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ORIGINAL RESEARCH

Biotransformation of varieties of food waste supplemented by bonemeal and eggshell powder using vermicomposting technology

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Abstract

Purpose: The quality of compost is a significant concern worldwide. This study aims to improve vermicompost quality through the utilization of enriched materials.

Method: This research aimed to evaluate the impact of bonemeal and eggshell powder treatments on the quality of vermicompost derived from three waste varieties: cooked tea waste, vegetable waste, and mixed food waste. The vermicomposting process was conducted in plastic containers, utilizing *Eisenia fetida* as the biological agent. The quality assessment included laboratory analyses and germination index tests using gram seeds.

Results: The study revealed that the incorporation of bonemeal powder significantly increased nitrogen content, with increments of 12.84% for tea waste vermicompost, 61.51% for vegetable waste, and 65.70% for mixed food waste vermicompost. Vermicompost derived from tea waste exhibited particularly high nitrogen content. Eggshell powder not only mitigated acidity in the raw materials but also increased calcium content. Furthermore, all treatments resulted in germination index (GI) values exceeding 70% for gram seeds, indicating a reduced presence of phytotoxic compounds.

Conclusion: The application of bonemeal powder positively influenced nitrogen content in the final vermicompost, while eggshell powder proved effective in maintaining an optimal pH level. These findings emphasize the potential of using these enriched materials to enhance the nutrient composition and reduce phytotoxicity in vermicompost, contributing to more sustainable composting practices.

Keywords: Earthworm, Enriched materials, Vermicompost, Phytotoxicity, Tea waste

Introduction

Over the last decade, food waste has gained global attention. Every year, nearly 1.3 billion metric tons of food, or one-third of the total amount of food produced for human consumption, are wasted on a global scale (Kaza et al. 2018). According to Papargyropoulou et al. (2019), restaurants, food courts, canteens, home kitchens, and food processing businesses all contribute to the waste produced during the preparation of fruits and vegetables. During production, distribution, and consumption, 25-50% of fruits and vegetables are lost (Bancal and Ray 2022). Food loss and food waste have an impact on society, the economy, and the environment (Steffen et al. 2015). Reducing food waste is, therefore, one of the recommended strategies for enhancing the sustainability of agriculture and the food system (Foley et al. 2011). The majority of food waste produced by retail, food service, and consumer households is related to nations with high standards of living for consumers (Kummu et al. 2012). Food waste in consumer households has been proven to be a relatively complex issue (Aschemann et al. 2015). Food waste generation in consumer households is influenced by several stages, including planning, food purchase, storage, preparation, consumption to final disposal (Aschemann et al. 2019). Food waste is rich in nutrients, and it is an important source of raw materials for compost making. Vegetable waste is a component of food waste, which is also produced by the residential sector and vegetable market waste. It is regarded as an important source of nutrients that can be managed by vermicomposting technology (Mainoo et al. 2009).

Tea, derived from the leaves of the Camellia sinensis plant, is well recognized as a highly favored non-alcoholic beverage on a global scale. The study from the International Tea Committee states that more than 5.8 million tons of tea were consumed globally in 2019. The popularity of products made from tea, such as bottled tea drinks, instant tea powder, tea seed oil, and tea extracts, has greatly increased (Wang et al. 2011), as a result, tea waste is produced in large amounts. It is generally thrown in landfill sites along with other waste.

Bonemeal is made from animal bones in the form of a fine and coarse grounded mixture which is the waste produced from slaughterhouses. It is an important source of phosphorus. Bonemeal is a difficult-to-dispose-of by-product of animal slaughter in slaughterhouses. However, farmers and researchers have become interested in alternative sources of phosphorus, such as organic or organo-mineral fertilizers, mostly because they are inexpensive and provide a gradual release of phosphorus (Bøen and Haraldsen 2013). It is used as a chemical additive during the composting period. According to literature analysis, introducing chemical additives or supplements was more effective at minimizing nitrogen loss & ammonia volatilization (Cao et al. 2019; Wang & Zeng, 2018; Maharjan et al. 2022b). Superphosphate and salts of phosphorus and magnesium demonstrated the greatest potential for mitigation. (Cao et al. 2019). This is due to the crystallization and/or precipitation interaction of ammonium with phosphate and calcium magnesium ions, which inhibits the transformation of ammonium to ammonia (Li et al. 2018). The findings indicate that phosphorous additives could successfully reduce nitrogen loss. The addition of phosphogypsum could result in a considerable decrease in ammonia emissions and overall nitrogen loss. The use of 10% superphosphate reduced ammonia emissions and overall nitrogen loss, but it slowed down the decay of organic matter and compost maturity (Li et al. 2021).

Large amounts of eggshells are produced every day as biowaste around the world. Eggshells are a waste product generated from the residential and fast-food industries. Eggshells account for around 11% of the total weight of an egg (King'ori 2011). The Environmental Protection Agency (EPA) has listed eggshell waste as the 15th most significant food pollution issue. Improper disposal in the designated area can cause major environmental pollution. It poses a health risk due to the growth of fungi on the eggshell (Tomczyk et al. 2018). Although eggshells are considered a waste product, they are an important source of calcium ($CaCO_3$) and have the property to increase the pH of the soil (Gaonkar and Chakraborty 2016). It enhances the nutritional intake of plants (Hamester et al. 2012). Eggshell has pH 7.86, EC (mS/cm) 0.21, total nitrogen 0.47%, total phosphorus 0.009%, potassium 0.08%, magnesium 0.15%, copper 3.07 ppm, iron 4.37 ppm, zinc 6.81 ppm (Yatoo et al. 2022).

