Research Article

Production of Bio Fortified Vermicompost and its Efficacy Against Onion Basal Rot Disease Caused by *Fusarium oxysporum* f. sp. *cepae*

Kandiah Pakeerathan*, Konesalingam Jeyavithuyan, Aruchchunan Nirosha and Gunasingham Mikunthan

Department of Agricultural Biology, Faculty of Agriculture, University of Jaffna, 44000, Ariviyal Nagar, Kilinochchi, Sri Lanka.

Abstract | The success of organic agriculture is relied on biologically fortified super compost to sustain the yield potential of high-yielding improved varieties as well as boost the soils that substantially store water, and nutrients, and suppress soil-borne diseases. Considering the scenario, an investigation was planned to recycle plant waste into biologically fortified vermicompost. Four substrates paddy straw, garden waste (banana and maize leaves), sawdust, and kitchen waste were used as mushroom substrate and then mushroom grown waste was converted into bio-fortified vermicompost using exotic earthworm *Eisenia foetida*+ *Trichoderma viride* + *Pseudomonas fluorescens*. Onion growth parameters, yield, and DSI were recorded from the experiment conducted in a complete randomized design and subjected to ANOVA using SAS 9.1. Turkey's HSD multiple comparison test and Person-correlation analysis were performed to identify the best treatment combination at $P < 0.05$. The results were significant among them at $P < 0.05$. Bio-fortified vermicompost's pH range was 7.28-8.11, C/N ratio was 25.01-9.96, and OMC was 22.66-51.53. Nitrogen, P and K ranges were 1.06% to 2.1%, 0.73%-1.87%, 0.654% to 1.38%. *Trichoderma viride* + *P. fluorescens* enriched showed lower DSI. The highest growth, yield parameters, and lower Fusarium basal rot incidents were recorded in *T. viride* and *P. fluorescens* fortified paddy straw and kitchen waste-based vermicompost. Actual yield of the "*Poovallarai*" onion is higher than the theoretical yield of 15-20 Mt/ha in paddy straw and kitchen waste-based vermicompost too. C/N ratio and growth parameters were strongly co-related (R^2 >0.5). These findings could be new eco-friendly low-cost approaches to manage soil-borne diseases as well as properly manage organic wastes into super compost.

Received | May 05, 2022; **Accepted** | July 25, 2023; **Published** | September 15, 2023
***Correspondence** | Kandiah Pakeerathan, Department of Agricultural Biology, Faculty of Agriculture, University of Jaffna, 44000, Ariviyal Nagar, Kilinochchi, Sri Lanka; **Email:** pakeerathank@univ.jfn.ac.lk
Citation | Pakeerathan, K., K. Jeyavithuyan, A. Nirosha and G. Mikunthan. 2023. Production of bio fortified vermicompost and its efficacy against onion basal rot disease caused by *Fusarium oxysporum* f. sp. *cepae. Sarhad Journal of Agriculture,* 39(3): 692-703.
DOI | https://dx.doi.org/10.17582/journal.sja/2023/39.3.692.703
Keywords | Organic waste, Spent mushroom substrate, Bio-fortification, Fusarium basal rot, *Trichoderma viride*, *Pseudomonas fluorescens*

Introduction

Traditionally, three major red onions (*Allium cepa* L.) landraces such as *Jaffna local*, *Vallari*, and *Vethalam* have been cultivated as a major cash crop in the Northern part of Sri Lanka and used as a condiment, vegetable, and medicine based on the varietal attributes like colour, pungency, and taste

(Araskesary *et al*., 2014a; b). Sri Lankans demand 100,000 Mt red onion per year out of the total annual requirement of both big and red onion of 300,000 Mt. Out of this red onion requirement around 72,000 Mt are produced locally (Department of agriculture Sri Lanka, 2021). Onion diseases like bulb rot (fungal bulb rot and bacterial bulb rot), Fusarium basal rot, leaf twister disease (anthracnose), and purple blotch account for a major share of total yield losses (Priyantha *et al*., 2014). For several decades' farmers relied mainly on fungicides, even though, integrated disease management strategies were proposed. According to the world bank report 2018, Sri Lanka is in 4th place of the highest chemical fertilizer-consuming countries in Asia (kilograms per hectare of arable land). To avoid these problems, the Sri Lankan government has banned the importation of synthetic pesticides and fertilizers. Sudden import restrictions caused significant yield losses of all most all the crops around 30-60% nationwide in the year 2021 Maha season (unpublished data). Anyhow, pre-green revolution agriculture relied on organic manures only that evidenced good for soil health but was slow in response to crop yield (Mahmood *et al*., 2017). Therefore, we have to produce nutritionally rich organic compost at the commercial level to sustain crop production and manage crop diseases. Recycling bio-wastes and fortification with beneficial microbes could be an ideal way to produce super compost (Das *et al*., 2019).

