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ORIGINAL PAPER

Sustainable agriculture and soil enrichment through diverse organic vermicompost synthesized from different organic waste

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Abstract
This study investigates the potential of vermicompost, derived from five types of organic waste, collected from different sites at Kurukshetra University, Kurukshetra, Haryana, India to improve soil health and crop yield. Six types of vermicompost were made, one for each type of waste and one containing a mixture of all types of waste in equal proportion. The composting process involved the use of *Eisenia fetida* to facilitate the decomposition. The mixture of waste takes 45–50 days for a complete transformation into vermicompost. Physicochemical analysis of the resulting vermicompost revealed a drop in pH, organic carbon, and a rise in electrical conductivity. Significant changes have been noticed in the C: N and C: P ratios, as well as increases in nitrogen, availability of phosphorus, and potassium. The vermicompost synthesized using a mixture of waste is found to be more enriched and agronomically beneficial as compared to others. Subsequently, a pot experiment was conducted using a completely randomized block design to evaluate the effects of mixed vermicomposts on soil properties and plant growth. *Spinacia oleracea* (spinach) and *Brassica nigra* (mustard) plants were cultivated and results indicated that vermicompost treatments significantly enhanced nutrient availability compared to the control. The plants grown in mixed vermicompost-amended soils exhibited superior growth parameters. The study emphasizes the significance of specialized waste management techniques for creating vermicompost. While addressing waste management issues, implementing such a sustainable plan not only diverts organic waste but also improves soil health, thus providing a sustainable crop production technique to the farmers.

Keywords Waste management · Green campus · Earthworm · Micronutrients · Pot experiment · Physio-chemical analysis

Introduction

The expression "waste to wealth" originated from the process of transforming waste into goods that may be used in multiple applications (Kumar and Agrawal 2020; Gour and Singh 2023). As a result, there has been a growing interest in finding innovative and eco-friendly solutions for waste management and agricultural practices. One of the key challenges faced by urban areas and educational institutions like Kurukshetra University is the proper disposal of organic waste generated on their premises. Organic waste, which includes kitchen scraps, garden trimmings, and agricultural residues, has the potential to become a valuable resource

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through the process of vermicomposting (Singh et al. 2011; Tammam et al. 2023; Enebe and Erasmus 2023). Vermicomposting is a natural and eco-friendly method that involves the use of earthworms mainly *Eisenia fetida* (red worms) or *Lumbricus rubellus* to convert organic waste into nutrient-rich vermicompost (Thakur and Kumar 2021; Dey Chowdhury et al. 2023).

Vermicompost, often referred to as "black gold," is the end product of vermicomposting. The economic and commercial potential of vermicompost lies in its multifaceted benefits for agriculture, waste management, and environmental conservation (Gupta et al. 2022; Thirunavukkarasu et al. 2022; Suhani et al. 2023). Synthesis of vermicompost from organic wastes provides numerous benefits such as (i) waste diversion and management, (ii). low-cost production, (iii). high-quality organic fertilizer, (iv). market demand and potential, (v). adopting vermicomposting on a large scale, can contribute significantly to environmental conservation. Reduced methane emissions from landfills, minimized chemical fertilizer use, and enhanced soil health all contribute to mitigating climate change and promoting sustainable land use practices. The sustainable approach towards organic waste minimization is better for the environment (Bhukal et al. 2022; Mittal et al. 2023; Sharma et al. 2023a, 2024a, b, c; Solanki et al. 2024) and human health (Kumar et al. 2023; Sharma et al. 2023b).

The judicious use of organic wastes to form vermicompost represents a win–win situation for the environment, agriculture, and the economy. By harnessing the potential of earthworms to transform organic waste into a valuable resource, researchers can foster sustainable waste management practices, enhance agricultural productivity, and contribute to a greener and healthier planet (Zucco et al. 2015; Alshehrei and Ameen 2021; Rupani et al. 2023). By converting organic waste into nutrient-rich vermicompost, educational institutes like Kurukshetra University can enhance its campus environment while reducing its ecological footprint. The economic benefits stemming from cost savings on chemical fertilizers embrace this sustainable approach. Universities have the opportunity to set an example as a sustainable campus that prioritizes environmental responsibility. By promoting vermicomposting and eco-friendly practices, the university can contribute positively to the environment, inspire its community, and encourage others to follow suit. The journey towards a greener and more prosperous future begins with a single step—the transformation of organic waste into vermicompost.

This present study explores the judicious use of five types of organic wastes from the Kurukshetra University campus to form vermicompost. The objective of this work was to investigate the sustainability of vermicomposting of diverse wastes collected from academic institutions and the effects on soil nutrition with agronomic value. Improvements in several physicochemical, biological, and development characteristics, as well as micro and macronutrient assessment, were measured in the study. The present study was carried out from 15 Oct 2019 to 15 Feb 2020 at the Institute of Environmental Studies, Kurukshetra University, Kurukshetra, Haryana, India.

Materials and methods

Experimental setup for vermicomposting

Collection sites for different types of waste

The study was conducted at the cage house of the Institute of Environmental Studies, Kurukshetra University, Kurukshetra, Haryana, India (29.9556° N, 76.8195° E). The cage house was covered with a plastic sheet to protect earthworms and plants from rain, fog, and severe cold. It also helped maintain and regulate the favorable temperature for the survival of the earthworms. Five types of organic wastes were selected and procured from different sites for making vermicompost. Leaf litter was collected from various places at Kurukshetra University like sides of the University roads, gardens, etc. Vegetable waste was collected from the Pratap Bhawan (Hostel) of Kurukshetra University. Fruit and Tea waste was collected from the University market. Flower waste was collected from the Durga Temple, near the main gate of Kurukshetra University. Figure 1 represents the geographical map of the University location and collection sites.