Vermicomposting is a method that combines the action of microorganisms and earthworms (Domínguez 2018; Singh et al. 2011). It is a process of conversion of organic waste by specific earthworm species to valuable humus-like material (Bhat et al. 2018) which could be used as a natural soil conditioner (Domínguez 2018). In this vermicomposting process, the biodegradation of organic matter is carried out by bacteria and fungi, with earthworms acting as the process drivers. The earthworms' biological activities change the growth medium's, chemical, physical, and biological properties, slowly lowering its carbon/nitrogen ratio, increasing the surface area exposed to microorganisms, and ultimately favoring them and further degradation (Sofo et al. 2023). Worms maintain an aerobic environment while ingesting organic solids, partially converting them into biomass and metabolite products, and then excreting the remaining partially stabilized product, known as vermicompost. Vermicompost has essential macronutrients such as nitrogen, phosphorus, and potassium (NPK) and micronutrients such as iron, calcium, manganese, and zinc (Maharjan et al. 2022a). It also has a good structure and helps the soil's aeration, drainage, and water-holding capacity (Domínguez 2018).

In vermicomposting technology, various enriched materials, also known as supplemented materials, are employed to enhance the quality of vermicompost, specifically in terms of NPK, calcium, magnesium, and various micronutrients. Additives like lime, bonemeal powder, eggshells, and rock phosphate are utilized to augment the overall quality of the vermicomposting process.

Previous research typically only investigated the quality of vermicompost derived from cow dung and sewage sludge supplemented by bonemeal. However, the use of bonemeal on tea waste, cauliflower leaves (vegetable waste), and mixed food waste is rarely reported. Chitrapriya et al. (2017) conducted research on the vermicomposting of cow dung supplemented by bonemeal and started the first study in vermicomposting using such a combination. They concluded that bonemeal mixed with cow dung is a suitable feeding material for the growth and reproduction of earthworms. Maximum biomass and cocoon formation were obtained in such a combination. However, a study on the effect of bonemeal on the quality of vermicompost is lacking. Thus, the main aim of this novel work is to evaluate the quality of vermicompost prepared from three varieties of organic wastes and to assess the effect of bonemeal and eggshell powder on vermicompost quality. Vermicomposting of these wastes could be an effective solution for the waste management sector.

Materials and methods

Raw material preparation

Three different wastes, (i) tea waste and (ii) vegetable waste, were separately collected from the vegetable market in Kathmandu city, and (iii) mixed food waste (leftover rice, tea, radish, and banana peelings) was collected from a nearby research area, Kathmandu. Bonemeal powder was purchased from a local nursery and sieved in a 1mm pore-size sieve. The eggshell powder was prepared by the following process: sun-dried, crushed in a grinder machine, sieved (1mm), and stored in a plastic container. The average eggshell (dried) prepared from one egg was equivalent to 5.03±0.057 gm (the average weight of one egg is 59.56±3.54 gm). For waste feeding, the vegetable waste (leaf of cauliflower) was shredded into small pieces about 1 inch in size. The large size of mixed food waste was also chopped into small pieces so that earthworms could easily consume it.

Experimental set-up

The experiment was conducted within an enclosed space throughout the summer season. For the preparation of vermicompost, twenty-seven equal-size plastic containers with 35 cm diameter and a depth of 13 cm were selected (Fig. 1). Three replications for each control and treatment were made. In order to mitigate water logging problems, openings were created at the base of the container. The sawdust was used as bedding material. It was soaked and placed at the bottom of the container. Above the bedding material, 300 adult worms (*Eisenia fetida*) were introduced to each container. The waste, including tea waste (cooked), vegetable waste, and mixed food waste, was separately fed to earthworms every week. 300 gm of each organic waste was fed each week and covered by cotton cloth. While feeding, 10 gm of each bonemeal powder (<1mm) and eggshell powder (<1mm) as supplement materials were also used except in the control. The feeding routine was maintained for 12 weeks. Following a period of 12 weeks, the vermicompost produced by each unit was collected and subsequently allowed to undergo an additional 2-week period to achieve full maturation. After maturation, the prepared vermicompost sample was taken from each replicate and brought to the laboratory to assess the quality of vermicompost manure. The sample identification code is presented in Table 1

Fig. 1 Vermicomposting in a plastic container (Tub basin)

Physico-chemical analysis

The collected samples were processed for analysis of moisture content, pH, electrical conductivity, total nitrogen (TN), total phosphorus (TP), total potassium (TK), organic carbon (OC), carbon/nitrogen ratio (C/N ratio), calcium and magnesium. Moisture content was measured gravimetrically (oven-dried at 105 ^{0}C for 24 hours). pH and Electrical conductivity of samples were measured by a digital pH meter (model PHS-3C) and Conductivity meter (model 4365), respectively. pH of the suspension was determined electronically on a direct reading in a pH meter, using a glass electrode with a saturated 1N potassium chloride-calomel reference electrode (1:5 compost: 1N KCl) (Milwaukee pH56 Martini Pocket pH Meter -Model pH56). Total nitrogen was determined by the Kjeldahl method (Sáez-Plaza et al. 2013). Organic carbon was estimated by the Walkley-Black method (Nelson and Sommers 1982). Total phosphorus was determined by the Vanadomolybdate phosphate method, and potassium was estimated by the Flame photometric method (Motsara and Roy 2008). Carbon/nitrogen ratio was calculated by nitrogen and organic carbon percent values. Calcium (Ca) and magnesium (Mg) were analyzed by dry ashing, followed by EDTA titration. Room temperature and bedding temperature (worms' container) were recorded weekly and measured by a compost thermometer.

A test for normality was conducted to ascertain whether the data adheres to a normal distribution. Due to the sample size being less than 50, the Shapiro-Wilk test was chosen as the preferred method for this assessment. For the analysis of data, an Independent T-test was computed to test the level of significance of differences between the vermicompost prepared in the control and treatment. ANOVA was used to test significant differences among three kinds of waste. All the data has been expressed as mean ± standard deviation.

