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ORIGINAL RESEARCH

Efficacy of vermicompost amended and bacterial diversity on plant growth and pathogen control

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Abstract

Purpose Organic solid wastes contain tremendous amounts of nutrients and beneficial microbes that cause environmental problems, such as pollution and shortage of dumping sites. Vermicomposting, considered as one of the most suitable stabilization and mass reduction methods, has been recognized for biowastes**.** This study aimed to evaluate the microbial diversity and analyze the ability of vermicompost produced from poultry litter, household, and guano of both insectivorous and frugivorous bats to reduce root-knot nematode's infection.

Method The assessment of microbial diversity was carried out by amplification of 16s rRNA gene in bacteria habitant in vermicomposit . Nitrogen content, organic carbon constituent and heavy metal concentration were evaluated.

Results The results obtained showed that organic matter ranged between 27.6% to 35.2%, while, C/N ratio was2.9 to 5.5 in the amended vermicomposite. Also, there is a remarkable reduction in root-knot nematode infection after vermicopositing with organic wastes. Interstingly, the obtained bacterial species were *Archangium gephyra*, *Corynebacterium glutamicum, Clostridium ultunense, Azospirillum sp*. and *Bacillus sp* in biowastes.

Conclusion According to these results, the produced vermicompost from different biodegradable wastes possesses bacterial diversity, lowers heavy metals' concentration, enhances plant growth parameter, and increases plant resistance against nematode infection.

Keywords Bacterial biodiversity, Biofertilizers, Plant growth, Root-knot nematodes, Vermicompost

Introduction

Wastes are considered a problematic issue that require spaces to create landfill sites and costs needed for their operation and re-cultivation. Thus, a simple solution to overcome the waste problem was discovered. For instance, vermicomposting that is considered the best and the cheapest solution to reduce costs and environmental pollution under the effect of wastes (Kostecka et al. 2018).

Vermicompost is the end product of non-thermophilic biodegradation of organic materials by the action of different species of earthworms as *Eisenia fetida*, *Lumbricus rubellus*, *Perionyx excavates*, and *Aporrectodea caliginosa* and their associated microbes (Arancon et al. 2004). Earthworms act as mechanical blenders that mix all soil ingredients to increase their fertility to be rich in humus, macronutrients, micronutrients, beneficial microflora and plant growth regulators (Adhikary 2012). *Aporrectodea caliginosa* is an endogeic earthworm species that is found in moist soil in temperate regions (Decaëns et al. 2011). It has the ability to live in low organic matter and moisture content soil (McDaniel et al. 2013). In addition, *A.caliginosa* plays a crucial role in the enhancement of nutrients availability of plants and microorganisms (Svensson and Frieberg 2007). Vermicompost is the combination of the earthworms and the associated microorganisms. It is rich in nutrient and microbial population. This is due to the activity of gut microflora of earthworms that ingest rhizocephalic bacteria or plant growth-promoting bacteria (PGPB) including *Bacillus*

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sp, *Azotobacteria* sp, *Azospirillum* sp, *Beijernkia* sp, and *Pseudomonas* sp. PGPB is responsible for plant growth, growth hormones production, nitrogen fixation in soil and suppression of plant-pathogen (Parlakova Karagöz et al. 2016).

The new approaches are to use vermicompost amended in farming to improve soil structure and fertility, and to increase crop yields. Besides, vermicompost has biological properties and microbial diversity that face plant parasites such as root-knot nematode. Different organic wastes can be used in vermicomposting as horse wastes, poultry droppings, hay residues, and plant decomposition (Garg and Kaushils 2005).

Using biofertilizers in Egypt reduced using chemical fertilizers that cause pollutant accumulation and soil fertility reduction (Hernandez et al. 2010). Egyptian agriculture faced a huge lack of organic fertilizers that cause rise in food prices.Also, bio-fertilization technology faced a lot of obstacles such as lack of fixed data describing the negative impacts of using chemical fertilizers and less educated farmers that lack awareness on bio-fertilization (Yanni et al. 2016). The application of vermicomposting technology in Egypt is an appropriate method to convert the huge quantity of wastes that are produced into rich nutrient compost (Kamergam et al. 1999). It is worth mentioning that vermicomposting of organic waste using earthworms is one of the best methods for waste management and organic manure production (Garg et al. 2006). Tomato is the most important and famous horticulture crop in Egypt. This crop is sussceful in growing in all environments and soil types in Egypt. So, it was cultivated during three seasons. Hence, it occupies the first place among horticultural crops in production yield in Egypt (Siam and Abdelhakim 2018). The present study aimed to detect and identify the unknown species of bacteria in vermicompost amended soils with different sources of organic solid wastes. Furthermore, it also focused on the possible role of bacterial community as plant growth promotor on a tomato plant, root-knot nematodes resistant, and soil heavy metals reducers.

Materials and methods

Vermicompost preparation

A. caliginosa was collected by hand sorting from different orchard biotopes in El Beheira Governorate, Egypt. Each biodegradable wastes composed from organic waste, soil, and plant residue mixtures. Poultry litter (P), household (H), guano of bats eating fruits (F), and guano of bats eating insects (I) were used as biodegradable organic wastes. Eight pots were filled with known weights of both *A. caliginosa* (avr.0.806 g) and a mixture of organic waste, soil, and plant wastes with different ratios as shown in Table 1 for 21 weeks of the composting period.

Table 1 Biodegradable organic wastes mixture Organic waste (O): Soil (S): Plant residue (P)

Organic wastes mixture (O:S:P)	Poultry litter (P)	Household (H)		Guano of frugivorous bats (F)	Guano of insectivorous bats (I)
	2:1:1	H_1	1:2:1	1:1:2	2:1:1
		H_2	1:1:2		

Chemical parameters

From well-mixed subsamples which were taken out at the end of the vermicomposting period, Organic carbon by a muffle furnace (Jimenez and Garcia 1992), and nitrogen concentration using nitric acid H_2O_2, as recommended by Naguib (1971), were evaluated. Heavy metals' concentrations of vermibeds were determined according to EPA method (USEPA 1993).