Ever-increasing human population generating waste is a major environmental hazard all around the globe (Kauser and Khwairakpam, 2022). Billions of tons of decomposable solid wastes generated from the hotels, gardens, animal farms, plant and animal-based wastes generated at the market, agro-based cottage industries (Eg: Mushrooms), and slaughterhouses are a major nuisance if it is not properly disposed of. Mushroom cultivation is one of the biggest agro-based industries around world generating a large amount of nutrition-rich left-over by-product called the spent mushroom substrate (SMS) (Janakiram *et al*., 2019). For example, every 1kg of mushroom production generates 5kg of SMS from the industry (Paredes *et al*., 2009). Vermicomposting is an eco-friendly approach to managing the organic wastes and minimizing the synthetic chemical fertilizer consumption tremendously (Garg *et al*., 2006; Motamedi *et al*., 2022).

The spent mushroom substrate is used for various agricultural applications such as animal feeding, fertilizer, and energy wastewater treatment (Mohd Hanafi *et al*., 2018). The spent mushroom substrate is a good source of crude fiber, hemicellulose, cellulose, lignin, carbohydrate, crude protein, ash, calcium (Ca), phosphorus (P), and many essential micronutrients but the available quantity depends on the substrate used for mushroom cultivation. Nitrogen, P, and K level can be further enriched by adding other animal wastes (Meng *et al*., 2019). Moreover, secondary metabolites excreted by the cultivated mushroom act as plant growth and yield enhancer, plant disease suppresser, and save guard the plants against the pest (Zhang *et al*., 2012; Abbasi *et al*., 2014; Yusidah and Istifadah, 2018).

Vermicompost is recognized as a potential agricultural input in sustainable agriculture since it can increase nutrient uptake by plants and stimulate plant tolerance to abiotic and biotic stress (Aguiar *et al*., 2013). Vermicomposting is the non-thermophilic bio-degradation of organic matter by earthworms and microorganisms. The red wiggler (*Eisenia foetida*) species are most frequently used in commercial vermicompost production due to its special attributes like being widely distributed, naturally colonizing on organic material, narrow life cycles, and resilience to survive a broad temperature, and moisture tolerance range (Dominguez and Edwards, 2011).

The artificial addition of beneficial microorganisms for the production of bio-fortified vermicompost is another super hierarchy of getting quality vermicompost from organic wastes called bio-fortification. Plant growth, yield, and suppression of soil-borne diseases would be improved by adding or enriching microbial inoculants into the vermicompost (Pakeerathan *et al*., 2009). Mahanta *et al*. (2012) reported that the incorporation of beneficial microbes *Azotobacter chroococcum*, *Azospirillum brasilense*, and *Pseudomonas fluorescens* has the ability to increase the N, P, and K levels of the compost by solubilizing and mobilizing the nutrients but also promoted the growth and reproduction of the rice plant. Rao *et al*. (2017) proved that the application of root-knot nematode's biocontrol agent *Bacillus subtilis* IIHR BS-2 added vermicompost managed the nematode and soft rot disease complex in carrot significantly than the seed treatment or direct application to the soil. Antagonistic fungi *Trichoderma viride* and bacterial antagonists *Pseudomonas fluorescens* control soil-borne diseases like basal rot in onion caused by *Fusarium oxysporum* f. sp. *cepae* very efficiently (Cramer, 2000).

Considering above mentioned scientific information, the present investigation was planned to produce bio-fortified vermicompost from mushroom grown wastes, and test its efficacy against Fusarium basal rot in the red onion cultivar *Vallarai*.

Materials and Methods

The field investigations of management of basal rot disease on red onion using bio-fortified compost were conducted at the experimental GPS location 9.316745167992368, 80.39934387060269 in the Northern Province of Sri Lanka.

Production of bio-fortified compost

Mushroom production from agro-bio wastes: The four different kinds of biodegradable wastes such as paddy straw, garden waste (banana and maize leaves), sawdust, and kitchen waste. Four substrates were collected, surface sterilized using 3% NaOCl, cut into small pieces (3-4 cm), soaked in excess water for four hours. Then the water was drained off and boiled wastes were subjected to wet sterilization in an autoclave at the standard sterilization conditions of 15psi at 121°C for 15 minutes. Sterilized wastes were mixed individually with 2% (W/W) $CaCO_3$ and filled in 5 L capacity polypropylene bags in five layers with each layer weight of 200g waste as mushroom substrate. Mother spawns *Pleurotus ostreatus* was spread in-between each layer of wastes. The final weight of the substrate made was 1kg of weight. Finally, mushroom inoculated substrate bags were kept hanging in the mushroom growing house. Two harvests of mushroom were derived 22 and 30 days of post-inoculation and then the mushroom grown substrates were used for bio-enriched vermicompost production.

Bio-enriched vermicompost production from mushroom wastes

Pre decomposed mushroom spent substrate wastes were mixed well with cow dung in the ratio of 4:6 (W/W) (Nair *et al*., 2006) in a 10L capacity plastic buckets and allowed to fermentation for seven days. Biocontrol agents *Trichoderma viride* and *Pseudomonas fluorescens* pure culture were collected and mass-produced in sterilized coconut scrapes and PDA respectively, from the Microbiology Laboratory of the Department of Agricultural Biology, Faculty of Agriculture, University of Jaffna, under aseptic conditions. Mature and uniform size red worms (*Eisenia foetida*) collected from the vermicomposting training unit of the same academic entity were released into the every fermented mushroom substrate at the rate of 100 per kilogram of substrate (Chaudhari *et al*., 2011).