Table 1. Sample Identification Code for Vermicompost

Sample	Control and Treatment	Sample Code
Tea waste	Control	TW-C
	Bonemeal	TW-BM
	Eggshell	TW-ES
Vegetable waste	Control	VW-C
	Bonemeal	VW-BM
	Eggshell	VW-ES
Mixed Food waste	Control	MFW-C
	Bonemeal	MFW-BM
	Eggshell	MFW-ES

Germination Index

Gram seeds were grown in plastic pots for studying the phytotoxicity of vermicompost. Nine pots were taken and filled with vermicompost sample (treatment) and one for soil sample (control). In each pot, five seedlings were sown and watered with tap water.

A total of five seedlings were planted in each pot and afterward watered with tap water. The unit was maintained at room temperature for 7 days. Following a period of 7 days after seed germination, the seedlings were extracted from their respective pots in order to conduct an analysis of the germination index. The measurement of the root length was conducted using a centimeter scale. The germination index was computed utilizing the mathematical expression (Zucooni 1981).

$$\text{GI}(\%) = \frac{\text{Seed germination x root length of treatment}}{\text{Seed germination x root length of control}} \text{X100} \quad (1)$$

Quality assurance and quality control

Quality assurance (QA) and quality control (QC) are crucial components of the vermicomposting process and the subsequent lab analysis of vermicompost. Environmental conditions such as appropriate moisture levels and optimum temperatures (Kaur 2020) were maintained and monitored during vermicomposting.

To prepare representative samples, the processed vermicompost was carefully homogenized and placed in clean, airtight plastic sample bags. All glassware underwent thorough cleaning, and instruments were calibrated during laboratory analysis to minimize instrumental errors. Reagent preparation involved the use of high-quality distilled water from Thermo Fisher Company, which was also employed to rinse all glassware.

A phytotoxicity test was conducted to determine the suitability of the prepared vermicompost for use. This involved utilizing gram seeds of uniform size, employing a consistently mixed soil as the growing medium, and using an equal amount of tap water for seed plantation through germination.

Results and discussion

Physicochemical parameters of feeding stocks used during vermicomposting

The waste material characterization was conducted before using it as feeding material in vermicomposting (Table 2). The quality of supplemented materials such as bonemeal and eggshell powder was also measured to analyze the effect on the quality of vermicompost.

Table 2. Physical and chemical characteristics of feeding stocks/raw materials (Tea waste, Vegetable waste, Mixed food waste, Bonemeal powder, and Eggshell powder) used for vermicomposting

Parameters	**Tea waste**	**Vegetable waste**	**Mixed food waste**	**Bonemeal powder**	**Eggshell powder**
Moisture Content (%)	75.7±0.35	91.1±1.95	83.1±2.90	15.9±1.00	1.6±0.20
pH	5.96±0.03	6.50±0.30	4.34±0.25	7.79±0.01	9.69±0.09
Electrical conductivity (dS/m)	0.407±0.006	1.159±0.0025	1.862±0.024	0.89±0.09	0.81±0.11
Total Nitrogen (%)	1.56±0.12	6.13±0.04	8.73±0.03	1.09±0.01	4.16±0.14
Total Phosphorus (%)	0.15±0.03	0.13±0.02	0.61±0.20	22.19±0.89	0.29±0.001
Potassium (%)	1.615±0.04	1.045±0.02	4.77±0.21	0.11±0.02	0.094±0.002
Calcium (%)	0.035±0.005	0.40±0.160	0.081±0.004	2.59±0.19	36.09±1.19
Magnesium (%)	0.015±0.004	0.054±0.004	0.0372±0.002	0.31±0.08	0.84±0.04

Mean ± standard deviation, n=3

Physicochemical parameters of vermicompost derived from tea waste, vegetable waste, and mixed food waste

The quality of vermicompost is influenced by various aspects, including the choice of raw materials, composting techniques, carbon-to-nitrogen ratio, incorporation of supplementary materials, moisture, temperature levels, and other relevant parameters. The maturity of vermicompost was physically measured by its black colour, odourless, and temperature measurement. The nutrient quality of vermicompost was assessed by its physico-chemical characteristics.

Moisture is an important parameter that determines the biodegradation rate of organic matter and the texture and quality of compost products. In the current study, the moisture content varied across different vermicompost types. In tea waste vermicompost, it ranged from 67.30±5.73% (TW-BM) to 71.53±3.17% (TW-C), in vermicompost derived from vegetable waste, it ranged from 45.20±7.40% (VW-ES) to 55.96±4.61% (VW-BM), and in mixed food waste vermicompost, it varied from 67.86±2.65% (MFW-ES) to 73.93±0.66% (MFW-C) (Fig. 2). The elevated moisture content in all vermicompost samples could be attributed to the ample water present in the respective feeding raw materials, with values of 75.7±0.35% in tea waste, 91.1±1.95% in vegetable waste, and 83.1±2.90% in mixed food waste (Table 2). Previous studies have consistently reported high moisture content in various types of vermicompost. Huntley and Ansari (2021) found that the moisture content in vermicompost made from fruit waste was 68.66%, and vegetable waste was 69.33%. Similarly, Lleó et al. (2013) reported 76% moisture in vermicompost derived from fruit and vegetable waste. The vermicompost derived from paddy straw was also rich in moisture which was 70.33% (Jaybhaye and Bhalerao 2016). Vermicompost prepared from animal dung was a rich source of moisture, which was recorded as 80.39% in elephant dung and

70.09% in rhino dung (Pérez-Godínez et al. 2017). In the present study, bonemeal and eggshell treatment reduces the moisture in vermicompost samples (Fig. 2). As bonemeal and eggshell are dry powders, some moisture from the waste was absorbed by it. From ANOVA test (Table 6), all samples found significant differences in terms of moisture content ($p<0.05$). The moisture observed in all samples of vermicompost exceeded the standard value (<25%) given by the Nepal government and other international standards.