Partial digestion of organic waste

Each type of organic waste was grinded separately into fine particles mechanically by using a mixer grinder. Before introducing the earthworms, the wastes were partially decomposed anaerobically for 15 days by adding cow dung and maintaining adequate moisture content to fasten the decomposition process as well as to form a congenial environment for the survivability of the earthworms. Figure 2 represents the collection and processing of wastes and earthworms used in the study. After 15 days, the partially decomposed wastes were introduced into large plastic containers lined with dry grass from the sides and bottom. For each type of waste, there are two large plastic containers or vermi beans. So, in total there are 12 plastic containers, ($5 \times 2 = 10$) ten for five types of waste and ($2 \times 1 = 2$) two for mixed vermicompost in which all types of wastes are mixed in equal proportion. An equal amount of cow dung was added to each container to enhance the process of vermicompost formation.

Fig. 1 Geographical map representing the University location and collection sites

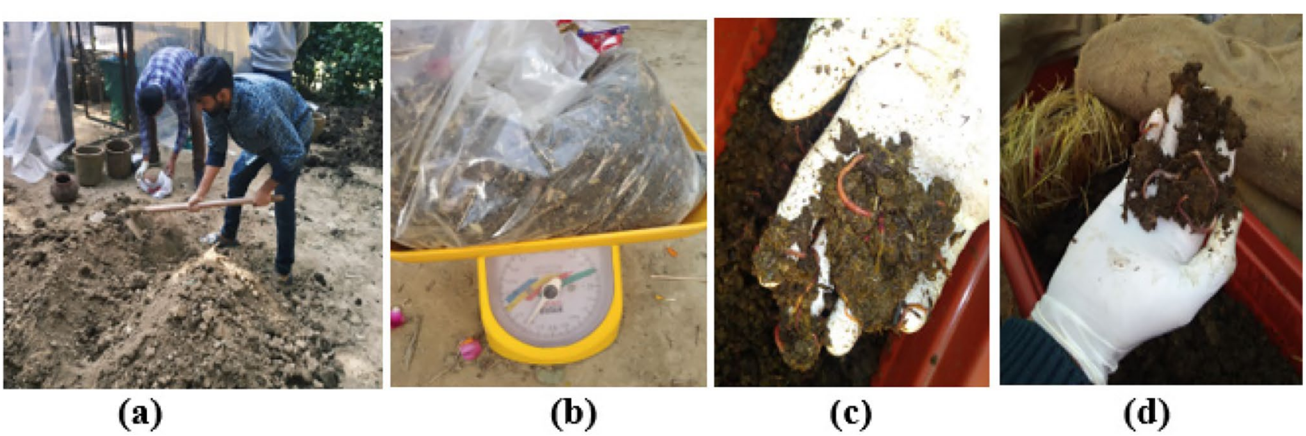


Fig. 2 **a** Mixing of soil and cow dung, **b** measuring the weight of tea waste, **c** and **d** *Eisenia fetida* used in the experiment

Introduction of earthworms for vermicompost formation

Thereafter, the earthworms were introduced into each container. *Eisenia fetida* species of earthworm was used for the formation of vermicompost from organic waste. 100–120 earthworms were equally distributed in each vermi bean containing different types of organic waste. The earthworm was procured from Shubham vermicompost, Murthal, Sonipat, Haryana, India. The activity of the earthworms was regularly monitored. Also, the time taken for the formation of each type of manure and the increase in the number of earthworms was noted. Each container contains an equal amount of cow dung added to enhance the process of vermicompost formation. Using *Eisenia fetida* (commonly known as red wiggler worms) in vermicompost formation offers several benefits due to their unique biological and ecological characteristics, such as faster decomposition, high nutrient content, improved soil structure, microbial activity enhancement, pH regulation, reduced greenhouse gas emissions, low space requirements, low odour, and noise (Gupta et al. 2022; Mago et al. 2022; Dey Chowdhury et al. 2023).

Physio-chemical and nutrient analysis of vermicompost

For the measurement of pH and EC, Whatman no. 42 filter paper was used to filter the extract of vermicompost and distilled water (1w:10v), which was then evaluated using a digital pH and EC meter. TOC was determined using the dry combustion method as reported by a previous study (Nelson and Sommers 1983). The total kjeldahl nitrogen (TKN) content was examined using the micro-Kjeldahl digestion technique(Bremner and Mulvaney 1982). Total available phosphorus (TAP) values were calculated using the ammonium molybdate method (spectrophotometric analysis after acid digestion). Total potassium (TK) values were examined utilizing acid-digested samples by flame photometer. values for available phosphorus, kjeldahl nitrogen, and organic carbon were used to calculate the C:N and C:P ratios (stability parameters). To determine micronutrients (Cu, Fe, Mn, Zn) the di-acid digest of nitric acid and perchloric acid was made at a ratio of 9v:1v and analyzed utilizing ICPMS (Thermo Scientific Model iCAPQc).

Analysis of plant growth

A pot experiment was performed in a completely randomized block design to compare different physiochemical as well as nutritional statuses of different types of vermicompost. *Spinacia oleracea* (spinach) and *Brassica nigra* (mustard) were the two test plant species selected for the experiments. The selected plants have a short life span and can be grown easily in winter with high nutritional values. Seeds of spinach and mustard were purchased from the Kurukshetra market. Seeds were sterilized before sowing. The following treatments were maintained:

Treatment 1: control (having soil and cow dung in a ratio of 3:1).

Treatment 2: mixed vermicompost (generated from a mixture of all types of wastes) was added to the control soil in a ratio of 4:1 (4 soil mixture and 1 mixed vermicompost).

Each treatment had four replicates with 5 plants in each pot. Plants (spinach and mustard) were grown for 30 days. After 30 days, plants were harvested, rinsed twice under running tap water, and then with double distilled water to remove the soil particles. Plant material was separated into roots and shoots to analyze various morphological and physiological characteristics of both the test plant species. The number of leaves and branches was counted manually, leaf area was calculated using the graph paper method, stem and root length using the mathematical ruler (15 cm length), chlorophyll index using chlorophyll meter, relative water content (RWC) was calculated using Eq. 1.

$$RWC = \frac{fresh\ weight - dry\ weight}{turgid\ weight - dry\ weight} \times 100 \quad (1)$$

Physio-chemical analysis of soil samples was performed using the same methods as discussed for vermicompost in section "Physio-chemical and nutrient analysis of vermicompost". Figure 3 represents the complete process of collection of organic waste and then synthesis of vermicompost, pot experiment in flow chart form.