A week after, 40 mL/kg (V/W) of $2*10^6$ spores/mL of *T. viride* and *P. fluorescens* solution were mixed (dos Santos *et al*., 2020) thoroughly with worm substrate. Experimental setup (Table 1) was arranged in randomized complete block design in a shady area. Mixing following spraying of water was carried out once in three days to expedite the composting process.

Physicochemical analysis of bio-enriched vermicompost

Total organic carbon was determined by the loss on ignition method as described by Ellert *et al*. (2008). Nitrogen was analyzed by semi-micro Kjeldahl method, Phosphorous percentage was measured by vanado-molybdate yellow spectrophotometric method at the wavelength of 450 nm, Potassium percentage, the percentage was measured by flame photometer [JENWAY- PFP7] (Jackson, 2005). pH value and EC value of the organic liquid fertilizers were measured using pH meter [DKK-TOA(HM-30P)] and Electrical Conductivity meter [DKK-TOA(CM-42X)], respectively.

Table 1: *Experimental design.*

	Cow dung (V1)	Paddy straw based SMS (V2) + Cow dung	Garden waste (V3) based SMS + Cow dung	Sawdust + Rice bran based SMS (V4) + Cow dung	Kitchen waste + Paddy straw (V5) based SMS+ Cow dung
Eisenia foetida (T1) (Control)	V1T1	-	-	-	-
Eisenia foetida + *Trichoderma viride* (T2)		V2T2	V3T2	V4T2	V5T2
Eisenia foetida +*Pseudomonas fluorescens* (T3)		V2T3	V3T3	V4T3	V5T3
Eisenia foetida + *Trichoderma viride* + *Pseudomonas fluorescens* (T4)		V2T4	V3T4	V4T4	V5T4

Efficacy testing of bio-enriched vermicompost against Fusarium oxysporum f.sp. cepae

Pot preparation for onion cultivation: The soil was collected and sieved sterilized (sterilized through Tyndallization process). Sterilized soil was filled at the ratio of bio-enriched compost: topsoil: 1:2 in 9 kg capacity plastic pots. Predominantly farmers of northern Sri Lanka growing recommended red onion variety '*Vallari*' which is susceptible to *Fusarium* basal rot disease was selected. Healthy and surface sterilized '*Vallari*' bulbs were planted as four bulbs per pot. Recommended agronomic practices for the red onion were followed from the planting to harvesting.

Inoculation of Fusarium oxysporum f. sp. cepae in the onion planted pot

After the 7 days of planting, the spore suspension of *F. oxysporum* f.sp. *cepae* was prepared by stirring of pure culture plate of 5-7 days old fungal mycelium in 20ml of distilled water. The spore concentration was adjusted to 2-3*10^7 conidia mL^{-1}using a hemocytometer and inoculated to each pot at the rate of 20mL/pot around the root zone with the help of a pipette.

Calculation of disease severity index (DSI)

The disease severity index was calculated according to the number of leaves tip wilting using the prescription scale of 1 (0-1 leaf wilt); 2 (2-4 leaves wilt); 3 (5-7 leaves wilt); 4 (8-10 leaves wilt) and 5 (>11 leaves wilt) (Chiang *et al*., 2017).

$$DSI\ \% = \frac{\sum(\mathit{frequency} \times \mathit{score\ of\ rating\ class})}{(\mathit{Total\ number\ of\ observation}) \times (\mathit{maximum\ desease\ index})} \times 100\%$$

Observation, data collection and statistical analysis

Onion leaflet length measurement was started after one week of *F. oxysporum* f.sp. *cepae* inoculation with 3 days of the interval from the 21 days and 28 days of planting the total numbers of leaflets and total numbers of leaflets infected were counted, respectively. 80 days after planting the plant height, root length, root: shoot ratio, yield, and disease severity index were measured. The CRD two-factor factorial design used ANOVA using SAS 9.1 (SAS Institute Inc., Cary, NC, USA). Tukey's HSD multiple comparison test was used to identify the best treatment combination at $P < 0.05$.

Results and Discussion

The results of physicochemical properties such as pH, Electric Conductivity (EC), organic matter content (OMC), total organic carbon (TOC), total nitrogen, total phosphorus, and total potassium content of the bio-fortified vermicompost were measured and summarized in Table 1. The pH of the vermicompost varied from 7.28 to 8.14 but they were not significant among them at $P < 0.05$. The lowest and neutral pH of 7.28 was observed in the garden waste-based vermicompost bio-fortified with *T. viride* and *P. fluorescens* whereas kitchen waste-based vermicompost fortified with *P. fluorescens* exhibited the highest pH of 8.28. The electrical conductivity range of bio-fortified vermicompost was from 1.11 to 2.36 mS/cm and was not significant at $P < 0.05$. Kitchen waste-based vermicompost fortified with *P. fluorescens* exhibited the highest EC value of 2.36 whereas the lowest EC of 1.11 was detected from the garden waste treated with *T. viride* and *P. fluorescens*. In other all treatments, EC was below 2.00.

