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Trichoderma Viride-mediated Bioconversion: A Promising Approach for Recycling of Household Kitchen Waste

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Abstract

Management of waste has become challenging issue for mankind to resolve. From diverse routes enormous quantities of waste are generated every day, the majority of waste is dumped on roadways, in open spaces, or near water bodies (such as streams, rivers, or drainage systems) or on the roadways, which is the main cause for polluting of the environment. Present study was designed to investigate different recycling approaches to remediate the kitchen waste into organic manure. Various experimental sets were designed to investigate the rate of decomposition of kitchen waste with different mixtures viz Set-I (Kitchen waste:Dung), set-II (Kitchen waste: Rice straw), Set-III (Kitchen waste:Dung: Rice straw), Set-IV (Kitchen waste:Dung +*Trichoderma viride*), Set-V (Kitchen waste:Rice straw+*Trichoderma viride*) and S et-V (Kitchen waste:Dung:Rice straw+*Trichoderma viride*). Results of the present study revealed that all the experimental sets showed ability to recycle the kitchen waste into organic manure. However significantly higher rate decomposition was observed in set-IV (KW: D+*Trichoderma viride*) such as change in physical features (color, odour, loss of weight and volume). Therefore, kitchen waste mixed with cow dung and *Trichoderma* was found to be the most suitable medium for the decomposition of kitchen waste. This method can be used for the recycling of other types of biodegradable waste to develop alternative organic fertilizer for agriculture purposes.

Keywords: Kitchen waste, vermi-remediation, Trichoderma viride, recycling, organic manure.

1 Introduction

Nature has provided us a healthy environment enriched with diverse types of living creatures like plants, animals, insect, fungi and algae and all these contribute in environmental sustainability. However, due to increasing anthropogenic activities, environment has become deteriorated and polluted due the excessive anthropogenic activities including generation of waste. Any substance or byproduct that has been discarded since it is no longer needed or valuable is known as waste. Rapid industrialization and urbanization makes more difficult to manage waste since it puts more stress on the infrastructure for managing such a large quantity of municipal solid waste (Hajam et al., 2023).

Generally, our kitchen produces fruits, vegetable peels, cooked leftovers, and uncooked leftovers. Larger enterprises like hotels, restaurants, and food factories also produces more organic waste If we use this organic waste in a good manner it may benefits the environment. Kitchen waste production is the major source of organic municipal solid waste (MSW). In developing countries, the organic waste does not gets managed properly, it can give rise to undesirable environmental conditions, odours, and the pollution of ground water by the penetration of pollutants (Guo et al., 2012). People exposed to these unhygienic conditions may suffer from major health issues because of poor waste management. It is one of the main causes of the occurrence of diseases like cholera, typhoid, dysentery, and malaria (Kumari et al., 2019). Solid waste disposal is difficult in metropolitan areas due to a lack of specific space. Still, most municipal corporations and other local organizations are recognizing as a real option for sustainable waste management solution. The most well-known methods for management of kitchen waste are open dumping, sanitary landfills, composting, and vermicomposting (Jain et al., 2021).In India millions of tones organic waste are disposed in landfills or burned annually, (Swati et al., 2018). Around 960 million tonnes of solid waste are reportedly produced in India each year from a various source, including industry byproducts, municipalities, mining, agricultural, and other activities (Pappu et al., 2007). Moreover, agricultural practices produce near about 350MT of waste (Pappu et al., 2007). Additionally, more than 90% of this waste gets disposed in landfills or other unscientific ways, which causes a variety of issues in environment and public health (Nandan et al., 2017), India lacks the suitable management policy for the management of organic waste, where on the one hand pollution is getting worse day by day as a result of the accumulation of waste derived organic pollutants. Maintainace of healthy biosphere and safely disposal of various types of wastes has become very crucial. However, improper waste disposal in public places can lead to obnoxious odours, ground water pollution, and soil pollution in the environment (De and Debnath, 2016). Ho et al. (2022) reported that composting is the most popular and ideal method for recovering minerals from organic municipal solid waste.
Kitchen waste or household waste is a main source of environmental contamination. Conversion of kitchen waste into organic compost using biological agents is one of the possible solutions to minimize the heaping of kitchen waste. Organic compost is known to be environmental friendly as compared to fertilizer. Organic compost is having least adverse effect on environment and is also economically more beneficial for organic farming. Organic compost prepared by using the biological agents are beneficial to improve the vegetable crop yield and financial viable. One of the significant methods for the management of waste might be use of various microbes, such as actinomycetes, fungus, and bacteria, these microbes helps to decrease the quantity of waste produced in the environment and completes the process of decomposition at faster rate (Sharma et al., 2022).Fungi are known to contribute an important role in composting process such as *Phanerochaetechry sosporium*, *Pleurotus ostreatus*, *Polyporusostri formis, and Trichoderma harzianum* (Singh and Kalamdhad, 2015). Fungi breaks breakdown the lignin, extensively by the action of extracellular enzymes such “laccase, lignin peroxidase and manganese peroxidase. Fungi are also well known to perform cellulolytic activity for the degradation of cellulose (Tsegaye et al., 2019). Considering, the importance of fungi in the breakdown processes of waste material. Present study was designed to explore the potential of *Trichoderma viride* as a natural decomposition agent for the recycling of kitchen waste into organic manure.