Results and discussion

Synthesis of vermicompost

All types of wastes take different time to be transformed into vermicompost and different amounts of vermicompost are generated from all types of wastes. Figure 4 represents the setup used for the synthesis of all types of vermicompost. Table 1 represents the time taken for vermicompost formation and the quantity of vermicompost generated. It is visible from Table 1 that tea and litter waste take the minimum and maximum time respectively. While the mixture of wastes takes an average time (45–50 days). The highest amount (6 kg) of vermicompost was generated from litter and vegetables and the minimum amount (4 kg) from tea and flower waste. 5 kg of vermicompost generated from a mixture of wastes. Figure 5. represents the final form of vermicompost ready for pot experiments.

Changes in physio-chemical parameters (pH, EC, and TOC)

The pH of the waste degradation process is an important component in deciding its fate. pH levels of 6–8 (near neutral) are thought to be suitable for the process of mineralization and waste material stabilization during

Fig. 3 Collection of different types of waste for vermicompost formation, followed by pot experiment

vermicomposting (Mago et al. 2022). In the current investigation, a decrease in pH was detected at the end of the breakdown process. The overall pH declined by about 12% maximum in flower waste. The declining nature of pH by different vermicompost is shown in Table 2.

The initial feedstocks' electric conductivity (EC) ranged from 2.26 to 3.72 mS/cm, while vermicompost's EC ranged from 3.12 to 3.84 mS/cm. Table 2 represents the physicochemical parameters of diverse Initial organic waste and final vermicompost from different vermi beans. An increase in EC could be caused by the conversion of non-available nutrients into more available forms, as well as the formation of salts, ammonium, and inorganic ions. The EC of a vermicompost is an important aspect in determining whether it is suitable for agricultural use. The EC of the vermicompost produced in this study was within the EC limitations (< 4mS/cm) and can be utilized as organic fertilizer (Lukashe et al. 2019).

The earthworms and microorganisms absorb organic carbon, reducing the amount of total organic carbon (TOC) throughout the composting process. The TOC in various vermi beans had declined by 10.16 to 26.52% at the final stage of the experiment in the current research. As organic matter mineralizes, TOC reduction is observed during the vermicomposting of vegetable market trash supplemented with rice straw (Hussain et al. 2016). At the end of the vermicomposting process, the humification and decomposition of carbonaceous elements contained in the feedstocks cause TOC reduction (Negi and Suthar 2018). One of the elements for improving earthworm and microbial activity, which in turn results in a greater reduction of organic carbon, is the mixture of cow dung with feed substance (Boruah et al. 2019).

Nutrient (NPK) profile and micronutrient analysis:

TKN in the initial organic waste ranged from 11.62 to 23.41 g/kg, rising to 20.16 to 42.41 g/kg in the vermicompost following the experiment setup. Table 3 represents the nutritional (NPK) parameters of diverse initial organic

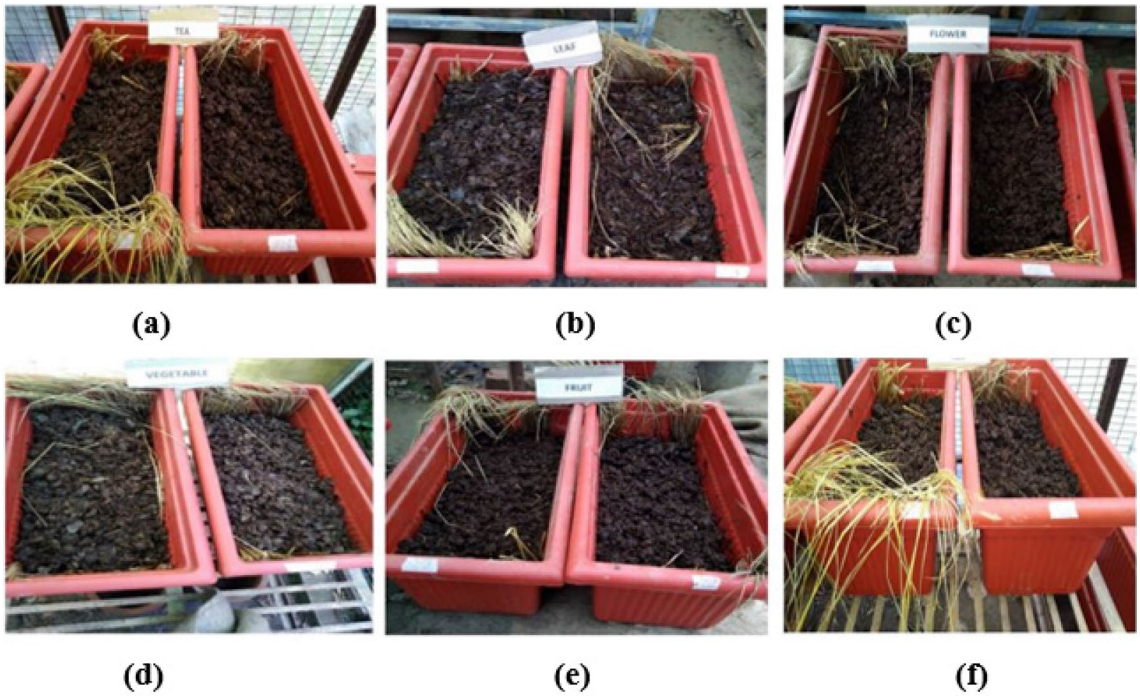


Fig. 4 The setup was used for the synthesis of all types of vermicompost. **a** Tea, **b** leaf, **c** flower, **d** vegetable, **e** fruit, **f** mixed

Table 1 Time taken for vermicompost formation and quantity of vermicompost generated

Type of organic waste	Time taken for formation of vermicompost (days)	Initial quantity of waste (Kg)	Quantity of vermicompost generated (kg)
Leaf Litter	55–70	17	6
Vegetable waste	45–48	17	6
Fruit waste	44–48	17	5
Tea waste	40	17	4
Flower waste	42	17	4
Mixture of waste	45–50	17	5

waste and final vermicompost from different vermi beans. TKN measurements throughout the experiment revealed a constant rise in all the vermi beans. Explanations for greater TKN levels after vermicomposting include the activity of N-fixing bacteria, nitrogenous detoxifying substances by earthworms, degraded tissues, earthworm coelomic fluids, and so on (Suthar 2009). The reduction of biomass due to CO, as well as the aerobic activity of the waste-degrading communities throughout vermicomposting, isolates nitrogen in vermicompost. The outcomes of this investigation are similarly related to previous research that discovered a significantly higher TKN in green waste vermicompost (Mago et al. 2022).