Bacterial analysis

Soil DNA was extracted from vermicompost amended using innuSPEED Soil DNA kit (Analytik Jena, Germany). This method could eliminate the soil humic acid that inhibits the PCR reaction. DNA concentration of each sample was measured using Nanodrop ND-1000 spectrophotometer (NanoDrop Technologies, Wilmington, Delaware; USA). The bacterial 16srRNA gene was amplified using polymerase chain reaction (PCR) with universal primers $ETSS_2$-F (5′-TAACAAGGTTTCCGTAGGTGAA-3′) and $ETSS_1$–R (5′-TGCTTAAGTTCAGCGGGT-3′). The reaction was performed in a sterile 0.2 ml PCR tubes with total volume of 25µl. Amplification was carried out in a thermocycler (Bio-Rad gene cycler, VSA) with 30 cycles. PCR products were analyzed on 1.5% agarose containing 5 µg/l ethidium bromide and compared with 1 Kb ladder (100-1000bp). For sequencing, the DNA template was prepared as follows: Agarose gel blocks containing DNA fragment were cut out and purified with Promega wizard® SV Gel and the PCR Clean-up system. PCR products for sequencing were obtained with the Genome lab DTCS Quickstart kit and sequences were determined with the primers $ETSS_2$ and $ETSS_1$. Cycle sequencing products were purified with Dyna-beads® sequencing clean-up to remove unincorporated dye-labelled nucleotides. Direct sequencing was performed with Beckman Coulter CEQ 8000 Genetic Analysis system and then identified using NCBI Blast. The closest Blast results are reported below each taxon (Atlschul et al. 1997).

Seedling

After 21 week, *A. caliginosa* was separated from mature vermicomposts to evaluate their quality. Tomato seeds were planted in PVC pots with vermicomposts amended soil. After 120 days of transplantation, the plants were harvested; then plant growth and biological parameters as infection with root-knot nematodes were detected in different treated groups.

Root-knot nematodes detection

The tomato roots were infected with *Meloidogyne incognita* at the root zone when they were 10 days in both group of pots with or without vermicomposte (positive control). The root of each harvested tomato plant was washed separately and dabbed dry with tissue paper. Galling was scored from scale 0- 10 (Bridge and Page 1980); also a number of galls to each group were evaluated.

Plant growth parameters

Growth parameters were measured during and after planting tomatoes such as plant shoot length, plant root length, number of leaves and total plant biomass.

Statistical analysis

The probability (P) of variations and the significance value of the difference between two means of all tested parameters (Snedecor and Cochram 1967) were calculated .The rate of increase of different parameters was assumed and represented graphically in comparing with the positive control value, whereas the Rate of the significance of plant growth parameters was assumed by the designation of χ^2 (chi-square). Tukey's method for multiple comparisons was used to detect all pairwise differences between different treatments. For all statistical tests P-values < 0.05 were considered to be statistically significant. Data and statistical analysis were performed using Minitab version 19. All tested plots were designed in five replications.

Results and discussion

Chemical parameters of vermicompost

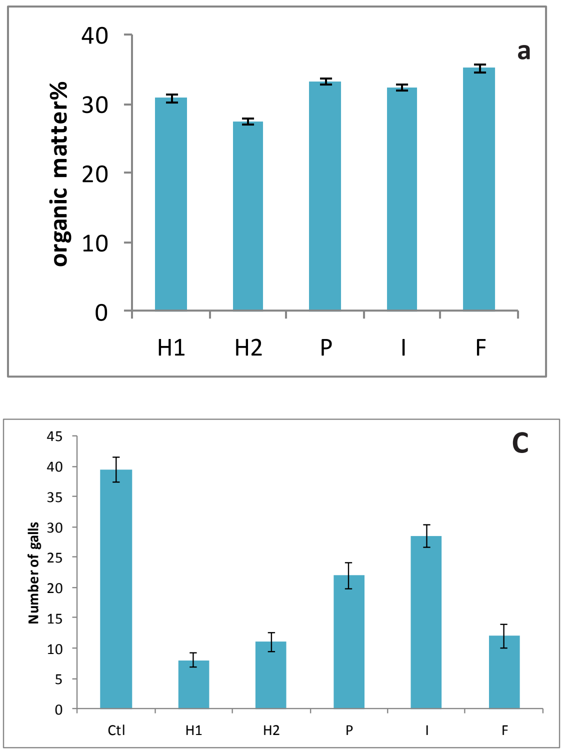
The organic solid wastes used in the present study were household, poultry litter, frugivorous and insectivorous bat guano, with different ratios combined with plant wastes and soil. The industry of poultry produces large amounts of waste materials such as wasted feed followed by dead birds, broken eggs, bedding materials. Therefore, poultry litters (P) can improve crop production when applied to agricultural land because they contain high amount of organic carbon and macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) (Bernhart and Fasina 2009). Interestingly, household waste or kitchen waste has a high pH value and organic carbon, but very trace amounts of both nitrogen and phosphorus have been detected (Albasha et al. 2015). Bat guano is known for containing all the macro and micronutrients that plants require in a natural way and therefore, it serves as a plant fertilizer, soil cleaner, fungicide, nematocide and compost activator. The use of vermicompost to improve soil fertility is becoming more popular; however, we have little knowledge of the use of bat guano as organic manure (Goveas et al. 2006). Insectivorous guano has higher levels of carbon and phosphorus than frugivorous guano which has a high nitrogen concentration (Shahack-Gross et al. 2004).