2 Materials and methods

2.1 Experimental site

This research work was carried out at the Sant Baba Bhag Singh University, Jalandhar, Punjab, India.

2.2 Materials Required

Kitchen waste was collected from the Boys hostel and girl’s hostel, Sant Baba Bhag Singh University. Cow dung was procured from cow dairy farm Dera Sahib near to University Campus of Sant Baba Singh University. Rice straw was collected from agriculture field of university campus. *Trichoderma viride* was procured from Agriculture University of Punjab (Figure 1).

Figure 1: Showing *Trichoderma viridie*

2.3 Experimental Design

Kitchen waste was decomposed by preparing different experimental sets with different mixtures viz Set-I (Kitchen waste:Dung), set-II (Kitchen waste: Rice straw), Set-III (Kitchen waste:Dung: Rice straw), Set-IV (Kitchen waste:Dung+*Trichoderma viride*), Set-V (Kitchen waste:Rice straw+*Trichoderma viride*) and Set- V (Kitchen waste:Dung:Rice straw+*Trichoderma viride*) (Table 1).

Table 1: Experimental design for the recycling of Kitchen waste (KW) into organic manure by using different formulations.

Sets	Components	Ratio	Total weight	Total weight in ratio
1	Kitchen waste:Dung	2:2	3kg	1.50kg:1.50kg
2	Kitchen waste: Rice straw	2:2	3kg	1.50kg:1.50kg
3	Kitchen waste:Dung: Rice straw	2:1:1	3kg	1.50kg:0.75kg:0.75kg
4	Kitchen waste:Dung+*Trichoderma viride*	2:2+ 20gm	3kg	1.50kg:1.50kg+20gm
5	Kitchen waste:Rice straw+*Trichoderma viride*	2:2+20 gm	3kg	1.50kg:1.50kg+20gm
6	Kitchen waste:Dung:Rice straw+*Trichoderma viride*	2:1:1+20 gm	3kg	1.50kg:0.75kg:0.75kg+20gm

2.4 Degradation of kitchen waste

Different combinations were designed to decompose the kitchen waste by using *Trichoderma viride* in some experimental sets, whereas in some experimental sets *Trichoderma viride* was not used. Six different experimental sets were prepared with different materials (kitchen waste, cow dung, rice straw and *Trichoderma viride)* to decompose the kitchen waste and same replicates were prepared in beds. In each experimental set, 3kg of culture medium was taken. At the bottom of each experimental set jute cloth lining was placed to minimize the sticking. Holes were made in each set to drain out the excess water. Changes in weight were calculated by using the following formula.

$$\text{Percentage in weight} = \frac{\text{Initial weight- Finial weight}}{\text{Initial weight}} \times 100$$

2.5 Assessment of changes in physical characteristics of kitchen waste during its bioconversion using *Trichoderma viridi*

Following observations were made from the decomposed solid waste: Change of color, odor, temperature, volume and weight losses of decomposed organic solid waste. Data were recorded in every 10 days' interval up to 30 days.

