doi.org/10.1007/s003740050014

[43] Pramanik P, Ghosh GK, Ghosal PK, Banik P. Changes in organic - C, N, PM and K and enzymatic activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresourc Technology 2007; 98: 2485-2494. https://doi.org/10.1016/j.biortech.2006.09.017

[44] Parthasarathi K, Ranganathan LS, Anandi V, Zeyer J. Diversity of microflora in the gut and casts of tropical composting earthworms reared on different substrates. J Environ Biol 2007; 28(1): 87-97.

[45] Sharma K. Biofertilizers for Sustainable Agriculture, 1st Edition. Agrobios, India 2003.

[46] Suthar S. Potential utilization of guar gum industrial waste in vermicompost production. Bioresource Technology 2006; 97(18): 2474-2477. https://doi.org/10.1016/j.biortech.2005.10.018

[47] Benitez E, Saizn H, Melayar R, Nogales R. Vermicomposting of a lignocellulosic waste from olive oil industry: A pilot scale study. Waste Management and Research 2002; 20: 134-142. https://doi.org/10.1177/0734242X0202000205

[48] Satchell JE. Lumbricidae. In: Soil Biology, (Burges A and FRaw, Eds) Academic Press, London 1967.

[49] Lee KE. Some trends opportunities in earthworm research or: Darwin's children. The future of our discipline. Soil Biology and Biochemistry 1992; 24: 1765-1771. https://doi.org/10.1016/0038-0717(92)90185-Z

[50] Vinotha SP, Parthasarathi K, Ranganathan LS. Enhanced phosphotase activity in earthworm casts is more of microbial origin. Curr Sci 2000; 79(9): 1158-1159.

[51] Edwards CA, Burrows I, Flecher KE, Jones BA. The use of earthworms of composting farm wastes. In: Composting of Agricultural and other Wastes (Gasser JKR, Ed.), Barking, V.K. Elsevier Applied Science Publishers Ltd 1985; pp. 229-242.

[52] Haimi J, Huphta V. Comparison of compost produced from identical wastes by vermistabilization and conventional composting. Pedobiologia 1987; 30: 137-144.

[53] Karmegam N, Daniel T. Abundance and population density of three species of earthworms (Annelida: Oligochaeta) in foot hill of Sirumalai (Eastern Ghates). India J Environ & Ecoplan 2000; 3(3): 461-466.

[54] Meentemeyer V. Macroclimate and lignin control of litter decomposition rates. Ecology 1978; 59: 465-472. https://doi.org/10.2307/1936576

[55] Parthasarathi K, Balamurugan M, Prashija KV, Jayanthi L, Ameer Basha S. Potential of *Perionyx excavatus* in lignocellulosic solid waste management and quality vermifertilizer production for soil health. Int J Recycl Org Waste Agricult 2015; 5: 65-86. https://doi.org/10.1007/s40093-016-0118-6

[56] Loquet M, Vincelas M, Roulle J. Cellulasic activity in the gut of *Eisenia fetida*. Appl Biochem Biotechnol 1984; 9: 377. https://doi.org/10.1007/BF02798984

[57] Tiwari SC, Tiwari BK, Mishra RR. Microbial populations, enzyme activities and nitrogen – phosphorus – potassium enrichment in earthworm casts and in the surrounding soil of a pineapple plantation. Biol Fertil Soils 1989; 8: 178-182. https://doi.org/10.1007/BF00257763

[58] Mulongoy K, Bedoret A. Properties of wormcasts and surface soils under various plant covers in the humid tropics. Soil Biol Biochem 1989; 21: 197-203. https://doi.org/10.1016/0038-0717(89)90095-3

[59] Alves MR, Landgraf MD, Rezende MOO. Sorption and desorption of the herbicide alachlor on humic acid fractions from two vermicomposts. J Environ Sci Health 2001; 36: 797-808. https://doi.org/10.1081/PFC-100107413

[60] Parthasarathi K, Ranganathan LS. Supplementation of pressmud vermicasts with NPK enhances growth and yield in leguminous crops (*Vigna mungo* and *Arachis hypogaea*). J Curr Sci 2002; 2(1): 35-41.

[61] Parthasarathi K, Balamurugan M, Ranganathan LS. Influence of vermicompost on the physico-chemical and biological properties in different types of soil along with yield and quality of the pulse crop-blackgram. Iran J Environ Health Sci Eng 2008; 5(1): 51-58.

[62] Suthar S. Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium sativum* L.) field crop. International Journal of Plant Production 2009b; 3(1): 27-38.