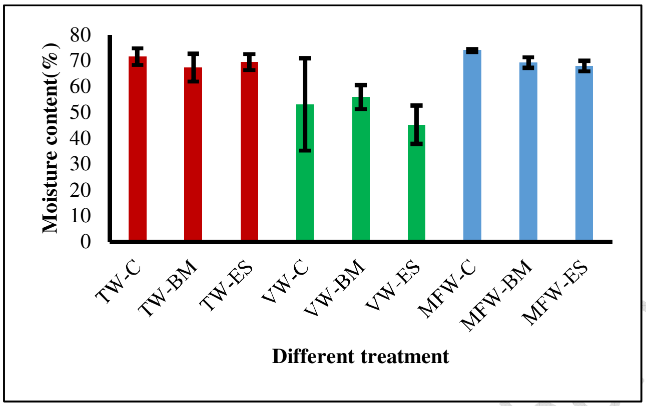

Fig.2 Moisture in vermicompost prepared from different wastes

In this study, the pH of vermicompost prepared from tea waste, vegetable waste, and mixed food waste supplemented by eggshells is comparatively higher than that of control samples. The pH ranged from 6.57 ± 0.19 (TW-C) to 7.16±0.09 (TW-ES) in the vermicompost of tea waste, 7.02±0.46 (VW-C) to 7.45±0.07 (VW-ES) in vermicompost of vegetable waste, and 6.87±0.2 (MFW-C) to 7.61±0.06 (MFW-ES) in vermicompost prepared from mixed food waste (Fig. 3). Significant differences were obtained in eggshell treatment ($p<0.05$). The results showed that the use of eggshells was capable of neutralizing the acidic raw materials (Table 2) because eggshell is composed of calcium carbonate (Kristl et al. 2019). Moreover, the increase in pH is mainly due to the utilization of organic acids and an increase in nutrients of the organic wastes during vermicomposting (Jadia and Fulekar 2008). The decomposition of nitrogenous components may be the cause of the pH increase, which is also reported by Muthukumaravel et al. (2008). The use of paper, peanut shells, sawdust, and ca-bentonite may raise pH during composting (Iqbal et al. 2010). The drop in pH levels can effectively mitigate nitrogen loss by preventing the conversion of ammonia (Chen et al. 2010). Changing pH during biodegradation by earthworms can be attributed to several factors. The difference in pH among organic waste feed mixtures may be due to feeding quality, which affected mineralization during vermicomposting.

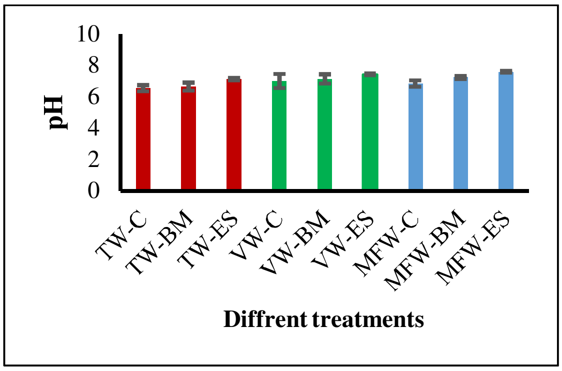

Fig. 3 pH in vermicompost prepared from different wastes

Various researchers found the pH in food and vegetable waste, which is presented in Table 3.

Table 3. pH recorded in vermicompost by different researchers

Study	Types of waste	pH
(Getachew et al. 2018)	Fresh food waste	7.6
(Majlessi et al. 2012)	Food waste	7.53
(Amouei et al. 2017)	Household solid waste	8.2
(Cao et al. 2016)	Vegetable and fruit waste	7.3
(Huntley and Ansari 2021)	Vegetable waste	7.34

Electrical Conductivity (EC) is measured to identify the concentration of salt in the vermicompost sample. The highest electrical conductivity was recorded in MFW-ES (1.630±0.01 dS/m), and the minimum was TW-C (0.434±0.01 dS/m) (Table 4). The result showed that EC was comparatively higher in all vermicompost samples supplemented by eggshell powder. It might be due to a sufficient amount of calcium in eggshells. The findings recorded by various researchers were very wide even within food waste: 0.54 dS/m in household solid waste (Amouei et al. 2017), 1.55 dS/m in fruit waste, 2.14 dS/m in vegetable waste (Huntley and Ansari 2021), and 4.9 dS/m in food waste vermicompost (Majlessi et al. 2012). EC value of mature compost must be very low to support plant growth. Various authors have set different EC limits. Awasthi et al. (2014) used 4 dS/m as the EC value limit for compost to be applied to the soil. EC values (Table 4) recorded in all samples were within the limits for the growth of the plant. Moreover, for the survival of earthworms, the electrical conductivity should be less than 2 dS/m (Hoekstra et al. 2002).

Table 4. Electrical conductivity recorded in vermicompost

Control and treatment combination	Electrical conductivity (dS/m)
TW-C	0.434±0.014
TW-BM	0.500±0.011
TW-ES	0.730±0.017
VW-C	0.900±0.012
VW-BM	1.241±0.001
VW-ES	1.455±0.014
MFW-C	1.053±0.026
MFW-BM	0.649±0.029
MFW-ES	1.603±0.017

The present study showed that vermicompost prepared from all three kinds of waste were rich in organic carbon percentages ranging from 28.37±2.23 (VW-ES) to 37.99±2.47 (VW-C) (Table 5)**.** The result showed that organic carbon in vermicompost was slightly less in the treatment group than in the control group, but no significant difference was obtained (Table 6). According to Venkatesh and Evera (2008), earthworms and microbes use a significant portion of carbon and nitrogen for the decomposition of organic wastes, which may have reduced the amount of organic carbon that is converted to CO_2.