For volume loss the following formula was used:

V=pr2h, V=Volume of the garbage, r=Radius of the tray,

h=Height of the decomposed garbage.

Percentage of volume loss was measured using the following formula:
Volume loss (%) = VV1/V ´100,
V = Initial volume, V1=Final volume.
Percentage of weight loss of decomposed garbage was also calculated by using the following formula:
Weight loss (%) = W-W1/W ´100
Where, W=Initial weight, W1=Final weight.

3 Results

3.1 Assessment of changes in weight

The sets I, V, and VI showed a moderate reduction in weight, whereas sets II and III showed a less prominent reduction in weight. Consequently, significantly higher reduction in weight was observed in set-IV (Table 2).

Table 2: Showing weekly changes in weight.

		Changes in Weight							
Sets	Composition	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**
I	KW: D (2:2)	3.46	3.36	3.27	3.19	3.06	2.99	2.83	2.70
II	KW:RS (2:2)	3.45	3.39	3.31	3.25	3.18	3.07	2.97	2.91
III	KW: RS:D (2:1:1)	3.78	3.71	3.59	3.43	3.29	3.15	2.93	2.76
IV	KW:D+ *T.viride* 2:2 +20gm	3.29	3.18	3.03	3.96	2.85	2.80	2.72	2.66
V	KW:RS+ *T.viride* 2:2 +20gm	3.36	3.31	3.18	3.11	3.06	2.95	2.82	2.69
VI	KW:RS:D+*T. viride* 2:1:1+20gm	3.56	3.47	3.41	3.29	3.17	3.03	2.86	2.74

3.2 Assessment of weekly changes in different set during the decomposition of kitchen waste

All sets including Set-I- Kitchen waste (KW): Dung (D), Set-II-Kitchen waste (KW) : Rice Straw (RS), Set-III-Kitchen waste (KW): Rice Straw (RS): Dung (D), Set-IV-Kitchen Waste (KW): Dung (D)+*Trichoderma (T.viride)*, Set-V-Kitchen Waste (KW): Rice Straw (RS)+*Trichoderma viride* (*T. viride*), and Set-VI- Kitchen Waste (KW): Rice Straw (RS): Dung (D)+*Trichoderma viride* (*T. viride*),showed decomposition of kitchen waste. However, significantly higher rate of decomposition was observed in Set-IV (KW: D+*T. viride*) (table 2 and 3). All the visible changes are represented in different symbols. The various visual changes were documented at the commencement of experimental and were continued during the whole experimental period on weekly basis (Figure 2). Set I, II, and III showed the least decomposition rate, however set V and VI showed a moderate rate of decomposition. But, significantly higher decomposition rate was clearly observed in set–IV (Table 3).

Figure 2 : Showing the effec of *Trichoderma viride* on the recycling of kitchen waste into organic manure.

Table 3: Major visible observations during recycling of kitchen waste.

Sets	Composition	Ratio	Week 1	Week 2	Week 3	Week 4	Week 5	Week6	Week7	Week 8
I	KW:D	2:2	……	*	*	**	**	**	***	***
II	KW:RS	2:2	……	……	*	*	*	**	**	**
III	KW: RS:D	2:1:1	……	*	*	**	**	***	***	***
IV	KW:D+*T.viride*	2:2+20gm	*	*	**	***	***	****	****	*****
V	KW:RS+*T.viride*	2:2+20gm	……	*	*	*	**	**	***	****
VI	KW:RS:D+*T.viride*	2:1:1+20gm	……	*	*	**	**	***	***	****

[…......] No decomposition
[*] Initiation of decomposition
[**] Under decomposition
[***] Slight decomposition
[****] Moderate decomposition
[*****] Complete decomposition