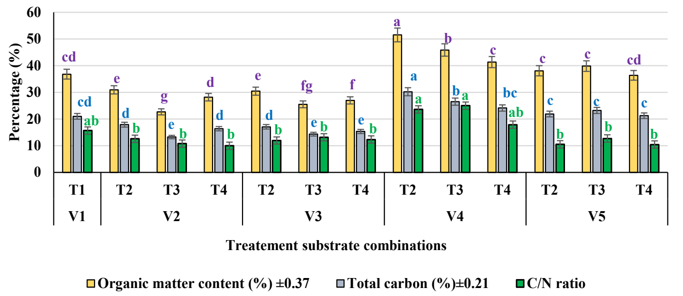

Figure 1: *Organic matter content and organic carbon percentage of formulated bio-fortified compost.*

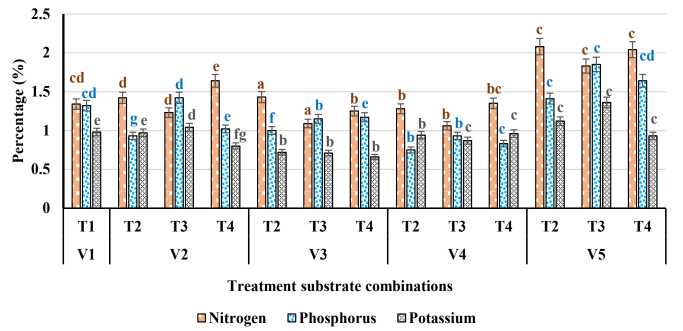

Figure 2: *Nitrogen, phosphorus and potassium percentage of formulated bio-fortified compost.*

Organic matter content (OMC) and TOC of these studied vermicomposts were ranging from 23.6% to 52.4% and 13.39% to 30.39%, respectively (Figure 1). The OMC and TOC were significantly on par at $P < 0.05$. A highly significant OMS was observed in V4T2. The OMC among V4T3 (46.5%), V4T4 (41.8%), and V5T3 (40.5) were significant and were in 2nd rank. The OMC in V2T3 and V3T3 were the lowest non-significant. Total organic carbon was highly significant with the value of 30.39% in paddy straw substrate based vermicompost fortified with *P. fluorescens*. The highest organic matter content and total organic carbon were observed in sawdust substrate-based vermicompost bio-fortified with *T. viride*. Total nitrogen content of these bio-fortified vermicompost ranged from 1.06% to 2.1%. The highest significant nitrogen value of 2.1% was recorded in the kitchen waste-based *T. viride* fortified bio compost at P <0.05. The lowest nitrogen value was recorded in sawdust substrate-based vermicompost fortified with *P. fluorescens* with a value of 1.06% (Figure 2).

The C/N ratio of the produced compost was varied from 25.01-9.96. The C/N ratio was significantly highest in Sawdust + Rice bran-based compost 17.86-25.01 which was significant when compared to all other substrate based compost's C/N ratio at $P < 0.05$. The highest total phosphorus content of 1.87% was observed in kitchen waste-based *P. fluorescens* fortified vermicompost whereas the lowest phosphorus value of 0.73 % was recorded in the sawdust substrate vermicompost fortified with *T. viride*. The total potassium content of these bio-fortified vermicomposts ranges from 0.654% to 1.38%. The highest potassium value of 1.38% was recorded in kitchen waste substrate-based vermicompost fortified with *P. fluorescens*. The lowest potassium value was recorded in garden waste-based vermicompost fortified with *T. viride* and *P. fluorescens*.

Efficacy of bio-fortified vermicompost on onion growth and yield parameters

The mean height, fresh weight, root length and dry weight of the onion plant showed significant among substrates, and substrates and treatments interaction, but not significant among the treatments at $P < 0.05$ and 0.01.

Onion height

When analyze the substrate effect, significantly highest mean onion plant height of 37.56 cm was recorded in bio-fortified kitchen based vermicompost (V5) at $P < 0.05$, where as in bio fortified paddy straw based vermicompost (V2), the onion plant height was 35.29 cm which was not significant when compare to bio fortified garden waste (V3) with the height of 35.29 cm. Whereas the lowest onion height (28.27 cm) was observed in control (Figure 3A).

When test the substrates and treatments interaction, the highest significant mean height of 41.29±0.04 cm was recorded in Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V2T4) (Table 3) but this was not significant when compared to Garden waste based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V3T4), Sawdust + Rice bran based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V4T4) and Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V5T4) with the values of 38.34±0.09, 38.45±0.43 and 38.72±0.20, respectively at $P < 0.05$.