Table 5. Organic carbon recorded in different types of waste combination

Control and treatment combination	Total organic carbon (%)
TW-C	35.70±2.65
TW-BM	33.19±0.51
TW-ES	31.07±3.32
VW-C	37.99±2.47
VW-BM	29.81±1.44
VW-ES	28.37±2.23
MFW-C	37.33±1.35
MFW-BM	31.33±5.05
MFW-ES	31.03±6.76

Table 6. Comparison of vermicompost prepared among three types of waste

SN.	Parameters	F Value	P- value
1	Moisture content (%)	5.75	0.001
2	pH	6.64	0.001
3	Electrical conductivity (dS/m)	1577.39	0.001
4	Organic carbon (%)	2.99	0.025
5	Total nitrogen (%)	118.98	0.001
6	Total phosphorus (%)	663.64	0.001
7	Total potassium (%)	82.51	0.001
8	C/N ratio	30.27	0.001
9	Calcium (%)	1094.34	0.001
10	Magnesium (%)	103.23	0.001

The maximum amount of nitrogen in the vermicompost sample prepared from tea waste was found as 6.85±0.12% (TW-BM), 7.73±0.29 (TW-ES), and 6.30±0.12 (TW-C), indicating that tea waste is the good raw material for compost manure. However, total nitrogen in vermicompost derived from vegetable waste was comparatively lower than other waste, ranging from 3.56±0.29 in (VW-C) to 3.67±0.36% **(Fig. 4).** This might be due to leaching and volatilization of nitrogen compounds during vermicomposting because vegetable waste unit produced more leachate. In the present study, the nitrogen content in tea waste vermicompost (6.85±0.12%) was significantly increased as compared to raw material (1.56±0.12%).

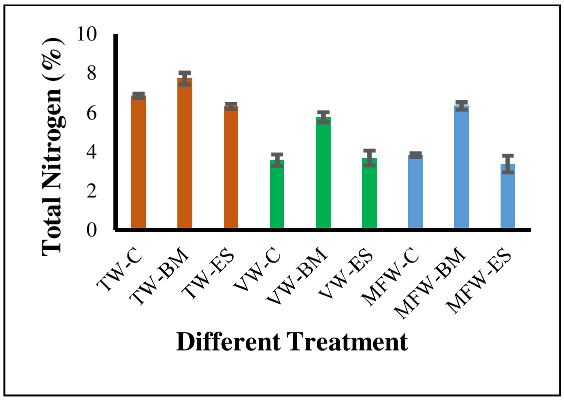

Fig. 4 Total Nitrogen in vermicompost prepared from different wastes

Moreover, the study revealed that the use of bonemeal powder in all waste also enhanced the nitrogen content in vermicompost. The total nitrogen was comparatively higher by 12.84% in TW-BM, 61.51% in VW-BM, and 65.70% in MSW-BM as compared to their respective control groups. T-test showed there was a significant difference between control and treatment in all vermicompost samples ($p<0.05$). However, eggshells did not contribute to the nitrogen in the vermicompost. Like bonemeal powder, the use of phosphorus additives (phosphogypsum and superphosphate) can conserve nitrogen and the maturity of manure composting (Li et al. 2021). The reason behind enhancing nitrogen content in prepared compost manure is the reduction of ammonia and total nitrogen loss during waste decomposition (Li et al. 2021). The result is supported by Zhang and Lau (2007), indicating that the use of struvite in poultry manure conserves nitrogen and prevents a maximum amount of nitrogen from being liberated into the surrounding environment as ammonia or nitrate as ammonium nitrogen is fixed in struvite. The results showed that ammonia emission was reduced by 40% and 84%, while nitrogen retention in the compost was improved. Several studies showed different concentrations of nitrogen content in vermicompost. Vermicompost derived from food waste was recorded as 2.56% nitrogen (Pierre et al. 2020), fresh food, 1.1% (Majlessi et al. 2012), vegetable waste 1.73% (Huntley and Ansari 2021), fruit and vegetable waste 2.04% (Lleó et al. 2013), cow dung with maize straw 3.09% (Geremu et al. 2020), water hyacinth 1.34% (Karmakar et al. 2013), cow dung 1.33% (Moustafa et al. 2021), green waste, 2.56% (Cai et al. 2018). In general, nitrogen content in vermicompost is dependent upon the raw material used and the degree of decomposition (Suthar and Singh 2008). The maximum amount of nitrogen content in vermicompost is especially due to the nitrogenous excretory substance produced by earthworms (Tripathi and Bhardwaj 2004).

Bonemeal powder is the source of phosphorus (22.19±0.89%), which is presented in Table 2. The study revealed that a high amount of phosphate percentage was present in vermicompost made by vegetable waste 9.61±0.12, followed by mixed food waste 8.45±0.43 and tea waste 5.36±0.35 which was treated by bonemeal as supplement materials. The independent t-test showed that there was a significantly different ($p<0.05$) phosphorus content between control and treatment in all kinds of vermicompost prepared by waste materials. The total phosphorus content in all treatment groups was 470.21% more in TW-BM, 252.01% in VW-BM, and 333.33% in MFW-BM than in the respective control group (Fig. 5). The results also showed that there was maximum total phosphorus in prepared vermicompost than raw materials. The reason is due to the mineralization and mobilization process of phosphorus, which is aided by bacterial and phosphatase enzymes in the intestines of earthworms (Adhikari et al. 2008). The result of phosphorus in vermicompost derived from vegetable waste is less or more similar to the study carried out by Muthukumaravel et al. (2008). The phosphorus in vermicompost derived from vegetable waste was found to be 1.10%, and in the present study, it was 1.38% (VW-C). Phosphorus in all vermicompost samples follows the standard set by the Nepal Government (>0.5 %).