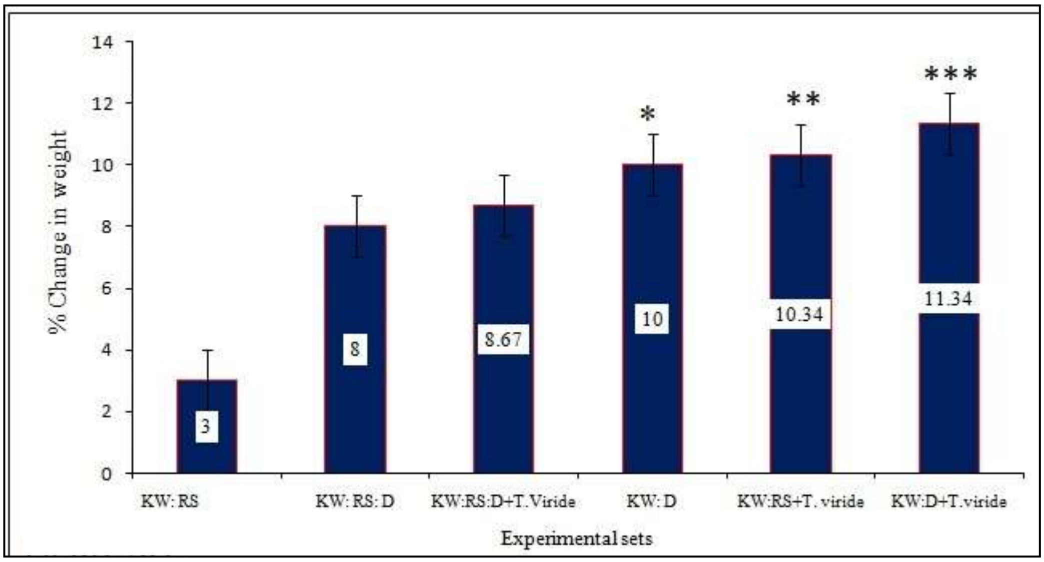

Figure 3: Showing the graphical representation of percent change in weight and their correlation with respective to different formulations

3.3 Assessment of percent (%) change in weight in different experimental sets

The percentage change in weight were determined in different sets, and the results was 10%, 3%, 8%, 11.34%, 10.34%, and 8.67%, respectively, for sets I, II, III, IV, V, and VI. Results showed decomposition has taken place all sets. However significantly higher decomposition was observed in set IV (KW: D+*T. viride*) which corresponds with maximum change in weight (11.34%), demonstrating that set IV has a higher decomposition rate (Table 4 and Figure 3).

Table 4: % Change in weight in different experimental sets during recycling of kitchen waste.

Sets change	Composition	Ratio	Initial weight	Final weight	Gross weight (%)
I	KW: D	2:2	3kg	2.70	10*
II	KW: RS	2:2	3kg	2.91	3
III	KW: RS: D	2:1:1	3kg	2.76	8
IV	KW:D+*T.viride*	2:2+20gm	3kg	2.66	11.34***
V	KW:RS+*T. viride*	2:2+20gm	3kg	2.69	10.34**
VI	KW:RS:D+*T.viride*	2:1:1+20gm	3kg	2.74	8.67

3.4 Assessment of net change in weight in different experimental sets

The net change in weight was determined in different sets, and the results showed significant variations in different experimental sets viz. 0.3, 0.09, 0.24, 0.34, 0.31, and 0.26 in sets I, II, III, IV, V, and VI respectively. Aaqswll sets showed net change in weight but highest net change in weight was determined in set IV (Table 5 and figure 4) and yield of compost varied among the different sets highest yield of compost was recorded in set set-VI followed by V and VI respectively.