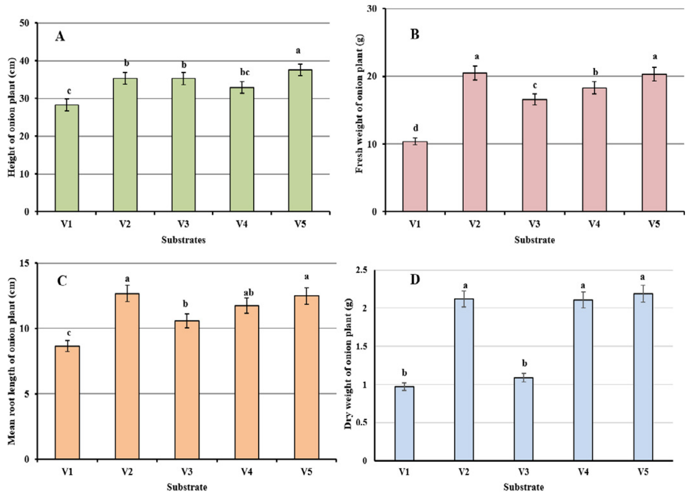

Figure 3: *Substrate effect on growth parameters of onion.*

Onion plant fresh weight

When analyze the substrate effect, mean onion plant weight was significantly on par among them at $P < 0.05$. Significantly highest mean onion plants fresh weight of 20.45g was recorded in bio fortified paddy straw SMS based vermicompost (V2) which was non-significant when compared to bio-fortified kitchen SMS based vermicompost (V5) with the value of 20.35g at $P < 0.05$. Onion plant mean weight was 18.3 g, 16.58g and 10.35g in Sawdust + Rice bran (V4), Garden waste (V3) SMS based and Control (V1), respectively (Figure 3B).

When test the substrates and treatments interaction, the highest significant mean onion plant fresh weight of 28.90±0.03 g was recorded in Paddy straw-based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V2T4) (Table 2) but this was not significant when compared to Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V5T4) with the value of 27.01±0.11. The least onion plant ferest weight of 10.35±0.02 recorded in control which was not significant when compared to the fresh weight gained by the onion plants in V2T3:

Table 2: *Interaction of effect of substrate and treatment on onion mean growth and yield parameters.*

Interaction effect (Substrate Vs Treatments)	Height	Fresh weight	dry weight	Root length	Root: Shoot ratio	Disease severity	Yield	Yield loss (%)
V1T1: Control (Cow dung)	28.27±0.06^{c}	10.35±0.02^{d}	0.97±0.10^{c}	8.65±0.31^{d}	0.31±0.17^{b}	81.22±0.61^{a}	10.15±0.14^{c}	46.25
V2T2: Paddy straw based SMS + Cow dung + *Eisenia foetida* + *Trichoderma viride*	35.29±0.01^{b}	24.81±0.12^{ab}	2.02±0.03^{ab}	14.95±0.07^{a}	0.42±0.04^{a}	29.97±0.21^{b}	20.65±0.09^{a}	-2.25*
V2T3: Paddy straw based SMS + Cow dung + *E. foetida* +*Pseudomonas fluorescens*	29.25±0.11^{c}	11.65±0.14^{d}	1.09±0.10^{c}	9.95±0.44^{cd}	0.34±0.01^{b}	31.22±0.18^{b}	13.46±0.12^{bc}	32.70
V2T4: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens*	41.29±0.04^{a}	28.90±0.03^{a}	2.16±0.02^{a}	16.15±0.03^{a}	0.39±0.02^{ab}	18.72±0.64^{c}	20.34±0.08^{a}	-1.70*
V3T2: Garden waste based SMS + Cow dung + *E. foetida* + *T. viride*	29.56±0.07^{c}	10.93±0.13^{d}	0.99±0.10^{c}	9.80±0.51^{cd}	0.33±0.01^{b}	32.47±0.73^{b}	13.02±0.07^{bc}	34.90
V3T3: Garden waste based SMS + Cow dung + *E. foetida* +*P. fluorescens*	33.67±0.11^{b}	20.10±0.21^{b}	1.67±0.04^{b}	11.55±0.06^{c}	0.34±0.01^{b}	32.25±0.64^{b}	15.25±0.06^{b}	23.75
V3T4: Garden waste based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens*	38.34±0.09^{a}	18.71±0.08^{bc}	1.53±0.06^{b}	16.35±0.05^{a}	0.43±0.05^{a}	18.67±0.48^{c}	15.72±0.04^{b}	21.40
V4T2: Sawdust + Rice bran based SMS + Cow dung + *E. foetida* + *T. viride*	33.11±0.06^{b}	15.76±0.28^{c}	1.33±0.02^{bc}	11.25±0.11^{c}	0.34±0.01^{b}	43.25±0.53^{b}	13.02±0.07^{bc}	34.90
V4T3: Sawdust + Rice bran based SMS + Cow dung + *E. foetida* +*P. fluorescens*	33.68±0.54^{b}	20.91±0.19^{b}	1.84±0.05^{ab}	11.45±0.13^{c}	0.34±0.01^{b}	39.72±0.36^{b}	13.23±0.03^{bc}	33.85
V4T4: Sawdust + Rice bran based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens*	38.45±0.43^{a}	18.23±0.09^{bc}	1.45±0.03^{b}	16.50±0.07^{a}	0.43±0.04^{a}	23.32±0.91^{b}	15.88±0.04^{b}	20.60
V5T2: Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride*	33.82±0.11^{b}	21.98±0.04^{b}	1.85±0.05^{ab}	13.15±0.34^{ab}	0.39±0.07^{ab}	26.65±0.28^{b}	15.12±0.01^{b}	24.40
V5T3: Kitchen waste + Paddy straw based SMS+ Cow dung + Paddy straw+ *E. foetida* +*P. fluorescens*	33.44±0.06^{b}	16.07±0.02^{c}	1.46±0.03^{b}	9.15±0.71^{cd}	0.27±0.03^{b}	24.85±0.72^{b}	13.77±0.08^{bc}	31.15
V5T4: Kitchen waste + Paddy straw based SMS+ Cow dung + Paddy straw+ *E. foetida* + *T. viride* + *P. fluorescens*	38.72±0.20^{a}	27.01±0.11^{a}	1.50±0.03^{b}	16.25±0.27^{a}	0.42±0.06^{a}	14.90±0.36^{c}	20.24±0.11^{a}	-1.20*
CV value	2.34	2.64	1.64	3.63	0.15	2.80	4.28	