[63] Jayanthi L, Sekar J, Ameer Basha S, Parthasarathi K. Influence of vermifertilizer on soil quality, yield and quality of chilli, *Capsicum annuum*. Online International Interdisciplinary Journal 2014; 4: 206-218.

[64] Parthasarathi K, Gunasekaran G, Ranganathan LS. Efficiency of mono and polycutlured earthworms in humification of organic wastes. J Ann Univ Science 2006; 42: 127-134.

[65] Clark FE, Paul EA. The microflora of grasslands. Adv Agron 1970; 22: 375-376. https://doi.org/10.1016/S0065-2113(08)60273-4

[66] Muscola A, Bovalo F, Gionfriddon F, Nardi S. Earthoworm humic matter produces auxin like effects on *Daucus Carota* cells growth and nitrate metabolims. Soil Biol Biochem 1999; 31: 1303-1311. https://doi.org/10.1016/S0038-0717(99)00049-8

[67] Berg B, Matzner E. Effect of N deposition on decomposition of plant litter and soil organic matter in forest ecosystem. Environmental Reviews 1997; 5: 1-25. https://doi.org/10.1139/a96-017

[68] Suthar S, Singh S. Feasibility of vermicomposting in biostabilization of sludge from a distillery industry. Science of the Total Environment 2008; 394: 237-243. https://doi.org/10.1016/j.scitotenv.2008.02.005

[69] Duminguez J, Edwards CA, Ashby J. The biology and population dynamics of *Eudrilus eugeniae* (Kinberg) (Oligochaeta) in cattle waste solids. Pedobiologia 2001; 45: 341-353. https://doi.org/10.1078/0031-4056-00091

[70] Murchie WR Biology of Oligochaeta Biomastos Zetekismith and Gittins in northern Michigan. Am Midd Nat 1960; 64: 194-215. https://doi.org/10.2307/2422902

[71] Evans AC, McL Guild WJ. Studies on the relationships between earthworms and soil fertility. IV. On the life-cycles of some British Lumbricidae. Ann. Appl Biol 1948; 35: 471-484. https://doi.org/10.1111/j.1744-7348.1948.tb07391.x

[72] Flack FM, Hartenstein R. Growth of the earthworms, *Eisenia fetida* on microorganisms and cellulose. Soil Biol Biochem 1984; 16: 491-495. https://doi.org/10.1016/0038-0717(84)90057-9

[73] Parthasarathi K, Ranganathan LS. Influence of pressmud on the development of ovary, oogenesis and the neurosecretory cells of the earthworm, *Eudrilus eugeniae* (Kinberg). African Zoology 2000; 35(2): 281-286.

[74] Ranganathan LS, Parthasarathi K. Precocious development of *Lampito mauritii* (Kinberg) and *Eudrilus eugeniae* (Kinberg) reared in pressmud. Pedobiologia 1999; 43: 904-908.

[75] Parthasarathi K, Ranganathan LS. Pressmud: A rich source of organic manure. Vermeco (in press) 2015.

[76] Suthar S. Nutrient changes and biodynamics of epigeic earthworm *Perionyx excavatus* (Perrier) during recycling of some agriculture wastes. Bioresource Technology 2007a; 98: 1608-1614. https://doi.org/10.1016/j.biortech.2006.06.001

[77] Parthasarathi K. Life cycle of *Lampito mauritii* (Kinberg) in comparison with *Eudrilus eugenia* (Kinberg) cultured on different substrates. J Environ Biol 2007b; 28(4): 803-812.

[78] Edwards CA, Dominguez J, Neuhauser EF. Growth and reproduction of *Perionyx excavatus* (Perrier) (Megascolecidae) as factors in organic waste management. Biol Fertil Soils 1998; 27: 155-161. https://doi.org/10.1007/s003740050414

[79] Streans SC. The Evolution of Life History. Oxford University Press, New York, USA 1992.

[80] Ranganathan LS. Vermibiotechnology – From Soil Health to Human Health. Agrobios, Jodhpur, India 2006.

[81] APHA American Public Health Association: American Water Works Association and Water Environment Federation, Standard Methods for the Examination of Water and Waste Water, 21st Edition, APHA, Washington 2005.

Received on 26-05-2016 Accepted on 05-10-2016 Published on 05-12-2016

DOI: http://dx.doi.org/10.6000/1927-3037.2016.05.04.5

© 2016 Prashija and Parthasarathi; Licensee Lifescience Global.
This is an open access article licensed under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted, non-commercial use, distribution and reproduction in any medium, provided the work is properly cited.