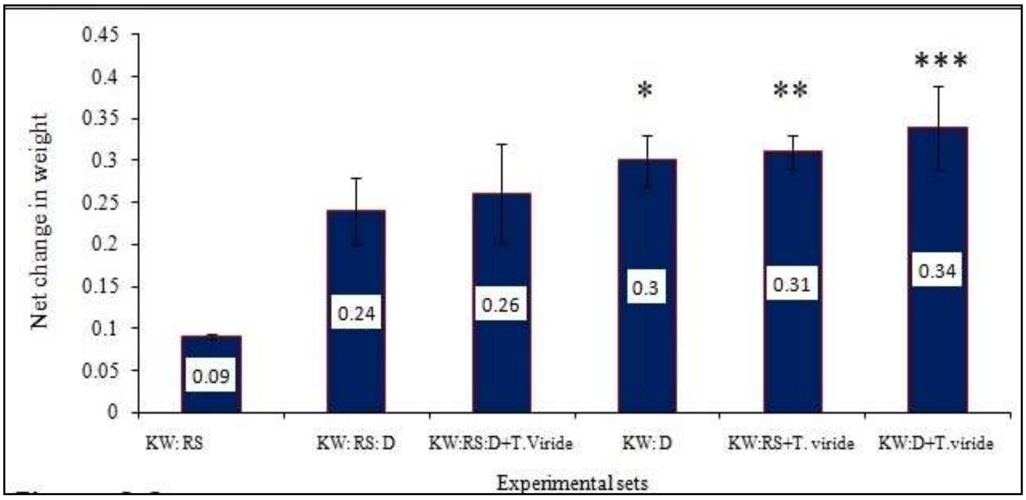

Figure 4: Showing the graphical representation of percent net change in weight and their correlation with respective to different formulations

Table 5: Represents the net changes in weight from initial to final stages of recycling.

Sets change	Composition	Ratio	Initial weight	Final weight	Net change in weight
I	KW: D	2:2	3kg	2.70	**0.3**
II	KW: RS	2:2	3kg	2.91	**0.09**
III	KW: RS: D	2:1:1	3kg	2.76	**0.24**
IV	KW:D+*T.viride*	2:2+20gm	3kg	2.66	**0.34**
V	KW:RS+*T. viride*	2:2+20gm	3kg	2.69	**0.31**
VI	KW:RS:D+*T. viride*	2:1:1+20gm	3kg	2.74	**0.26**

3.5 Assessment of changes in physical characteristics of kitchen waste during its bioconversion using *Trichoderma viridi*

Results of the present study revealed that all experimental sets showed reduction in volume and weight following the treatment of *Trichoderma viride* with kitchen waste blended with rice straw and cow dung. However, significantly higher reduction in volume and weight was observed in set-IV at 4^{th} week (8.34±0.56 & 9.61±0.76) and 8^{th} week (23.45±0.65 & 22.84±0.92) followed by V, I and VI sets at 4^{th} and 8^{th} week (Table 5).

Table 6: Changes in physical characteristics of kitchen waste during its bioconversion using *Trichoderma viridi*

		Change of characteristics of kitchen waste at 4 weeks					**Change of characteristics of kitchen waste at 8 weeks**				
Sets	**Composition**	**Colour**	**odour**	**Temp. (ºC)**	**Volume (inch)**	**Weight loss (gm %)**	**Colour**	**Odour**	**Temp (ºC)**	**Volume loss**	**Weight loss (gm%)**
I	KW:D	Green	Foul	28	5.23±0.44	6.23±0.34	grey	Light foul	28	13.45±0.56	15.56±0.89
II	KW:RS	Green	Foul	28	2.34±0.34	1.21±0.31	Greyish black	Light foul	28	4.65±0.22	5.76±0.26
III	KW: RS:D	Green	Foul	28	3.12±0.23	3.81±0.26	Grey black	Light foul	28	8.44±0.34	6.45±0.34
IV	KW:D+*T.viride*	Green	Light foul	32	8.34±0.56	9.61±0.76	blackish	No odour	27	23.45±0.65	22.84±0.92
V	KW:RS+*T.viride*	Green	Foul	29	6.54±0.34	7.21±0.24	Light black	Light foul	28	14.54±0.76	18.91±0.65
VI	KW:RS:D+*T.viride*	Green	Foul	29	7.65±0.39	8.32±0.39	Light black	Light foul	8	12.97±0.34	13.45±0.67

4 Discussions

Changes in weight are the primary sign of decomposition. In all the experimental sets 3kg of mixture were taken. During the Ist week the weight of all the sets were observed to be increased in all sets viz, set-I, (3.46), set-II, (3.45), set-III, (3.78), set-1V, (3.29), set-V, (3.36) and set-VI(3.56).This increase weight might be due to the regular sprinkling of water.