Organic-matter percentage (OM%)

After 21 weeks of vermicompsting using different types of organig wastes, the organic matter percentage (OM%) showed non-significant values ranged between 27.6% and 35.2% (Fig. 1a). The effective parameters in bioorganic wastes are, among others, organic matter (OM), C: N ratio and heavy metals that affect the quality of biofertilizer. Vermicomposting accelerated the stabilization of organic matter (OM) and greatly modified its physical and biochemical properties (Domínguez 2004). The biochemical decomposition of OM is primarily accomplished by the microbes; however, earthworms are the crucial drivers of the process by fragmenting and conditioning the substrate, and by increasing the surface area of OM available for microbial attack (Domínguez et al. 2010). In the current study, the percentage of OM ranged from 27.6 to 35.25% in different treatments of vermicompost. These findings are in contrary with Ali et al. (2015) who reported significant results of vermicomposting of cowdun g, cattle dung and poultry on OM. Also, the previous data is inconsistent with the results of Yuvaraj et al. (2019) on vermicomposting of bat guano and poultry amended soil. The values of OM in the current work cope with the standard rate of Institute of standards and industrial research of Iran **(**ISIRI 2011).

C/N-ratio

C/N ratio of all treated groups as Poultry waste (P), household (H_1 and$H_{2)}$, frugivorous guano (F), insectivorous guano (I), showed values ranged between 2.91 to 5.5 (Fig. 1b). Microorganisms require carbon and macronutrients such as N, P and K, and trace elements for their growth**.** Carbon and nitrogen compounds serve as an energy source for microbial maintenance and growth. At maturity, the vermicompost has C/N ratio ranged between 25 to 35 (Tuomela et al. 2000). The lower the ratio of C/N, the efficient the bio-fertilizer was detected. C/N ratio ranged between 2.9 to 4.9 in the present data. This ratio is inconsistent with the ratio obtained in vermicompost amended template waste (Chakole and Jasutkar 2014).



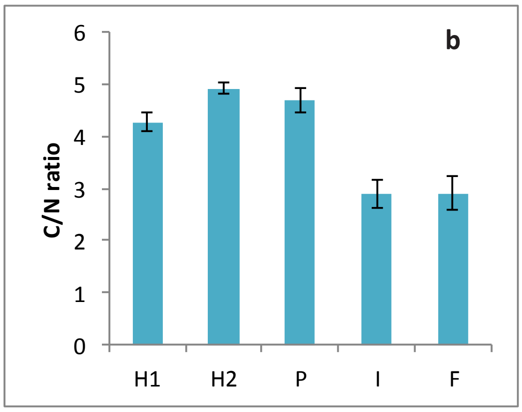


Fig. 1 a) organic matter, **b)** C:N ratio of vermicomposts after 21 weeks as affected by different and frugivorous guano (F) indicates different ratio, **c)** Effect of different ratios of biodegradable organic wastes on number of galling of tomato plants

Heavy metals

As shown in Table 2, insectivorous guano vermicompost (I) showed a significant decrease in the concentration of Cu, Cd, Fe, Mn, Ni while household vermicompost (H_2) has the lowest Ni and Zn concentrations. The treatment with poultry wastes decreased the content of Pb. Metal contamination in wastes is known for differently affecting the earthworms that affect their growth, activities, mortality and cocoon production when accumulating a certain amount of metals in their tissues. Hence, it could be transfered through the food chain to humans. Vermicompost amended insectivores guano bat showed their high reduction of heavy metal concentration compared to other biowastes. Variable values of heavy metals in biowastes could be affected by many factors. For instance, accumulation of waste pollutant in earthworms` tissue, mass reduction of OM and microbial diversity that affect metal solubility (Suthar 2008). Although frugirovorus and household biowastes showed their highest value of heavy metal contents in the current study, this may be due to food preference of earthworm and low activity of microbes. The study of Amouei et al. (2017) is in accordance with the previous results that revealed the high content of heavy metals in the household wastes. The increase in the heavy metals in the vermicompost might be due to the enhanced decomposition of organic matter by bacteria leading to an increase in the organic carbon content and dry weight reduction of the substrate (Jaybhaye and Bhalerao 2015). The microorganisms also reduce the bioavailability of heavy metals in the substrate for earthworms by bioaccumulation (actively) and biosorption (passively); therefore, the heavy metals accumulate in the substrate of the organic waste. The total heavy metal content of the final vermicompost was low in most treatments; thus, its application as a biofertilizer is presumed safe in farming using certain treatments according to (USE PA 1993). All the previous parameters have a direct effect on the growth of tomato crop, which were evaluated by biomass, leaves number, roots and shoot length increase.

Table 2 The heavy metal concentration (mg/kg) of different biosourced vermicomposts

Different biosourced vermicomposts	Cu	Cd	Fe	Mn	Ni	Pb	Zn
H1	105.55 ^{b}	29.5 ^{d}	50800^{c}	904^{d}	72.5^{c}	124.5^{b}	194.5^{c}
H2	171.5 ^{d}	17.5 ^{c}	37495 ^{b}	699^{c}	49^{a}	124 ^{b}	117^{a}
P	125 ^{c}	15 ^{b}	34385 ^{b}	570.5^{b}	53^{b}	30.5^{a}	206^{d}
I	92.5 ^{a}	4.5 ^{a}	22835^{a}	514^{a}	50.5^{a}	455.5^{d}	208.5^{c}
F	125.5 ^{c}	15.5 ^{b}	33490 ^{b}	802.5^{d}	53.5^{b}	235^{c}	129 ^{b}
Commercial Vermicompost	106.8	0.00	8.645	377	19.5	0.00	234

Means that do not share a letter are significantly different (P ≤ 0.05) according to Tukey pairwise comparisons.