The result showed that the highest percentage of potassium (4.10 ±0.46) was obtained from vermicompost derived from mixed food waste, and the lowest value (0.80 ±0.04) was found in tea waste vermicompost (TW-C). The potassium concentration in tea waste vermicompost exhibited relatively lower levels in comparison to vermicompost derived from vegetable and mixed food waste. The feeding material of mixed food waste is also rich in potassium content (4.77%). The independent t-test showed that there was no significant difference between control and treatment among three kinds of waste. According to previous studies, the potassium was measured as 3.26% in vermicompost made from vegetable waste (Muthukumaravel et al. 2008), 0.8% in fresh food (Getachew et al. 2018), 1.72% in food waste (Pierre et al. 2020) , and 1.2% in vegetable and fruit waste

(Cao et al. 2016). This showed that potassium was comparatively high in vegetable and mixed food waste in the present study (Fig. 6).

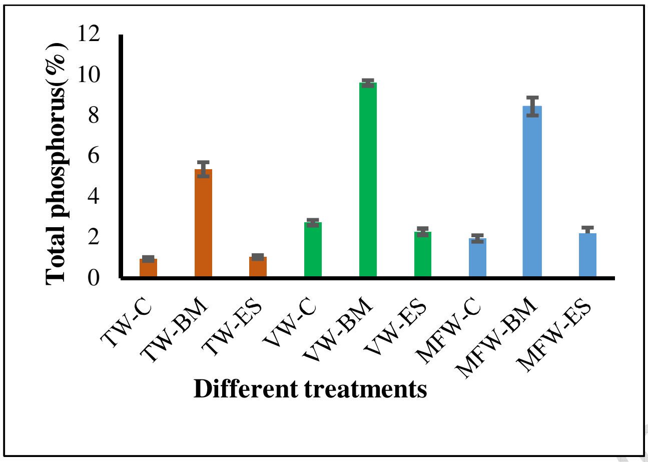

Fig. 5 Total Phosphorus in vermicompost prepared from different wastes

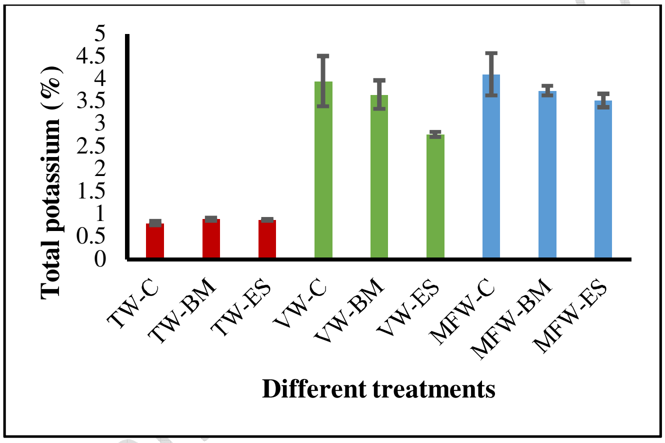

Fig. 6 Potassium in vermicompost prepared from different wastes

The Carbon/nitrogen (C/N) ratio is an indicator to measure the maturity and stabilization of organic matter. A C/N ratio of less than 20 is regarded to show adequate maturity and 15 or less is preferred (Raj and Antil 2011). A wide range of C/N ratios is not suitable for the growth of plants. Plants can only assimilate nitrogen when the C/N ratio is less than 20. The C/N ratio in all control and treatment in the present study follows within this acceptable range. It ranged from 4.28±0.12 (TW-BM) to 10.68±0.56 (VW-C). The current investigation was supported by Albasha et al. (2015) found that the C/N ratio in Kitchen waste was 5.45 during 60 days of vermicomposting. However, in agricultural waste, the C/N ratio was found to be higher as compared to food waste. The study carried out by Jaybhaye and Bhalerao (2016) found C/N ratio of 23.25 in paddy straw and 38.85 in rice straw and cow dung mixture. Vermicompost has a lower C/N ratio as compared to other general composts, which is a suitable means for nutrient availability in the soil (Gajalakshmi and Abbasi 2008). A C/N ratio observed in this research was matched to the prescribed threshold established by the government of Nepal (<20). The value of the C/N ratio depends upon the nitrogen and organic matter present in the prepared vermicompost.

Calcium in the present study varied from 0.724±0.070 (TW-C) to 7.306±0.101 (MFW-ES) (Fig. 7). The results indicate that the utilization of eggshell powder is the primary factor contributing to the enhancement of calcium levels in the prepared vermicompost. In every three types of vermicompost added with eggshell powder, calcium was present in a higher amount as compared to control and bonemeal powder treatment (Fig. 7). Independent T-test for calcium revealed that there were significant differences between control and eggshell treatment in all types of waste (<0.001). A study carried out by other researchers, such as Cao et al. (2016), found 1.0% calcium in vegetable and fruit waste and 0.9% in green waste vermicompost (Domínguez et al. 2018).