From the week 2^{nd} [set-I (3.36), set-II (3.39), set-III (3.71), set-IV (3.18), set-V (3.31) and set-VI (3.47)] upto the 4^{th} week [(set-I (3.19), set-II (3.25), set-III (3.43), set-IV (3.96), set-V (3.11) and set-VI (3.29)] weight in all the experimental sets showed gradual decrease in weight. Gradual decrease in weight indicates that process of decomposition has begun in all the experimental sets. However, this decrease in weight was not found constant in all experimental sets. Highest decrease in weight was observed in set-IV followed by set I and V respectively. The decrease in weight was examined and interpreted through different ways to confirm the process of bioconversion of kitchen. From 5^{th}upto the 8^{th} week of experimental study, the process of bioconversion showed significant increase in all the experimental set. Nonetheless rate of bioconversion was not found constant in all experimental sets, but change in weight was caused by the application of different formulations.

The experimental study on the bioconversion process of kitchen waste over an eight-week period revealed significant insight into decomposition dynamics. Fluctuations in weight within the experimental sets served as primary indicators of the progression of bioconversion. Initially, all sets experienced increased weight, likely due to regular water sprinkling, facilitating microbial activity initiation. Subsequently, from the second to the fourth week, gradual weight decreases suggested onset of decomposition, with variations in rates among sets. The non-constant weight decrease implied external influences, potentially from different formulations, emphasizing the need to consider treatment methods' impact on bioconversion efficiency. From the fifth to the eighth week, all sets displayed a significant increase in bioconversion, indicating thriving microbial populations. Use of *Trichoderma viride* increases the breakdown of kitchen waste in different experimental sets, due to the presence of cellulase and xylanase (Siddiquee et al., 2017). *Trichoderma virdes*, produces a significant amount of degrading enzymes, which speeds up the process of breaking down of lignocellulosic wastes (Amira et al., 2011) *Trichoderma* produces cellulolytic and ligninolytic enzymes that help it to break down of organic wastes (kitchen waste) into humidified substances (Fukasawa et al.,2012). Nonetheless, varying rates of bioconversion across sets suggested factors beyond time, such as specific formulations, influencing effectiveness. Hence, these results underscored the dynamic nature of bioconversion processes and the importance of optimizing strategies for sustainable kitchen waste management. Fungal formulation *Trichoderma viride* promotes microbial inoculation (MIT) that speeds up the decomposition of kitchen waste (Voberkovaet al., 2017). The fungus *Trichoderma* is well known for its degrading qualities (Novy et al., 2019).

In set-II and III the decomposition rate was found minimum because in all these sets *Trichoderma viridi* was not added, only kitchen waste, dung and rice straw was used. However, among these three set minimum rate of decomposition was observed in set-II in which only kitchen waste and rice straw was used followed by set II (3%) and set III (8%). All of these sets consists of rice straw, which contains lignin, it has studied that lignin gets decomposed more slowly than other plant materials and has few nutritional components. This indicates that *Trichoderma viride* is a major agent which induces decomposition due to the stimulation of enzymatic reactions, along with the *Trichoderma viride* dung provides suitable medium for the microbial life. Therefore, in set-IV significantly higher reduction in weight, % change and net changes were observed. However, moderate percentage changes (i.e. 10% and 10.34%, respectively) were observed in sets I and V. These two sets contained rice straw and dung, and it was found that the dung accelerated the composting process.

The observed differences in decomposition rates among the experimental sets, particularly in sets II and III, underscore the crucial role of *Trichoderma viride* in enhancing decomposition efficiency. The absence of *Trichoderma viride* in these sets resulted in minimum decomposition rates compared to sets where it was present. Interestingly, even among the sets without *Trichoderma viride*, set II exhibited the slowest decomposition rate, despite containing kitchen waste and rice straw. This disparity highlights the impact of rice straw, known for its slow decomposition due to lignin content, which provides fewer nutritional components compared to other plant materials. The introduction of *Trichoderma viride* in set IV significantly accelerated decomposition, suggesting its vital role in stimulating enzymatic reactions and facilitating microbial activity. The presence of dung in conjunction with *Trichoderma viride* further promoted decomposition, providing an optimal medium for microbial life. Sets I and V, containing rice straw and dung, exhibited moderate percentage changes, demonstrating the supportive role of dung in accelerating the composting process. These findings emphasize the importance of microbial agents like *Trichoderma viride* and the composition of organic materials in influencing decomposition rates. Optimizing microbial inoculation and organic material composition can enhance decomposition efficiency, contributing to more effective waste management strategies and promoting sustainable practices.