Plant growth parameters

Root, shoot length, the leaves number and total plant biomass were measured to evaluate plant growth parameters of the tomato plant. the root length of different ratios of vermicompost amended soils was shown in Fig 2a and the results obtained showed that poultry waste (P), insectivorous guano (I) and frugivorous guano (F) vermicompost were increased significantly (P<0.005) compared to the control group. The Shoot length was increased significantly (P<0.05) in all treatments of household (H1, H2), poultry waste (P), insectivorous guano (I) and frugivorous guano (F) vermicompost (Fig. 2b). The leaves number was increased significantly (P<0.005) in treated groups compared to control with the following ratio frugivorous>insectivorous>household$_1$>Poultry waste vermicompost while household (H_2) showed the lowest number of leaves after 21 weeks (Fig. 2c). The highest value of total plant biomass was represented by insectivorous guano vermicompost (Fig. 2d). In the current study, the plant biomass reached their maximum value with insectivorous biowastes. While shoot length and leaves number showed their maximum growth in frugivorous biowastes, Poultry litter had a great effect on root length of tomato. The enhancement of tomato growth could be attributed to the abundance of phytohormones in vermicompost amended biowastes and the activity of microbes (Nogales et al. 2005). The high concentration of vermicompost in variable ratios of biodegradable wastes could cause an excess amount of soil nutrient (Eghball 2003). Hence, it could affect tomato growth parameters negatively due to phytotoxicity and eutrophication (Tucker 2005).

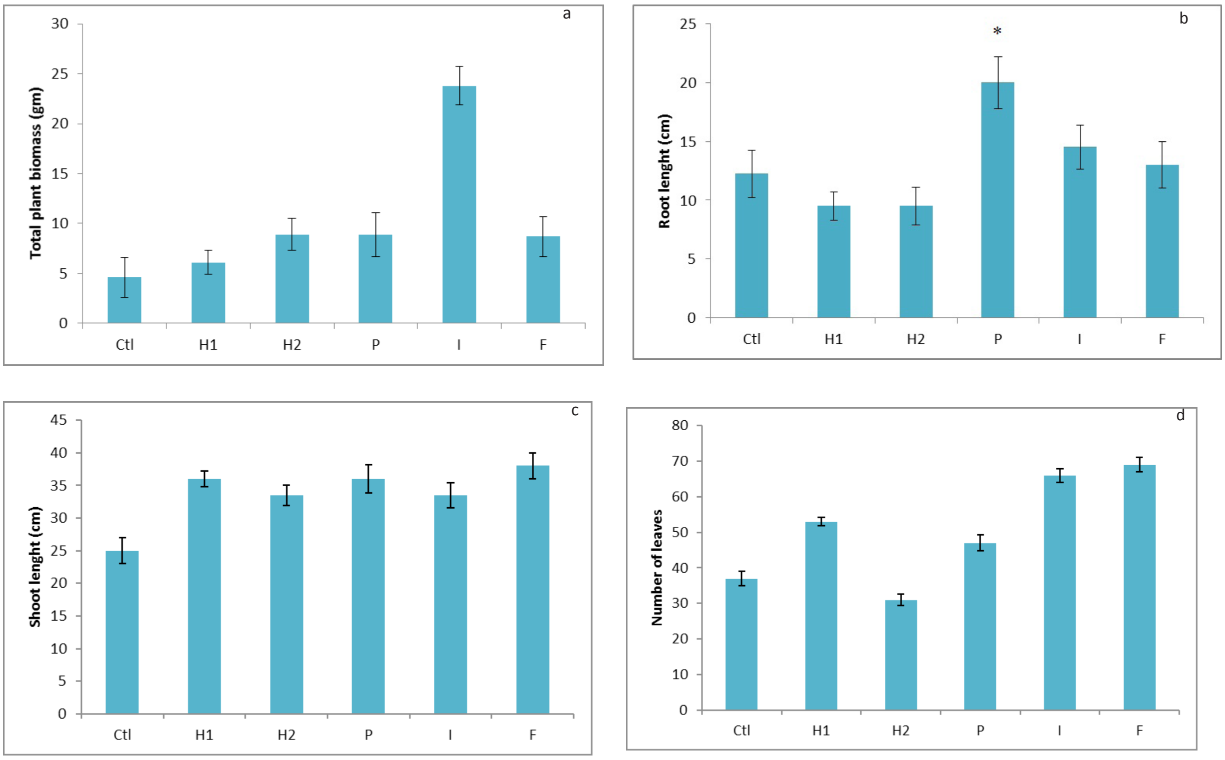


Fig. 2 Mean **a)** total plant biomass, **b)** root length, **c)** shoot length, **d)** number of leaves of root knot nematode-inoculated tomato plants in pots as affected by different vermicompost ratios compared with Control (Ctl)

Biological parameters

Nematode resistance

After nematode infection, a number of galls per each root were counted to indicate the rate of infection (Table 3). The results obtained showed that poultry (P) and household (H_1) vermicompost amended soil has the best resistance to root-knot nematodes with a class (2), which has clearly visible small knots. Frugivorous (F) and insectivorous (I) guano vermicompost showed resistance of root knots nematode with class 3, with large knots. Household (1:1:2) vermicompost is more susceptible to infection with root-knot nematode than the other treated groups (Fig 1C). Earlier studies suggested that organic amendments could suppress plant-parasitic nematodes due to root defence system (Chauvin et al. 2015). In the present work, biodegradable organic wastes with different ratios reduced the number of root-knot nematodes gallingby altering -chemical parameters of the soil. Hence, alteration of nitrogen content and root herbivorous had a critical role in nematode resistance (Awmack and Leather 2002; Kraus et al. 2004). The results obtained by Xiao et al. (2016) matched the previous data, who stated that vermicompost could modulate primary and secondary plant metabolites.