*Mean values with the same alphabets are not significantly on par according to the Tukey's HSD multiple comparison test at α=0.05; *-Theoretical Yield (20t/ha) <Actual Yield.*

Paddy straw-based SMS + Cow dung + *E. foetida* + *Pseudomonas fluorescens* (11.65±0.14) and V3T2: Garden waste-based SMS + Cow dung + *E. foetida* + *T. viride* (10.93±0.13), respectively.

Table 3: *Pearson Correlation matrix of yield parameters of onion.*

	Correlation matrix	R^2
	Root: Shoot ratio	0.61
	Disease severity index	-0.74
Yield	Mean height	0.76
	Mean weight	0.80
	Dry weight	0.63
	Root length	0.72

Parameters correlated positively when R^2 > 0.5

Onion plant root length

The substrate effect on onion root length is significantly different compared to control at *P* <0.05 (Figure 3C). The highest significantly longer root of 12.68cm was recorded in Paddy straw-based SMS (V2) which was not significantly on par when compared to Kitchen waste + Paddy straw-based SMS (V5) and Sawdust + Rice bran-based SMS (V4). Lowest mean root length of 8.65 cm was recorded in control.

When test the substrates and treatments interaction, the highest significant mean onion root length of 16.50±0.07cm was recorded in Sawdust + Rice bran based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V4T4), where as in Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (V5T4), Garden waste+ *E. foetida* + *T. viride* + *P. fluorescens* (V3T4) and V2T4: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* with the root length values of 16.25±0.07, 16.35±0.05 and 16.15±0.03, respectively, were not significantly on par among them at *P* <0.05. The root length was highly significant when substrate treated with both *T. viride* + *P. fluorescens* than either *T. viride* or *P. fluorescens*.

Onion plant dry weight

The Figure 3D describe that onion mean dry weight was significantly different among bio fortified substrates at *P* <0.05. The significantly highest onion dry weight of 2.19g were recorded in Kitchen waste + Paddy straw based SMS (V5), but which was not significantly on par when compare to the Sawdust + Rice bran based SMS (V4) and Paddy straw based SMS (V2) with dry weight values of 2.11g and 2.12g, respectively. Lowest dry weight 0.97g were observed when onion grows cow dung substrate (control) without bio fortification.

The Table 3 described when test the substrates and treatments interaction, the highest significant mean onion plant dry weight of 2.16±0.02 g was recorded in Paddy straw based SMS + Cow dung + *E. foetida* + *E. foetida* + *T. viride* + *P. fluorescens* (V2T4) but this was not significant when compared to Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* (V2T2) and Sawdust + Rice bran based SMS + Cow dung + *E. foetida* +*P. fluorescens* (V4T3) at *P* <0.05. Lowest dry weight 0.97g were observed in control.

Root-shoot ratio

Root: Shoot ratio was significant when test the substrates and treatments interaction only at *P* <0.05 (Table 3). The highest mean Root: Shoot ratio of 0.43±0.05 was recorded in V3T4: Garden waste based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* but which was non-significant when compared to the V2T2: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride*, V4T4: Sawdust + Rice bran based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* and V5T4: Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* treatment substrate combinations at *P* <0.05.

Impact of bio-fortified compost on onion yield

The mean yield of onion was significantly different among bio fortified substrates at *P* <0.05 (Table 3). The significantly highest mean onion yield of 38.34±0.08 Mt/ha was recorded in V2T4: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens*, but which was not significantly on par when compared to the V2T2: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* (20.65±0.09 t/ha) and V5T4: Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* (20.24±0.11 t/ha). Lowest onion yield (10.15±0.14 t/ha) was recorded in cow dung substrate (control) without bio fortification. Moreover, Onion yield was strongly correlated with the C/N ratio of the produced compost [R^2= 0.71] at *P* <0.05 (Figure 4).

Onion yield was strongly correlated with the yield loss [R^2 = 0.66] and the maximum yield loss of 46.25% was recorded in control (Figure 5). The yield was above the theoretical yield of variety *Vallari* (11.2-15 Mt/ha) as per the (Araskesary *et al*., 2014a) and highly significant in V2T2: Paddy straw based SMS + Cow dung + *Eisenia foetida* + *Trichoderma viride*, V2T4: Paddy straw based SMS + Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* and V5T4: Kitchen waste + Paddy straw based SMS+ Cow dung + *E. foetida* + *T. viride* + *P. fluorescens* in comparison to other all substrate +biocontrol agent's combination tested at $P<0.05$ and 0.01.