In all experimental sets, maximum volume and weight changes were observed in sets in which *Trichoderma viride* was added with other mixtures. Maximum volume loss and weight loss was observed in set-IV at 4th week (8.34±0.56 &9.61±0.76) and 8th week (23.45±0.65&22.84±0.92) followed by V, I and VI sets at 4th and 8th week (Table 6). *Trichoderma viride* producing various polysaccharide degrading enzymes which assists to breakdown long chain carbon compounds specially the bulking materials. It has been reported that wood decay fungi degrades the turf thatch, by measuring the weight loss to record breakdown of tissues of Bermuda grass (*Cynodon dactylon* L.) stolons and zoysia grass (*Zoysia japonica* Steud., Mayer) stolons, and revealed that various wood decay fungi can decompose various turf thatch constituents (Bari et al., 2007). *Trichoderma viride* has been found very effective to decompose organic solid waste materials results in maximum loss of original materials as observed in the present study. Therefore, it might be suggested that *trichoderma viride* can be used to manage the household kitchen waste through its conversion into organic manure within short period.

Moreover, results of the present study also demonstrated that the addition of *Trichoderma viride* to the mixtures resulted in maximum volume and weight changes across all experimental sets. Set IV exhibited the highest volume and weight loss at both the 4th and 8th weeks, followed by sets V, I, and VI. This trend underscores the effectiveness of *Trichoderma viride* in accelerating the decomposition process. *Trichoderma viride* is known to produce various polysaccharide-degrading enzymes, which play a pivotal role in breaking down long-chain carbon compounds, particularly bulking materials. Previous studies have highlighted the ability of wood decay fungi, such as *Trichoderma viride*, to decompose organic materials effectively. For instance, research on turf thatch degradation revealed significant weight loss, indicating breakdown of tissue constituents (Organo et al., 2022). The potent decomposition abilities of *Trichoderma viride* observed in the present study suggest its potential application in managing household kitchen waste, converting it into organic manure within a relatively short period. These findings underscore the practical utility of *Trichoderma viride* in sustainable waste management practices, offering a promising solution for converting organic waste into valuable resources (Sinha et al., 2022; Ayilara et al., 2022).

5 Significance of this study

Research findings on viable technology for its dissemination have the requirements of a long study. This study will lead to everyone making compost from day-to-day kitchen waste to convert it into organic compost. In modern city, small kitchen gardens are becoming very popular. In these kitchen garden people may use their waste produced I kitchen to convert it into compost instead of throwing them in the public places, municipal dustbins etc. Thus, one startup company may take initiative to establish kitchen-based waste collection from hostels, big cafeterias, and public places, where huge quantities of waste are generated. Therefore, this study has a positive effect on how trash is handled not only in homes but also in hostel, large cafeterias, hostels and other places.

6 Conclusion

In conclusion, it has been found that exploration of suitable method for the recycling of kitchen waste into organic compost has a significant advantage over other methods, it requires minimum duration, prevents the spreading of smell, and repels the insects. The application of prepared organic manure could be used to increase the fertility of soil and reduced the waste induced stress on environment. Therefore, this remediation idea from kitchen wastage may be implicated in every household on a small scale and farmers on a large scale for higher yield in the agriculture sector. Small farmers can increase their profitability by reducing the cost of inputs (such as use of very costly chemical fertilizers). Our study recommended that more extensive research be conducted on the application of prepared organic manure in different doses for different seasons on different vegetable and plant cultivars. It will be on large-scale farming with a special emphasis on local demography and sustainable development on a regional level.

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Author contributions
YAH designed and coordinated the study, compiled all the data, data analysis and final manuscript preparation. MR executed all the experimental work, drafted the manuscript, collected all the data, and prepared the draft. All authors read and approved the final manuscript.

Data availability
Data will be available from the corresponding author upon good scientific reason and request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Completing interests
All authors declare that they have no proprietary, financial, professional, nor any other personal interest of any kind in any product or services and/or company that could be construed or considered to be a potential conflict of interest that might have influenced the views expressed in this manuscript.

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