TAP levels in different organic waste began in the range of 4.48–6.36 g/kg and grew to values ranging from 10.29 to 13.47 g/kg as the process proceeded. All feed combinations showed a gradual shift in TAP values over time. In general, the interaction between earthworms and microbes, such as phosphate-solubilizing bacteria and phosphatase enzyme, causes the organically associated phosphorus to be released into accessible forms, increasing the TAP concentration in vermicompost. According to a previous study, the microbial utilization of humic acids during the degradation process is responsible for the release of phosphorus from organic waste (Gusain and Suthar 2020).

When compared to the starting levels of organic waste (3.32–27.56 g/kg), the TK contents of vermicompost of different waste materials were higher (10.54–52.21 g/kg). Increased potassium during the process of vermicomposting is thought to be responsible for the decrease in organic

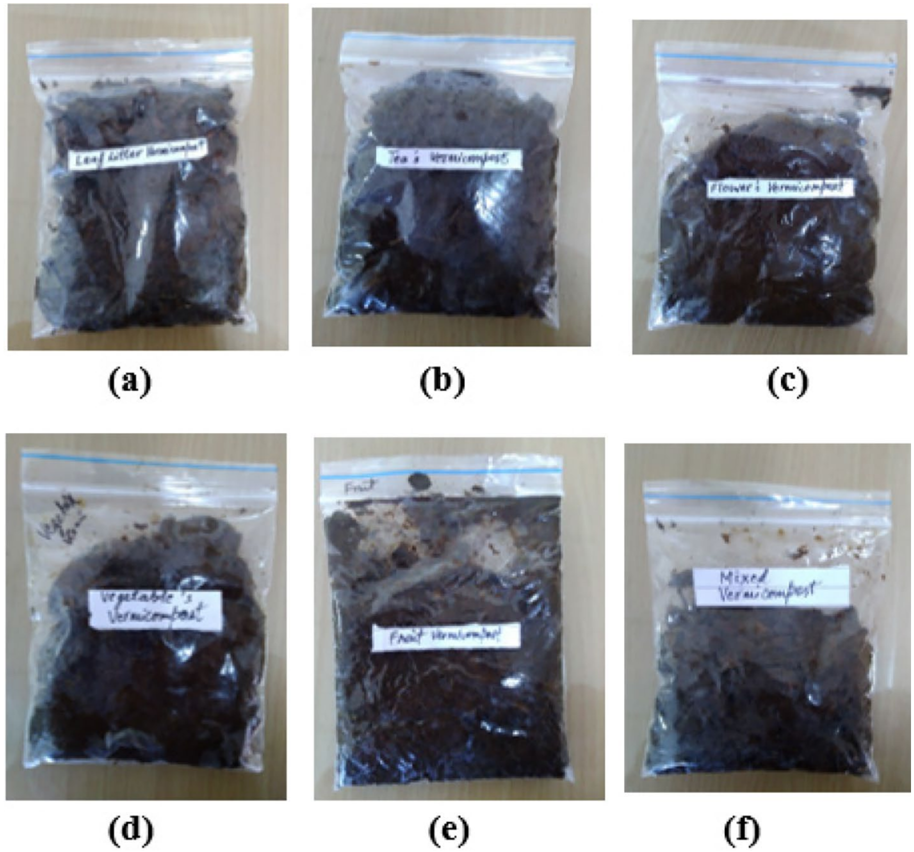


Fig. 5 Final vermicompost ready to be used for pot experiment. **a** Leaf, **b** tea, **c** flower, **d** vegetable, **e** fruit, **f** mixed

Table 2 Physicochemical parameters of diverse initial organic waste and final vermicompost from different vermi beans

Vermi beans	pH	EC (mS/cm)	TOC (g/kg)
Initial organic waste			
Tea	6.36 ± 0.067	3.27 ± 0.665	134 ± 0.467
Fruits	7.52 ± 0.151	2.39 ± 0.332	442 ± 0.154
Vegetables	8.29 ± 0.077	2.44 ± 0.762	446 ± 0.324
Flower	7.48 ± 0.215	2.69 ± 0.586	213 ± 0.886
Leaf	7.35 ± 0.049	3.34 ± 0.577	416 ± 0.785
Mixed organic waste	7.58 ± 0.063	3.19 ± 0.881	336 ± 0.577
Final vermicompost			
Tea vermicompost	6.31 ± 0.063	3.84 ± 0.026	119 ± 0.176
Fruits vermicompost	7.38 ± 0.023	3.12 ± 0.092	394 ± 0.063
Vegetables vermicompost	7.61 ± 0.146	3.43 ± 0.014	386 ± 0.162
Flower vermicompost	6.57 ± 0.205	3.52 ± 0.088	185 ± 0.142
Leaf vermicompost	6.53 ± 0.165	3.72 ± 0.176	373 ± 0.061
Mixed vermicompost	7.25 ± 0.012	3.46 ± 0.094	247 ± 0.165

Mean ± SE

Table 3 Nutritional (NPK) parameters of diverse initial organic waste and final vermicompost from different vermi beans

Vermi beans	TKN (g/kg)	TAP (g/kg)	TK (g/kg)
Initial organic waste			
Tea	23.41 ± 0.203	6.36 ± 0.058	3.32 ± 0.048
Fruits	13.21 ± 0.021	5.43 ± 0.206	6.51 ± 0.167
Vegetables	12.37 ± 0.118	6.17 ± 0.032	7.46 ± 0.205
Flower	11.62 ± 0.302	4.48 ± 0.135	27.56 ± 0.043
Leaf	16.28 ± 0.072	5.49 ± 0.092	14.38 ± 0.118
Mixed organic waste	14.45 ± 0.131	5.37 ± 0.133	10.25 ± 0.055
Final vermicompost			
Tea vermicompost	42.41 ± 0.102	13.34 ± 0.073	10.54 ± 0.052
Fruits vermicompost	24.46 ± 0.123	12.49 ± 0.104	16.25 ± 0.018
Vegetables vermicompost	26.42 ± 0.236	13.47 ± 0.086	18.43 ± 0.098
Flower vermicompost	20.16 ± 0.011	10.29 ± 0.122	52.21 ± 0.102
Leaf vermicompost	28.35 ± 0.202	12.59 ± 0.139	30.14 ± 0.072
Mixed vermicompost	23.56 ± 0.086	11.25 ± 0.042	22.66 ± 0.038