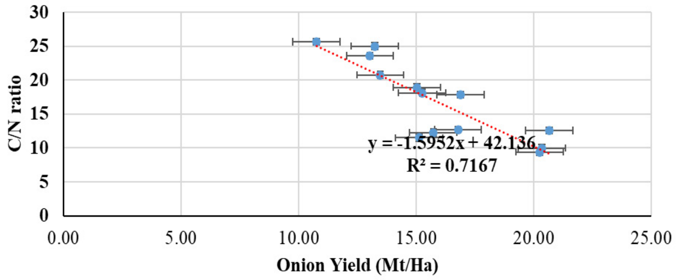

Figure 4: *Correlation between mean onion yield with C/N ratio of the produced compost.*

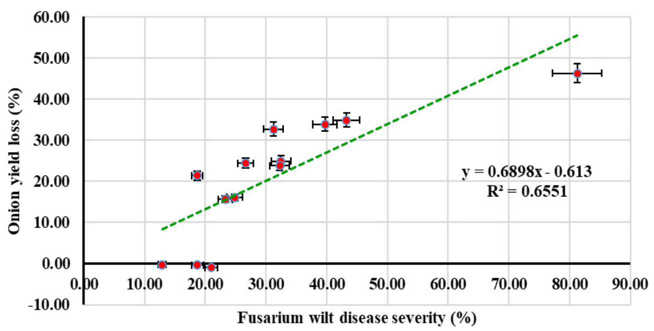

Figure 5: *Correlation between mean onion yield loss versus Fusarium wilt disease severity.*

Efficacy of bio-fortified compost on Fusarium wilt disease severity (FWDS)

Fusarium wilt disease severity was significantly different from each interaction (Table 3). The highest FWDS was recorded in control (81.22%) at $P<0.05$. The significantly lower FWDS range of 12.32±0.91-18.72±0.64 was observed in all the substrates treated with both *T. viride* + *P. fluorescens*. The substrates treated with either *T. viride* or *P. fluorescens* exhibited mild FWDS range of 24.85±0.72-43.25±0.53 which was significantly on par when compare to neither or either of *T. viride* or *P. fluorescens*.

Correlation analysis

Pearson's correlation analysis between the mean yield parameters with yield elucidate that all the yield related parameters were positively correlated with the R^2 value of <0.6. Moreover, disease severity index negatively correlated with the Pearson's correlation co-efficient of -0.74 and explains that when the disease index increase yield declines.

The success of organic agriculture is coupled with the availability of quality compost in sufficient quantity. The increasing trend of organic agriculture and ecological farming prioritize the research in the formulation of compost with superior quality to retain the yield from the post-revolution invented high yielding varieties.

Traditional composts are made by conversion of degradable organic wastes into stable products with the aid of microorganisms under controlled conversion. The shortcomings of traditional composts are the availability of harmful pathogens, low nutrient status, long duration of composting, long mineralization duration, and odor production. Vermicomposting needs limited controlled conditions, and nutritional qualities are further enhanced by the addition of earthworm's gut secretion and gut beneficial microflora which suppresses or kills the pathogen in the compost. The current research made bio-fortified vermicompost's pH range was 7.28-8.11, C/N ratio was 25.01-9.96, and OMC was 22.66-51.53. The pH, C/N ratio, OMC of the ideal compost use in agriculture should be around 7.5, 25 to 30, and 33.3% (but not less than 20%) (Azim *et al*., 2018). The good quality vermicompost should contain N, P, and K within the range of 0.51-1.61%, 0.19-1.02%, and 0.15-0.73%, respectively (Pankaj and Kumari, 2015). But current bio-fortified compost's N, P and K ranges were 1.06% to 2.1%, 0.73%-1.87%, 0.654% to 1.38%. Therefore, the current investigation produced that bio-fortified vermicompost's nutritional quality is superior. The nutritional enrichment may be the addition of earthworm's excretion which contains high N, P and K, micronutrients, beneficial soil microbes; nitrogen-fixing, phosphate solubilizing bacteria, actinomycetes and growth hormones auxins, gibberlins and cytokinins (Adhikary, 2012).

Moreover, mushroom products and the added *P. fluorescens* and *T. viride* could have added nutrients buy their secondary metabolites. Singh and Sharma (2002) reported that *Trichoderma* spp. enriched vermicompost's nitrogen content through mineralization. Further, Mahanta *et al*. (2012) also supported that the *P. fluorescens* and *T. viride* have the ability to solubilize the phosphate and make it into a freely available form of phosphorus. Current findings corroborated with the previous literature.

Composting is a long-used technology, though it has some shortcomings that have reduced its extensive usage and efficiency. When mushroom cultivates in the agro wastes, the composting process is being expedited due to enzymatic biodegradability (Chang *et al*., 2016). Strong positive correlations were found between plant growth parameters and the onion yield. High yield derived in paddy straw-based and kitchen waste-based vermicompost indicates that the organic matter amendments induced direct increase and enhanced cycling of these nutrients. These results are confirmatory with Mahmood *et al*. (2017) who stated that the incorporation of organic manures improves soil physico-chemical properties that may have a direct or indirect effect on plant growth and yield attributes. Moreover, the nutritional quality of the compost is highly influenced by the raw material used (Lim *et al*., 2015). The plant height and yield of vegetables have been improved when use mushrooms spent compost in different fractions (Chang *et al*., 2016; Umor *et al*., 2021). Moreover, vermicompost and its body liquid (vermiwash) are proven as both growth promoters and protectors for crop plants. This could be an added advantage to getting a high yield.