Table 3 Biodegradable organic soild waste classification according to root-knot nematode rating chart (Bridge and page 1980)

Organic waste mixture	Ratio	Class
H1	1:2:1	2
H2	1:1:2	4
P	2:1:1	2
F	1:1:2	3
I	2:1:1	3

0: No galling, 1: Few small knots that are difficult to find, 2: Clearly visible small knots, 3: Some large knots visible, 4: Large knots predominant

Bacterial diversity and phylogenetic relationships

The soil is very complicate and provides different microbial environments, which are facilitated by molecular tools (Lauber et al. 2009). In the current study, we investigated the microbial biodiversity of biodegradable wastes amended and their effects on the quality of produced vermicompost. The dominant bacterial species in different vermicompost were *Archangium gephyra*, *Corynebacterium glutamicum*, *Clostridium uitunense*, *Azospirillum sp*. and *Bacillus sp*. After PCR amplification, one band of 1000 bp Mwt has appeared (Fig. 3a). The bacteria were identified for each query, as summarized in Table 4. The phylogenetic analysis indicates the query of sample poultry vermicompost sample P that appeared to be in the same clade with *Archangium gephyra* strain DSM 2261, at 50% bootstrap value (Fig. 3b). Moreover, insectivorous guano vermicompost I query was homologous with a sequence with Genbank accession no. EU520168.1 which were *Corynebacterium glutamicum* with the similarity of 138% BLAST value (Fig. 3C). The phylogenetic analysis was conducted in sequencing regions of samples frugivorous guano vermicompost F that was homologous to the sequence of GenBank accession no. LT669839.1 which were *Clostridium ultunense* with BLAST value 42.8% (Fig. 3D). Finally, the query of household vermicompost H_1 and H_2 appeared to be in the same clade with *Azospirillum sp*. and *Bacillus sp.* at 62.6 and 48.2% BLAST value, respectively (Figs 3E and 3F).

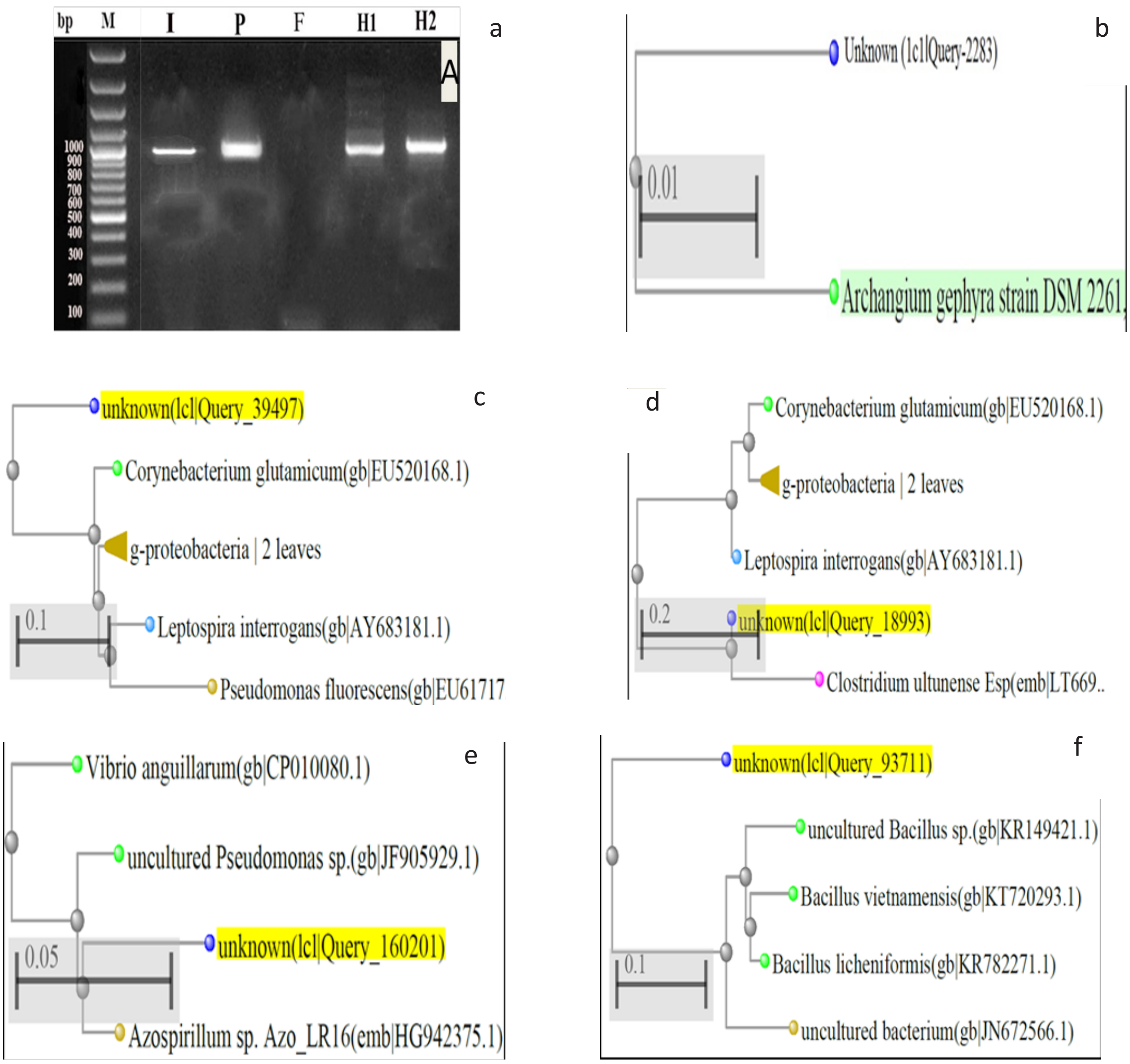


Fig. 3 **a)** PCR amplification of different biosourced vermicompost using ETTS1 and ETTS2 primers. M; DNA ladder (100:1000bp), P: poultry waste, H: household, (1 and 2); Neighbour joining tree of query, **b)** P based on 16S rRNA gene sequences. Scale Bar 0.01 indicates sequence divergence, **c)** I, Scale Bar 0.1, **D)** F, Scale Bar 0.2, **E)** H_1, Scale Bar 0.1, **F)** H_2, Scale Bar 0.05

Table 4 Identification of vermicompost bacterial strains based on 16S rRNA sequence and GenBank database (BLASTN 2.6.1+) (Altschul et al. 1997)