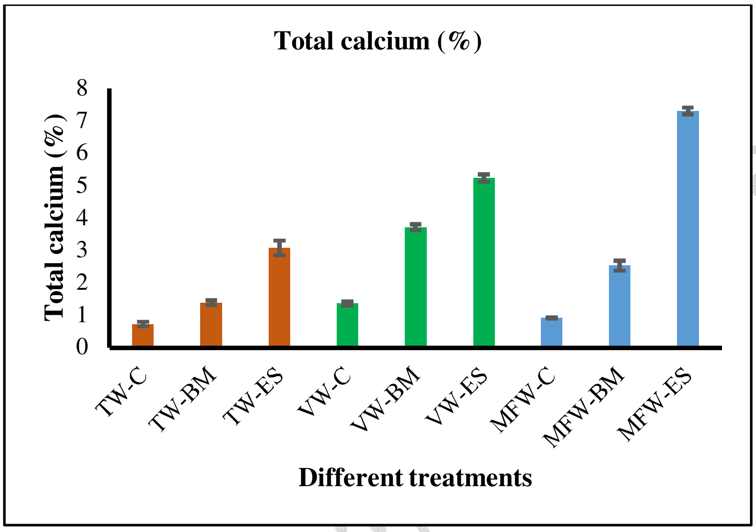

Fig. 7 Total Calcium in vermicompost prepared from different wastes

Magnesium in the present study varied from 0.108±0.010% in TW-C to 0.949±0.028 in MFW-ES. Magnesium (0.43%) in combination with vegetable and fruit waste was recorded by Cao et al. (2016), and 2.0% was recorded in food waste by Pierre et al. (2020).

The ideal temperature for earthworms is between 15 and 25 ^{0}C (Islam et al. 2018). In the present study, the bedding temperature ranged from 23.3 to 26.1 ^{0}C in tea waste and 23.3 to 25.5 ^{0}C in vegetable waste in the 12-week experiment. The temperance difference between control and treatment & among waste in this study is low as compared to other studies. This might be due to the use of interval waste feeding per week. The results showed that bedding temperature is proportional to the room temperature (Fig. 8 and 9). The temperature data revealed that the bedding temperature is less than room temperature. In general, the temperature of the bed is greater than room or ambient temperature due to the decomposition of organic waste by microbial agents (Ansari and Hanief 2015).

Germination Index (Phytotoxicity test)

The germination index was computed as a measure of quality assessment of vermicompost. In order to evaluate the efficacy of vermicompost, a gram seed was selected as the subject of the experiment (Fig. 10 and 11). In the present study, the Germination Index of Gram seed varied across all treatments, with values ranging from 84.67% (VW-C) to 164.32 (MFW-BM) (Table 7). The application of bonemeal and eggshell treatment resulted in higher germination index values. According to Helfrich et al. (1998), a Germination Index value of 70% is indicative of the maturity of vermicompost. The study observed germination index values exceeding 70% for gram seeds across all treatments, suggesting a reduced occurrence of phytotoxic compounds (Khatua et al. 2018). In a study conducted by Pottipati et al. (2022), it was revealed that the compost produced from a mixture of vegetable waste, cow dung, and sawdust had a germination index of 98±0.3%. In a study conducted by Khatua et al. (2018), it was observed that compost manure formed from the banana stem resulted in germination indices of 75.06% for rice and 85.98% for peas.