Mean ± SE

matter followed through CO respiration and the resulting release of TK. Increased TK in the final vermicompost compared to raw waste material is the consequence of the decomposition of waste mixture and generation of endogenic and/or exogenic enzymes as a result of the combined actions of earthworms and microorganisms. The results are in accordance with previous investigations on the vermicomposting of green garbage (Sharma and Garg 2018).

Micronutrients are beneficial for crop development at low amounts, but when their amount exceeds the allowable limits, they may interfere with the fertility of the soil and plant growth due to their bio-accumulation property, which leads to their introduction into the human food chain. As a result, before using vermicompost as fertilizer in agricultural fields, its nutrition level must be determined. Nutrient content in vermicompost may increase or decrease as a result of a reduction in volume and mass during vermicomposting (Malińska et al. 2017) and/or the dispersion of free metals from the binding state (Song et al. 2014). Metal interaction with humic acids inhibits metal reduction via leaching and bio-concentration, but smaller amounts may arise from the earthworm body accumulating nutrients (Liu et al. 2012). Both the initial organic waste and the finished vermicompost had their Fe, Cu, Zn, and Mn levels measured. Regardless of composition or initial values, it was discovered that the levels of micronutrients were different throughout the treatments. Table 4 represents the micronutrient (Fe, Cu, Zn, and Mn) parameters of diverse initial organic waste and final vermicompost from different vermi beans. Iron (Fe) concentration in the waste materials ranged from 3.86 to 1957.42 g/kg, while vermicompost had a Fe value of 504.25 to 2647.57 g/kg. Vermicompost had a copper (Cu) concentration ranging from 124.24 to 224.57 g/kg, whereas beginning organic waste had a Cu value of 10.29 to 84.39 g/kg. Other researchers have similarly observed an increase in Cu concentration following the vermicomposting of various kinds of waste (Sharma and Garg 2018). Following vermicomposting zinc (Zn) concentration increased 56.39–186.37 to 102.37–346.42 from organic waste. Similar outcomes regarding zinc enhancement in vermicompost than waste materials were also investigated in previous findings (Boruah et al. 2019). Manganese (Mn) content increased in vermicompost from 122.64–925.48 to 247.36–1063.19 g/kg from organic waste materials. Despite the incremental change in micronutrients after vermicomposting, the final concentration was lower compared to the threshold limitations, and these vermicomposts can be employed in potting media or used as fertilizer to improve soil conditions in crops.

Stabilization of C: N and C:P

Composting quality and stability are indicated by the C/N and C/P proportions. As the process neared completion, vermicompost in the experiment showed a falling trend in the C/N ratio. The C/N ratio ranged from 5.35 to 36.55 at first, changing to 2.62 to 16.29 in the final product vermicompost. A decrease in the C/N ratio of the vermicompost of waste mixtures has also been noted in earlier research studies, which has been attributed to organic matter mineralization, carbon dioxide losses through respiration, and an increase in nitrogen levels (Arumugam et al. 2018). The C/P ratio also indicates the stability of the vermicompost and indicates the organic material mineralization, carbon loss, and enhanced phosphorus availability in the composting material that results from the end of the process (Gupta et al. 2022). All six vermi-units in the current investigation showed a substantial variation in the decline in the C/P ratio. Table 5 represents the stabilization of C/N and C/P ratios of diverse initial organic waste and final vermicompost from different vermi beans. In the beginning, C/P levels in vermicompost ranged from 20.63 to 78.31; however, when they decreased,

Table 4 Micronutrient (Fe, Cu, Zn, and Mn) parameters of diverse initial organic waste and final vermicompost from different vermi beans

Vermi Beans	Total Fe (g/kg)	Total Cu (g/kg)	Total Zn (g/kg)	Total Mn (g/kg)
Initial organic waste				
Tea	130.53 ± 0.583	25.32 ± 0.053	56.39 ± 0.067	925.48 ± 0.101
Fruits	1957.42 ± 0.449	10.29 ± 0.078	71.73 ± 0.182	134.46 ± 0.182
Vegetables	1867.37 ± 0.615	84.39 ± 0.019	184.31 ± 0.039	122.64 ± 0.189
Flower	3.86 ± 0.015	42.55 ± 0.102	186.37 ± 0.068	142.29 ± 0.022
Leaf	526.28 ± 0.035	28.32 ± 0.038	62.42 ± 0.076	154.22 ± 0.052
Mixed organic waste	1143.18 ± 0.997	38.35 ± 0.038	107.49 ± 0.175	296.48 ± 0.154
Final vermicompost				
Tea vermicompost	1020.7 ± 10.152	182.39 ± 0.122	102.37 ± 0.052	1063.19 ± 0.041
Fruits vermicompost	2647.35 ± 0.044	150.42 ± 0.171	152.29 ± 0.025	266.37 ± 0.102
Vegetables vermicompost	2456.08 ± 0.035	215.53 ± 0.212	346.42 ± 0.289	247.36 ± 0.145
Flower vermicompost	504.25 ± 0.253	158.31 ± 0.032	324.54 ± 0.137	297.21 ± 0.048
Leaf vermicompost	938.32 ± 0.212	124.24 ± 0.031	175.26 ± 0.075	248.29 ± 0.235
Mixed vermicompost	2150.22 ± 0.102	224.57 ± 0.129	246.12 ± 0.047	434.35 ± 0.137

Mean ± SE

Table 5 Stabilization of C/N and C/P ratio of diverse initial organic waste and final vermicompost from different vermi beans