Query	GenBank	Strain	Similarity (BLAST)	E-value
P	CP011509.1	*Archangium gephyra* strain DSM 2261	50.0	0.021
	CP016020.1	*Bacillus sp.* Alg07	46.4	0.26
	LT629689.1	*Pseudomonas extremaustralis* strain DSM 17835	44.6	0.91
	CP017015.1	*Spiroplasma helicoides* strain TABS-2,	44.6	0.91
	CP002829.1	*Thermodesulfo bacterium* geofontis OPF15	44.6	0.91
I	EU520168.1	Corynebacterium glutamicum	138	0.064
	CP011464.1	Vibrio anguillarum strain PF7	131	0.81
	AY683181.1	Leptospira interrogans strain	118	0.064
	CP010080.1	Vibrio anguillarum strain PF4	113	0.064
	EU617172.1	Pseudomonas fluorescens clone 2	60.8	0.81
F	EU520168.1	Corynebacterium glutamicum isolate NW539B	95.1	0.005
	CP011464.1	Vibrio anguillarum strain PF7	87.8	0.064
	AY683181.1	Leptospira interrogans strain	82.4	0.018
	CP010080.1	Vibrio anguillarum strain	66.2	0.81
	LT669839.1	[Clostridium] ultunense Esp isolate	42.8	2.8
H_2	EU520168.1	Corynebacterium glutamicum isolate NW539B	75.2	0.064
	CP011464.1	Vibrio anguillarum strain PF7	66.2	0.064
	CP010080.1	Vibrio anguillarum strain PF4	62.6	0.064
	HG942375.1	Azospirillum sp. Azo_LR16	62.6	0.81
	JF905929.1	Uncultured Pseudomonas sp	59.0	0.005
H_1	KR149421.1	Uncultured Bacillus sp. clone HL-B82	51.8	0.005
	JN672566.1	Uncultured bacterium clone GBO51O2eO5	50.0	0.018
	CP011464.1	Vibrio anguillarum strain PF7	48.2	0.064
	KT720293.1	Bacillus vietnamensis	48.2	0.064
	KR782271.1	Bacillus licheniformis	48.2	0.064

The phylogenetic analysis of poultry vermicompost (P) revealed that *A. gephyra* was the dominant genus. This bacterial type is characterized mainly by the high ability of nitrogen fixation explained by low C/N ratio of poultry wastes (Kielak et al. 2016). It may be considered as Pb reducing bacteria in poultry amended in accordance with Mateos et al. (2006). From all the previous data, treatment with poultry vermicompost (P) has a great effect on organic matter, C/N ratio, total plant biomass, and Pb reduction. Moreover, the resistance of root-knot nematode (class 2) was obvious. *Clostridum sp* was the dominant bacteria discovered in frugivorous vermicompost in the current study, which showed remarkable results in zinc reduction. This data may be due to the expulsion of this metal (Zn) from the cytoplasm through the cell membrane into the environment by *Clostridum sp* bacteria. The relationship between microbes and the reduction of heavy metals was explained by Parthasarathi and Ranganathan (2002) by increasing the microbial population and its activity, then by forming humic acid, which chelates certain elements that are available for plant uptakes, such as Zn, Mn, and Fe. *Clostridum* sp has evolved three general metal tolerance mechanisms, one of which by expelling to the environment mediates resistance to Zn and Cd (Silver and Phung 1996). It was worth mentioning that *Clostridum* sp is a nitrogen fixer and cellulose digester (Skinner 1971), so based on these investigations the tomato crops in the present study exhibited high plant biomass may be due to high organic matter in the biosourced soil treated with frugivoros vermicomposting. This finding was in agreement with Eilers et al. (2010), and Fierer et al. (2007) who reported that a wide variety of bacteria particularly belonging to Actinobacteria, Proteobacteria and Bacteroidetes degrade organic molecules, amino acids, sugars, cellulose, lignin and chitin, which higher organisms cannot degrade and convert into organic material.

Interestingly, *Corynebacterium glutamicum* bacteria were detected in insectivorous vermicompost, which showed a decline in the heavy metals' concentrations (Cu, Cd, Fe, Mn, Ni) during vermi-processing. Mateos et al. (2006) referred that exposure of microbe to heavy metals has led to the evolution of mechanisms for detoxification. The mechanism was explained by Harrison et al. (2007) in which metals bind to cell constituents of bacteria.

Household vermicompost (H_1) contained bacteria of Bacillus type, which was the most widely recognized species. In accordance with Ryckeboer et al. (2003), *Bacillus* spp has obviously caused systemic resistance induction (ISR) to the pathogen spectrum abroad in host plants (Kloepper et al. 2004). This result was evidenced by its ability to tolerate nematode infection in the current data. This strain has been demonstrated in tomato, cucumber and pepper field trails that promote protection against leaf spotting fungal and bacterial pathogens, systemic viruses, a crown rotting fungal disease, root-knot nematodes, and stem fungal blight pathogen (Idris et al. 2002). Mirac et al. (2006) assumed that polypeptide antibiotics made up in Bacillus spp played an aggressive role in plant-pathogen protection.

Conclusion

It was concluded that using different organic biodegradable wastes with variable bacterial diversity could reduce heavy metal contents compared to raw material in the start product (SF 1), increased nutrient contents, enhanced plant growth parameters and then increased resistance to root-knot nematodes. The most efficient organic amended vermicompost was insectivorous biowaste.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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References

Adhikary S (2012) Vermicompost, the story of organic gold: A review. Agric Sci 3: 905-917. https://doi.org/10.4236/as. 37110

Albasha R, El Siddig A, El Nour M (2015) Comparative study on the metabolic constituents and genetic profile of *Jatropha glauca* and *Jatropha curcas*. J Biol Chem Res 32: 1010-1018

Ali U, Sajid N, Khalid A, Riaz L, Rabbani MM, Syed JH, Malik RN (2015) A review on vermicomposting of organic wastes. Environ. Prog. Sustain. Energy 34: 1050-1062. https://doi.org/10.1002/ep.12100

Altschul SF, Madden TL, Schäffer AA, Zhang J, Zhang Z, Miller W, Lipman DJ (1997) Gapped BLAST and PSI-BLAST: A new generation of protein database search programs. Nucleic Acids Res 25: 3389-3402. https://doi.org/10.1093/nar/25.17.3389