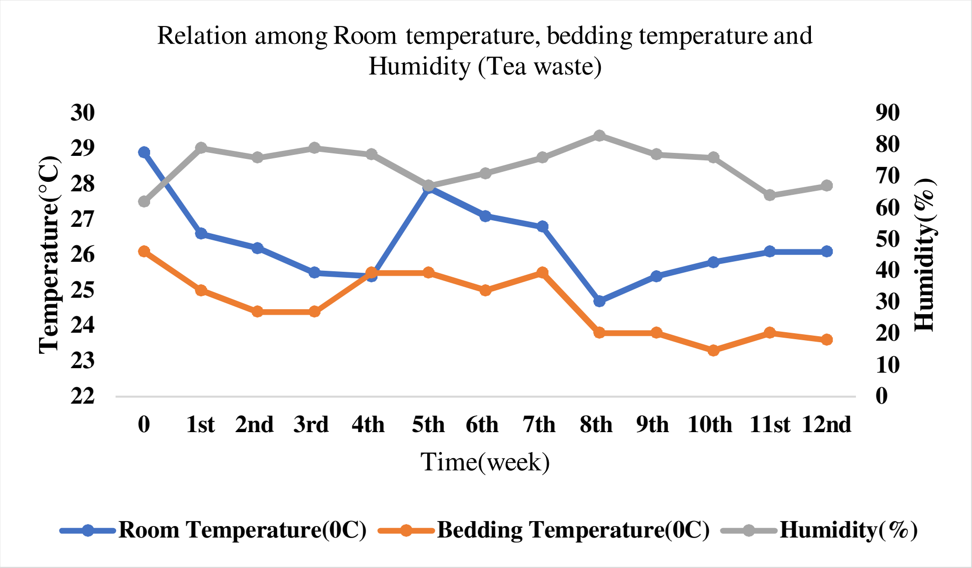

Fig. 8 Temperature and humidity recorded in tea waste experiment

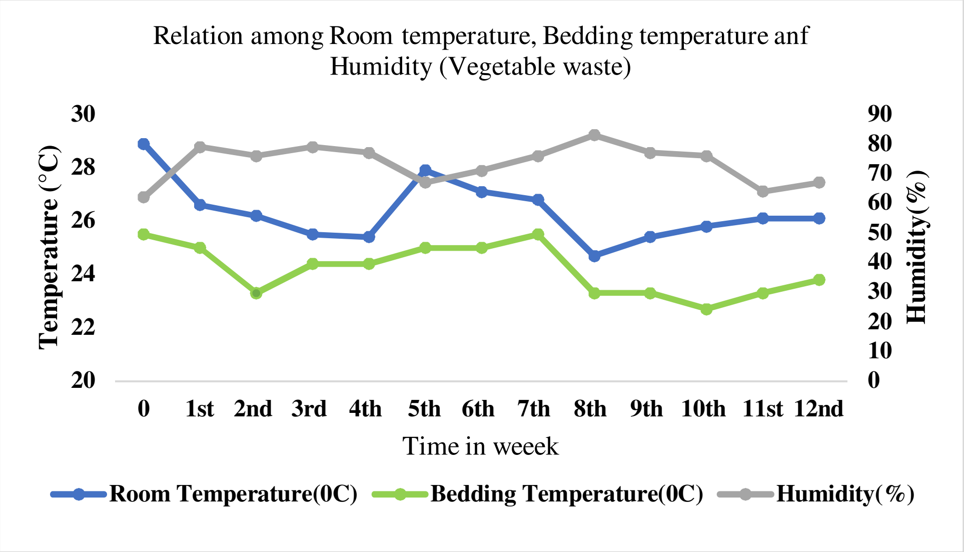

Fig. 9 Temperature and humidity recorded in vegetable waste experiment

Table 7. Germination Index

Waste treatment	Germination Index
TW-C	89.79
TW-BM	157.14
TW-ES	103.02
VW-C	84.67
VW-BM	132.67
VW-ES	134.69
MFW-C	85.71
MFW-BM	164.32
MFW-ES	161.22

Fig. 10 Gram seed germination

Fig. 11 Gram seed with developing roots and shoots

Comparison of vermicomposting with other methods of composting

The comparative study of composting methods (Table 8) highlights the versatility of vermicomposting, which can be employed both indoors and outdoors with a small footprint. Although it incurs higher initial costs, the long-term benefits, such as high-quality vermicompost and potential worm sales, contribute to its economic viability. Other methods, including windrow composting, pit composting, bin composting, and tub basin composting, each have their unique characteristics. The choice of method depends on factors like space availability, cost considerations, waste characteristics, and desired compost quality. Vermicomposting emerges as a favorable option for its adaptability, quality output, and potential economic returns, while other methods offer distinct advantages based on specific requirements.

Table 8. Comparison of vermicomposting with other methods of composting

Factors	**Methods of composting**				
	Vermicomposting (current study)	Windrow composting Ayilara et al. (2020)	Pit composting Rodale et al. (1975)	Bin composting (Karnchanawong and Suriyanon 2011)	Tub basin composting (Maharjan et al. 2022a)
Location	Can be performed indoors; nevertheless, it is also viable on a larger scale in an outdoor setting	Should be conducted in an outdoor setting	outdoor setting	Indoor	Indoor setting
Land required	Small	Large	Large	Small	Small
Cost	Higher initial costs due to the need for container, bedding materials, and a population of composting worms. However, the maximum benefit is realized towards the end, considering that the cost of vermicompost is higher compared to general compost available in the market. Additionally, the worms themselves can be sold, which cost approximately Nepalese Rupees 3000 per kilogram.	High	Depend upon size and quantity of waste used	Low	Low
Waste feeding	The introduction of organic waste to earthworms should be undertaken with care. Not all types of organic waste are suitable; those that are acidic, salty, possess high moisture content, or contain oil should be excluded from the feedstock.	Various organic wastes	Various organic wastes	Various organic wastes	Various organic wastes
Manpower	Although vermicomposting is generally easy to maintain, it is important to conduct regular monitoring and perform maintenance tasks to ensure the worms thrive in optimal conditions.	More labor	More labor	Low labor	Low labor
Process	Exclusively reliant on aerobic conditions	Aerobic	Anaerobic	Aerobic	Aerobic
Waste turning/Aeration	No turning is required; the earthworms naturally move up and down, effectively contributing to the aeration process.	required turning	Difficult to maintain	required turning	required turning
Quality	Vermicompost exhibits superior quality compared to standard compost, particularly in terms of nitrogen, phosphorus, and potassium content.	-	-	-	Lower in comparison to vermicompost
Time for maturation	Fast, but the rate is influenced by the quantity of earthworms.	Fast but depends upon the rate of waste turning	Slow (6-9 months)	Fast but depends upon the rate of waste turning	Fast but depends upon the rate of waste turning

Data uncertainty

In vermicomposting, data uncertainty can stem from multiple sources, including variations in the spatial and temporal composition of organic waste, necessitating careful and representative sampling. Heterogeneity within vermicompost batches, coupled with the distribution of earthworms, introduces uncertainties during sampling. Physico-chemical analyses are prone to variability due to differences in laboratory procedures and equipment, emphasizing the importance of standardized protocols and instrument calibration.

Conclusion

This research is designed to assess the effects of bonemeal and eggshell powder on the quality of vermicompost. The findings of this study suggest that the use of bonemeal powder is important for the enrichment of phosphorus. The addition of eggshell powder is attributed to the enhancement of calcium levels in the vermicompost. The utilization of bonemeal powder additionally improves the nitrogen composition in all vermicompost obtained from tea waste, vegetable waste, and mixed food waste. In addition to this, the use of eggshells reduced the acidity of the raw materials. The species *Eisenia fetida* is useful for the recycling of the organic waste produced by urban residents. Tea waste vermicompost is rich in nitrogen content. Except for moisture content, all vermicompost prepared from tea waste, vegetable waste, and mixed food waste were within the standards for vermicompost set by Nepal Government. In this study, the germination index values for gram seeds were all higher than 70%, which means there were fewer phytotoxic substances present. More in-depth research should prioritize the direct utilization of alternative feeding materials, such as fresh waste, without pre-composting.

The significance of vermicomposting extends well beyond its primary role in waste conversion. It encompasses broader implications for environmental sustainability, enhancement of soil health, and the generation of nutrient-rich organic matter. Vermicomposting stands as a potential solution to mitigate environmental pollution, improve soil structure, and offer a sustainable approach to organic waste management. Emphasizing these implications adds depth and context to highlight the broader significance of the research.

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