Vermi beans	C/N ratio	C/P ratio
Initial organic waste		
Tea	5.35 ± 0.226	20.63 ± 0.125
Fruits	33.32 ± 0.038	76.44 ± 0.162
Vegetables	36.55 ± 0.165	73.32 ± 0.058
Flower	17.48 ± 0.239	45.22 ± 0.041
Leaf	25.35 ± 0.076	78.31 ± 0.036
Mixed organic waste	23.34 ± 0.073	64.91 ± 0.501
Final vermicompost		
Tea vermicompost	2.62 ± 0.107	11.45 ± 0.183
Fruits vermicompost	16.29 ± 0.082	24.43 ± 0.142
Vegetables vermicompost	14.45 ± 0.174	20.48 ± 0.194
Flower vermicompost	9.14 ± 0.053	3.62 ± 0.052
Leaf vermicompost	12.49 ± 0.221	12.59 ± 0.136
Mixed vermicompost	10.36 ± 0.049	10.48 ± 0.172

Mean ± SE

they subsequently reached ranges between 3.62 to 24.43. According to past research investigations, the ratio of carbon to phosphorus also decreased (Karmegam et al. 2019).

Pot experiment study

For the pot experiment vermicompost synthesized from mixtures of all types of organic wastes was found to be suitable based on analysis of various parameters. *Spinacia oleracea* (spinach) and *Brassica nigra* (mustard) were selected as test plants and two types of treatment were designed as discussed in section "Analysis of plant growth". Figures 6 and 7 represent mustard and spinach respectively grown under different treatments. After 30 days plants were harvested and various physiochemical analysis was performed for both types of plants grown in all types of treatments. Physiochemical parameters of plants such as the number of leaves, leaf area, number of branches, stem length, root length, chlorophyll index, and relative water content percentage (RWP %) were

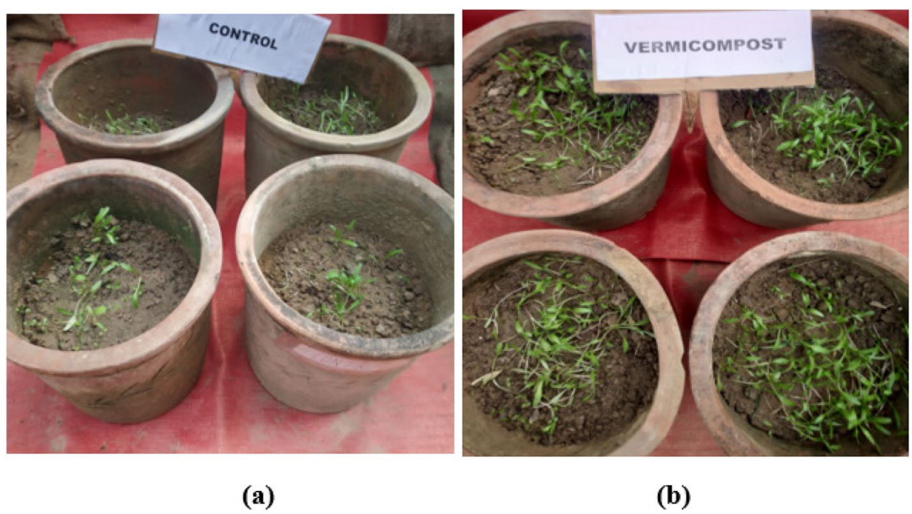


Fig. 6 *Brassica nigra* (Mustard) is grown under different treatments. **a** Control, **b** mixed vermicompost

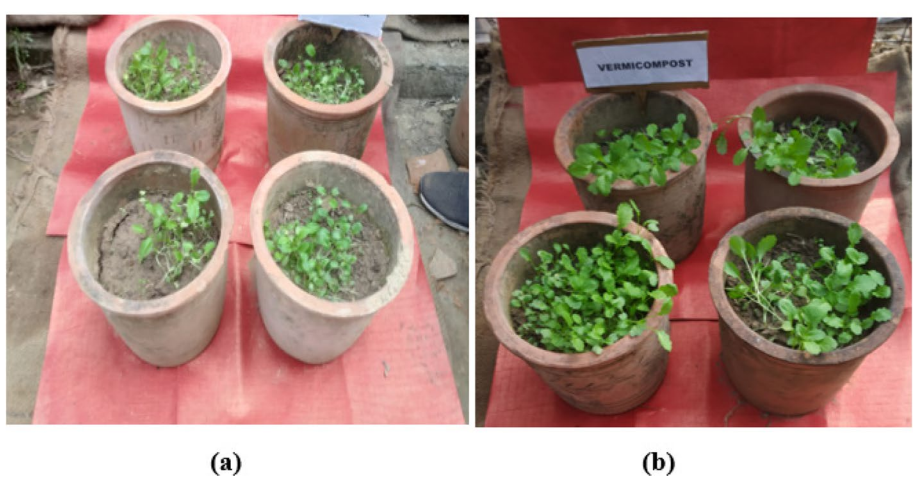


Fig. 7 *Spinacia oleracea* (Spinach) is grown under different treatments. **a** Control, **b** mixed vermicompost

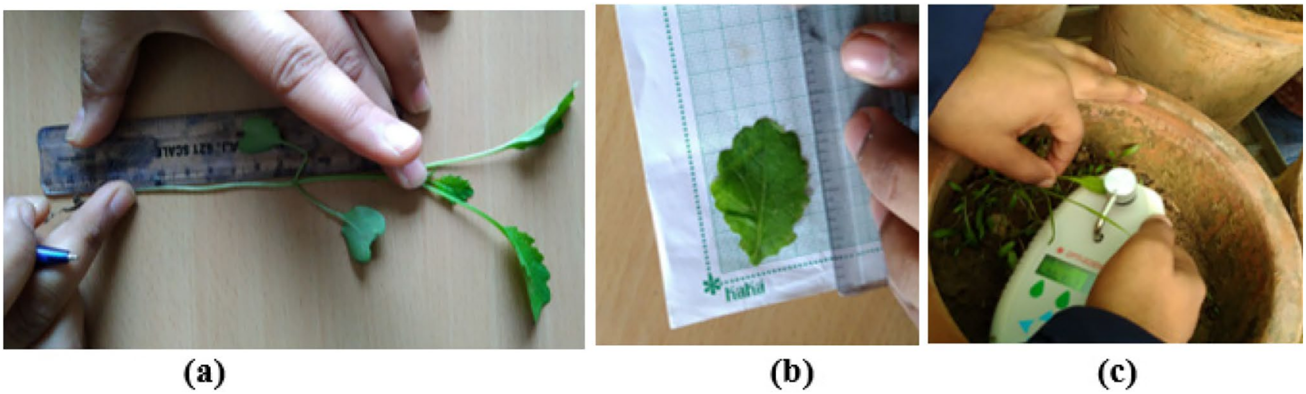


Fig. 8 Physiochemical analysis of plants. **a** Stem length, **b** leaf area, **c** chlorophyll using a chlorophyll meter