Amouei A, Yousefi Z, Khosravi T (2017) Comparison of vermicompost characteristics produced from sewage sludge of wood and paper industry and household solid wastes. J Environ Health Sci Eng 15: 1-6. https://doi.org/10.1186/s40201-017-0269-z

Arancon N, Edwards C, Bierman P, Welch C, Metzger J (2004) Influences of vermicomposts on field strawberries: Effects on growth and yields. Bioresour Technol 93: 145-153. https://doi.org/10.1016/j.biortech.2003.10.014

Awmack CS, Leather SR (2002) Host plant quality and fecundity in herbivorous insects. Annu Rev Entomol 47: 817–844. https://doi.org/10.1146/annurev.ento.47.091201.145300

Bernhart M, Fasina OO (2009) Moisture effect on the storage, handling and fow properties of poultry litter. Waste Manag 29: 1392–1398.

https://doi.org/10.1016/j.wasman.2008.09.005

Bridge J, Page S (1980) Estimation of root-knot nematode infestation levels on roots using a rating chart. Int J Pest Manag 26: 296-298. https://doi.org/10.1080/09670878009414416

Chakole PS, Jasutkar D (2014) Comparative study of nirmalya solid waste treatment by vermicomposting and artificial aeration composting. Current World Environment 9: 412-420. http://dx.doi.org/10.12944/CWE.9.2.23

Chauvin C, Dorel M, Villenave C, Roger-Estrade J, Thuries L, Risède JM (2015) Biochemical characteristics of cover crop litter affect the soil food web, organic matter decomposition, and regulation of plant-parasitic nematodes in a banana field soil. Appl Soil Ecol 96: 131–140. https://doi.org/10.1016/j.apsoil.2015.07.013

Decaëns T, Margerie P, Renault J, Bureau F, Aubert M, Hedde M (2011) Niche 581 overlap and species assemblage dynamics in an ageing pasture gradient in north-western 582 France. Acta Oecol 37: 212-219. https://doi.org/10.1016/j.actao.2011.02.004

Domínguez J (2004) State of the art and new perspectives on vermicomposting research, In: Edwards CA (Ed.) Earthworm Ecology, CRC Press, Boca Raton, Florida, pp. 401-424. http://dx.doi.org/10.1201/9781420039719.ch20

Domínguez J, Aira M, Gómez-Brandón M (2010) Vermicomposting: Earthworms enhance the work of microbes, In: Microbes at work: From wastes to resources, Insam H, Franke-Whittle I, Goberna M, (Eds.) 93-114, Springer, ISBN 978-3-642- 04042-9, Heidelberg, Germany

Eghball B (2003) Leaching of phosphorus fractions following manure or compost application. Commun Soil Sci Plant Anal 34: 2803–2815. https://doi.org/10.1081/CSS-120025207

Eilers KG, Lauber CL, Knight R, Fierer N (2010) Shifts in bacterial community structure associated with inputs of low molecular weight carbon compounds to soil. Soil Biol Bioch 42: 896-903. https://doi.org/10.1016/j.soilbio.2010.02.003

Fierer N, Bradford MA, Jackson RB (2007) Toward an ecological classification of soil bacteria. Ecology 88: 1354-1364. https://doi.org/10.1890/05-1839

Garg VK, Kaushik P (2005) Vermistablisation of solid textile mill sludge spiked with poultry droppings by an epigeic earthworm Eisenia foetida. Bioresour Technol 96: 1063–1071. https://doi.org/10.1016/j.biortech.2004.09.003

Garg V, Kaushik P, Dilbaghi N (2006) Vermiconversion of wastewater sludge from textile mill mixed with anaerobically digested biogas plant slurry employing Eisenia foetida. Ecotox Environ Saf 65: 412-419. https://doi.org/10.1016/j.eco env.2005.03.002

Goveas SW, Miranda EC, Seena S, Sridhar KR (2006) Observations on guano and bolus of Indian flying fox, Pteropus giganteus. Current Science 90: 160-162

Harrison JJ, Ceri H, Turner RJ (2007) Multimetal resistance and tolerance in microbial biofilms. Nat Rev Microbiol 5: 928-938. https://doi.org/10.1038/nrmicro1774

Hernandez A, Borquez A, Alcaino L, Morales J, Dantagnan P, Saez P (2010) Effects of autoclaving on the apparent digestibility coefficient of dehulled pea seed meal (*Pisum sativum* L.) in rainbow trout (*Oncorhynchus mykiss* W.). Cien Inv Agric 37(3): 39-46. https://doi.org/10.4067/S0718-16202010000300003

Idris EE, Makarewicz O, Farouk A, Rosner K, Greiner R, Bochow H, Richter T, Borriss R (2002) Extracellular phytase activity of bacillus amyloliquefaciens FZB45 contributes to its plant-growth-promoting effecta. Microbiol 148: 2097-2109. https://doi.org/10.1099/00221287-148-7-2097

ISIRI: Institute of standards and industrial research of Iran (2011) Vermicompostt compost physical chemical characteristics. http://www.isiri.org/Portal/Home/Default.aspx?CategoryID=5f6bbf1b-ac23–4362 a3099ee95a439628 no 13724

Jaybhaye M, Bhalerao S (2015) Effect of vermiwash on the growth parameters of *Solanum melongena* L.(Brinjal Plant). Int J Curr Res Biosci Plant Biol 2: 24-29

Jimenez EI, García VP (1992) Relationships between organic carbon and total organic matter in municipal solid wastes and city refuse composts. Bioresour Technol 41: 265-272. https://doi.org/10.1016/0960-8524(92)90012-M

Kamergam N, Alagumalai K, Daniel T (1999) Effect of vermicompost on the growth and yield of green gram (*Phaseolus aurus* Roxb.). Trop Agric 76: 143–146

Kielak AM, Barreto CC, Kowalchuk G, van Veen JA, Kuramae EE (2016) The ecology of acidobacteria: Moving beyond genes and genomes. Front Microbiol 7. https://doi.org/10.3389/fmicb.2016.00744

Kloepper JW, Ryu CM, Zhang S (2004) Induced systemic resistance and promotion of plant growth by Bacillus spp. Phytopathol 94: 1259-1266. https://doi.org/10.1094/PHYTO.2004.94.11.1259

Kostecka J, Garczyńska M, Podolak M, Pączka G, Kaniuczak J (2018) Kitchen organic waste as material for vermiculture and source of nutrients for plants. Jour Ecol Eng 19(6): 267–274. https://doi.org/10.12911/22998993/99691

Kraus T, Zasoski R, Dahlgren R (2004) Fertility and pH effects on polyphenol and condensed tannin concentrations in foliage and roots. Plant Soil 262: 95–109

Lauber CL, Hamady M, Knight R, Fierer N (2009) Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. Appl Environ Microbiol 75: 5111-5120. https://doi.org/10.1128/AEM.00335-09

Mateos LM, Ordóñez E, Letek M, Gil JA (2006) Corynebacterium glutamicum as a model bacterium for the bioremediation of arsenic. Int Microbiol 9: 207-215

McDaniel JP, Stromberger ME, Barbarick KA, Cranshaw W (2013) Survival of Aporrectodea caliginosa and its effects on nutrient availability in biosolids amended soil. Appl Soil Ecol 71: 1–6. https://doi.org/10.1016/j.apsoil.2013.04.010

Mirac Y, Haluk S, Yavuz B (2006) Antimicrobial activities of some *Bacillus* spp. strains isolated from the soil. Microbiol Res 161(2):127-131. https://doi.org/10.1016/j.micres.2005.07.001

Naguib M (1971) On the colorimetry of nitrogen components of plant tissues. Bulletin of Faculty of science Cairo University 43:1–5

Nogales R, Cifuentes C, Benitez E (2005) Vermicomposting of winery wastes: A laboratory study. J Environ Sci Health 40: 573–659. https://www.tandfonline.com/doi/abs/10.1081/PFC-200061595

Okon Y (1994) Azospirillum/plant associations. CRC Press, Boca Raton, Florida, USA. 175 pp. https://onlinelibrary.wiley.com/doi/10.1002/bdd.2510120409

Parlakova Karagöz F, Dursun A, Kotan R, Ekinci M, Yildirim E, Mohammadi P (2016) Assessment of the effects of some bacterial isolates and hormones on corm formation and some plant properties in saffron (Crocus sativus L.). Ankara University Journal of Agricultural Sciences 22(4):500-511. http://dx.doi.org/10.1501/Tarimbil_0000001408

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

Ryckeboer J, Mergaert J, Coosemans J, Deprins K, Swings J (2003) Microbiological aspects of biowaste during composting in a monitored compost bin. J Appl Microbiol 94: 127-137. https://doi.org/10.1046/j.1365-2672.2003.01800.x

Shahack-Gross R, Berna F, Karkanas P, Weiner S (2004) Bat guano and preservation of archaeological remains in cave sites J Archaeol Sci 31: 1259-1272. https://doi.org/10.1016/j.jas.2004.02.004

Siam G, Abdelhakim T (2018) Analysis of the tomato value chain in Egypt and establishment of an action plan to increase its efficiency. Research Report CIHEAM-IAMM, pp 118

Silver S, Phung LT (1996) Bacterial heavy metal resistance: New surprises. Annual Reviews in Microbiology 50: 753-789. https://doi.org/10.1146/annurev.micro.50.1.753

Skinner F (1971) Isolation of soil Clostridia, In: Shapton DA, Board RG (Eds.). Isolation of anaerobes. Academic Press Inc., New York, USA, pp 57-80

Snedecor GW, Cochran WG (1967) Statistical methods 6th edition. The Iowa State University, Iowa, USA. pp 593. https://doi.org/10.2307/2985653

Suthar S (2008) Bioconversion of post harvest crop residues and cattle shed manure into value-added products using earthworm Eudrilus eugeniae Kinberg. Ecological Engineering 32: 206-214. https://doi.org/10.1016/j.ecoleng.2007.11.002

Svensson K, Friberg H (2007) Changes in active microbial biomass by earthworms and grass amendments in agricultural soil. Biol Fert Soils 44(1): 223–228. https://doi.org/10.1007/s00374-007-0200-3

Tucker P (2005) Co-composting paper mill sludges with fruit and vegetable wastes. Dissertation, University of Paisley, Paisley. https://www.tandfonline.com/doi/abs/10.1080/1065657X.1999.10701961

Tuomela M, Vikman M, Hatakka A, Itävaara M (2000) Biodegradation of lignin in a compost environment: A review. Bioresour Technol 72(2): 169-183. https://doi.org/10.1016/S0960-8524(99)00104-2

USEPA (Environmental Protection Agency) (1993) Standards for disposal sewage sludge. Code of federal Regulations.Title 40. Federal Register 58 (19 February 1993): 9248. https://doi.org/10.1007/978-1-4613-1959-7_9

Xiao H, Smeekens M, Wu R (2016) Quantification of tunicamycin-induced protein expression and N glycosylation changes in yeast. Analyst 141(12): 3737-3745. https://doi.org/10.1039/C6AN00144K

Yanni Y, Zidan M, Dazzo F, Rizk R, Mehesen A, Abdelfattah F (2016) Enhanced symbiotic performance and productivity of drought stressed common bean after inoculation with tolerant native rhizobia in extensive fields. Agric Ecosyst Environ 232: 119–128. https://doi.org/10.1016/j.agee.2016.07.006

Yuvaraj A, Thangaraj R, Maheswaran R (2019) Decomposition of poultry litter through vermicomposting using earthworm Drawida sulcata and its effect on plant growth. Int J Environ Sci Technol 16: 7241–7254. https://doi.org/ 10.1007/s13762-018-2083-2