Table 6 Physiochemical analysis of mustard and spinach

Plant	Mustard		Spinach	
Treatment	Control	Mixed vermicompost	Control	Mixed vermicompost
Leaf no	5 ± 0.425	7 ± 0.562	4 ± 0.26	8 ± 0.351
Leaf area (cm^2)	10.24 ± 0.452	11.89 ± 0.245	3.12 ± 0.425	4.16 ± 0.425
Branch no	6 ± 0.256	7 ± 0.452	4 ± 0.462	7 ± 0.256
Stem length (cm)	14.67 ± 0.261	16.25 ± 0.252	6.36 ± 0.246	6.85 ± 0.425
Root length (cm)	5.67 ± 0.425	6.76 ± 0.425	4.34 ± 0.352	6.25 ± 0.425
Chlorophyll index	9.32 ± 0.531	15.67 ± 0.426	5.21 ± 0.426	8.79 ± 0.421
Relative water content (%)	90.57 ± 0.256	93.35 ± 0.526	86.92 ± 0.426	90.54 ± 0.426

Mean ± SE

analyzed. Figure 8 represents the physiochemical analysis of plants. Table 6 represents the physiochemical analysis of spinach and mustard plants. The physiochemical analysis of plants revealed that spinach and mustard grown in soil treated with vermicompost synthesized from a mixture of organic wastes showed better results as compared to plants grown in control soil. Plants with better results may exhibit several benefits such as increased photosynthesis, improved nutrient absorption, better structural support, enhanced chlorophyll content, water efficiency, increased resistance to stress, improved competitiveness, faster establishment, and enhanced reproductive success (Solanki et al. 2022; Raksun et al. 2022; Jung and Arar 2023; Ezzine et al. 2023). The physiochemical analysis of plants concludes that both the test plants (spinach and mustard) show better growth in soil treated with mixed vermicompost thus again confirming that vermicompost synthesized from a mixture of all types of wastes is of best quality.

Along with the physiochemical study of plants, soil from all types of pots was also examined. Parameters of soil such as pH, EC, available organic carbon (%), available nitrogen, available potassium, available phosphorus, and micronutrients such as manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) were analyzed. Tables 7 and 8 represent the analysis of soil parameters used for growing spinach and mustard respectively under different treatments. In comparison to the control soil, the soil of both the test plants treated with mixed vermicompost was found to have a higher value of available organic carbon (%). Organic carbon in soil is a critical component that influences soil fertility, structure, and overall health. When it comes to plants, having a high availability of organic carbon in the soil can provide several benefits such as nutrient availability, soil structure improvement, water retention and drainage, reduced erosion, microbial activity and diversity, carbon sequestration, improved cation exchange capacity (CEC), enhanced plant growth and productivity (Dhaliwal et al. 2019; Nabiollahi et al. 2021; Francaviglia et al. 2023). Figure 9a, b nutrient analysis of soil used for growing spinach and mustard respectively under different treatments.

When compared to control conditions, the soil of both the test plants treated with mixed vermicompost had superior results in terms of NPK value. These nutrients play crucial roles in different aspects of plant development, and having higher levels of NPK in the soil can offer several benefits. Promotes healthy plant growth, nitrogen (N) is essential for leaf and stem development, as well as overall plant growth. It is a key component of chlorophyll, the

Table 7 Analysis of soil parameters used for growing spinach under different treatments

Soil parameter (spinach)	Initial soil	control	Mixed vermicompost (after harvesting)
pH	8.12 ± 0.082	8.01 ± 0.617	7.65 ± 0.081
EC (mS/cm)	3.46 ± 0.183	2.98 ± 0.172	3.12 ± 0.119
Available OC (%)	1.24 ± 0.073	1.18 ± 0.257	2.46 ± 0.104
Available N (mg/kg)	56.12 ± 0.273	24.68 ± 0.352	34.76 ± 0.019
Available P (mg/Kg)	42.35 ± 0.017	35.17 ± 0.017	51.68 ± 0.812
Available K (mg/Kg)	78.53 ± 0.026	64.81 ± 0.252	234.62 ± 0.651
Available Fe (mg/kg)	42.13 ± 0.267	29.65 ± 0.019	52.86 ± 0.471
Available Cu (mg/kg)	1.12 ± 0.527	0.76 ± 0.091	2.45 ± 0.401
Available Mn (mg/kg)	15.26 ± 0.026	10.12 ± 0.602	16.54 ± 0.192
Available Zn (mg/kg)	3.52 ± 0.261	3.98 ± 0.081	5.29 ± 0.161

Mean ± SE

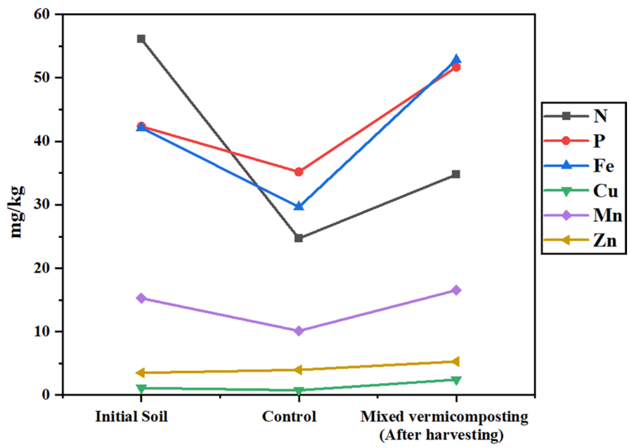
Table 8 Analysis of soil parameters used for growing mustard under different treatments

Soil parameter (mustard)	Initial soil	Control	Mixed vermicompost (after harvesting)
pH	8.24 ± 0.123	8.18 ± 0.123	7.75 ± 0.612
EC (mS/cm)	3.28 ± 0.129	3.26 ± 0.104	2.96 ± 0.812
Available OC (%)	1.31 ± 0.652	1.25 ± 0.765	2.58 ± 0.465
Available N (mg/Kg)	54.86 ± 0.162	22.74 ± 0.728	33.16 ± 0.812
Available P (mg/Kg)	41.98 ± 0.812	32.47 ± 0.176	50.62 ± 0.092
Available K (mg/Kg)	79.25 ± 0.098	66.72 ± 0.268	258.29 ± 0.872
Available Fe (mg/kg)	44.15 ± 0.091	30.37 ± 0.609	54.27 ± 0.071
Available Cu (mg/kg)	1.25 ± 0.982	0.82 ± 0.981	1.96 ± 0.254
Available Mn (mg/kg)	16.23 ± 0.772	12.25 ± 0.762	19.12 ± 0.451
Available Zn (mg/kg)	3.89 ± 0.712	4.12 ± 0.541	5.94 ± 0.145

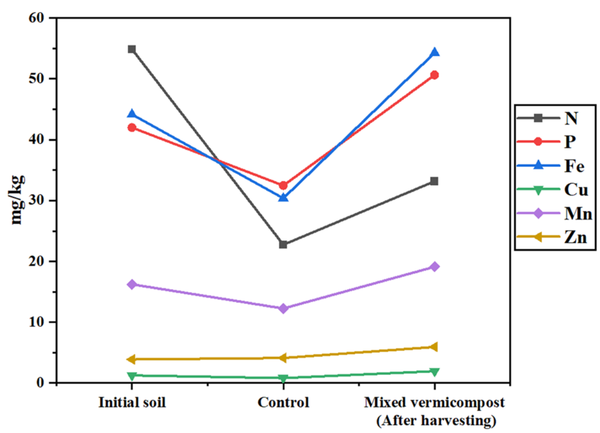
Mean ± SE

pigment responsible for photosynthesis. Phosphorus (P) is important for root development, flowering, and fruiting. It plays a vital role in energy transfer and storage within the plant. Potassium (K) aids in various physiological processes, including enzyme activation, water uptake, and overall plant health. NPK increased yield, improved root development, enhanced disease resistance, better drought resistance, optimal flowering and fruiting, improved photosynthesis, balanced nutrition, and crop quality (Akbar et al. 2023; Navghare et al. 2023; Raj et al. 2023; Das and Ghosh 2023). In addition to having more organic carbon and NPK content, mixed vermicompost-treated soil of both the test plants performs better when it comes to micronutrients like Mn, Zn, Fe, and Cu. Micronutrients are essential for plant growth, even though they are required in smaller quantities compared to primary nutrients like nitrogen, phosphorus, and potassium. Having higher levels of these micronutrients in the soil can offer several benefits to plants such as enzyme activation, photosynthesis enhancement, nutrient uptake and transport, root development, disease resistance, stress tolerance, flowering and seed formation, improved nutrient use efficiency, color, and nutritional quality, overall plant health and vigour (Enyoh et al. 2022; Sengupta et al. 2022; Xu et al. 2022).

In the present pot experiment, both spinach and mustard show better physiochemical analysis in the case of soil treated with mixed vermicompost. Along with this soil analysis also confirmed that soil treated with mixed vermicompost has higher values of organic carbon, NPK, and micronutrients. Thus, it seems evident that vermicompost composed of organic waste mixtures not only improves plant development but also improves soil nutrient levels.



(a) Nutrient analysis of soil used for growing spinach under different treatments.



(b) Nutrient analysis of soil used for growing mustard under different treatments.

Fig. 9 **a** Nutrient analysis of soil used for growing spinach under different treatments. **b** Nutrient analysis of soil used for growing mustard under different treatments

Chalenges and prospects

Synthesis of vermicompost using various types of waste collected from university campuses poses both challenges and opportunities, especially when its large-scale implementation is in consideration. The first challenge is the collection and proper storage of waste because contamination of waste can hinder the quality of vermicompost. When a small-scale setup of vermicompost needs to be transformed into a large scale then it needs careful planning and investment. Large-scale vermicompost setups can also attract pests and lead to odour issues. When it comes to opportunities then this technique has the potential to be an effective eco-tool for managing organic waste and cow dung, both of which are abundant, and it could help open the way for more sustainable management. It provides an opportunity to convert organic waste into nutrient-rich products, thereby reducing the carbon footprint of universities and waste disposal costs. Large-scale implementation of vermicompost setup can engage local people through outreach programs, fostering a sense of environmental sustainability amongst them. Overall large-scale projects on vermicomposting can contribute to the circular economy by synthesizing vermicompost from waste, which can enrich the soil of the university garden, and potential revenue from vermicompost sales adds further incentive to embrace this sustainable approach.

Conclusion

It can be concluded from the experimental study that vermicompost synthesized from a mixture of five types of wastes collected from Kurukshetra University was found to be enriched and agronomically beneficial as compared to others. The resulting vermicompost was uniform and dark. It had all the necessary macro, and micro-nutrients for plants, including N P K, Mg, Mn, Cu, Zn, and Fe, proving that it was successful in creating an environmentally safe, nutrient-rich fertilizer for utilization in agriculture. The mixed vermicompost was further studied in a pot experiment which also concluded that the pot treated with it showed better results, both in phytochemical analysis of plants (spinach and mustard) and analysis of soil. The findings of this research also advise the use of vermicompost for the management of waste at colleges and universities pursuing sustainability and greener campus development. A circular economy approach will be supported by the implementation of a zero-waste managing strategy. Thus, integrated waste management through vermicomposting is a means to sustainable development.

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Data availability statement All the data generated or analyzed during this study are included in this article.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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