As per the results, Fusarium basal rot severity was significantly very high when the onion is grown without treating bio-control agents *P. fluorescens* and *T. viride*. Onion yield is strongly correlated with the growth parameters of the onion. If onion gets the disease, automatically all the growth parameters go down, because it affects the root zone of the onion and causes a lack in the absorption of water and essential nutrition for the growth of onion, and if the disease severity of Fusarium basal rot in onion is low plant become healthy. Zhao *et al*. (2019) reported that vermicompost can suppress the *F. oxysporum* itself. Naguleswaran *et al*. (2014) and Rajendran and Ranganathan (1996) reported that *T. viride* has the ability to suppress the *F. oxysporum*. Because of bio-fortification of fungal antagonists and bacterial antagonists produce antibiotics as well as will compete with the pathogen for food and will make protective cover around the rhizosphere, therefore, less chance of pathogen to attack the host. Moreover, added antagonists increase the availability of essential macro nutrition such as nitrogen, phosphorus, and potassium due to that, the yield and other growth parameter was recorded higher than un-fortified vermicompost.

Conclusions and Recommendations

Based on the experimental results, the bio-fortified vemicompost's nutritional qualities are superior. This bio-fortified vemic-compost's N, P and K level is 25-35% more of the traditionally made vermicompost. Highest growth, yield parameters and lower Fusarium basal rot incidents was recorded in *T. viride* and *P. fluorescens* fortified paddy straw and kitchen waste based vermicompost. Actual yield of the *Poovallarai* onion is higher than theoretical yield (15-20 Mt/ha) in paddy straw and kitchen waste based vermicompost too. These experimental facts could be a new eco-friendly low cost approaches to manage soil-borne diseases as well as properly manage organic wastes into super compost.

Acknowledgements

The authors thanks to Japanese government for providing equipment facilities through JICA grant to Faculty of Agriculture, University of Jaffna, Sri Lanka.

Novelty Statement

This research reports new technique and method to produce cheapest biofortified compost to manage the soilborne diseases.

Author's Contribution

Kandiah Pakeerathan: Conceived the research idea, and wrote and edited the manuscript.
Aruchchunan Nirosha: Conceived the research idea.
Gunasingham Mikunthan: Conceived the research idea and edited the manuscript.
Konesalingam Jeyavithuyan: Conducted experiments and wrote the manuscript.
Kandiah Pakeerathan and Konesalingam Jeyavithuyan contributed equally.

Funding
This research was carried out under the UBL grant of the University of Jaffna Grant Number AHEAD/RA3/UBL/JFN/OVAA/26.

Conflict of interest
The authors have declared no conflict of interest.

References

Abbasi, N., A.M. Torkashvan and H. Rahanandeh. 2014. Evaluation of mushroom compost for the bio control root-knot nematode. Int. J. Biosci., 5: 147-153. https://doi.org/10.12692/ijb/5.8.147-153

Adhikary, S., 2012. Vermicompost, the story of organic gold: A review. Agric. Sci., 3(7): 905-917. https://doi.org/10.4236/as.2012.37110

Aguiar, N.O., F.L. Olivares, E.H. Novotny, L.B. Dobbss, D.M. Balmori, L.G. Santos-Júnior, J.G. Chagas, A.R. Façanha and L.P. Canellas. 2013. Bioactivity of humic acids isolated from vermicomposts at different maturation stages. Plant Soil, 362(1): 161-174. https://doi.org/10.1007/s11104-012-1277-5

Araskesary, S.J., S. Gobigeetha and B.G.R.C. Balasooriya. 2014a. Characterization and agronomic evaluation of cluster onion (*Allium cepa* L.) landraces grow in Jaffna district, 2014, Book of abstract: SLCARP, IARS, 2014. Sri Lanka Council for Agricultural Research Policy, 11-12 August, 2014, Colombo, Sri Lanka. pp. 9.

Arsakesary, S.J., M.G.S.P. Pathirana, H.M.C. Hitinayake, D.M.J.B. Senanayake and B.I. Hettiarachchi. 2014b. Achievements, current status and future challenges in cluster onion improvement in Sri Lanka In: D.K.N.G. Pushpakumara *et al*. (eds.) Proceedings of the International Workshop on Onion Seed Production and Crop Husbandry, 22-24th December 2014 at the Hotel Cinnamon Lakeside Colombo, Sri Lanka, pp. 87-100.

Azim, K., Y. Faissal, B. Soudi, C. Perissol, S. Roussos, and T.I. Alami. 2018. Elucidation of functional chemical groups responsible of compost phytotoxicity using solid-state 13 C NMR spectroscopy under different initial C/N ratios. Environmental Science and Pollut. Res., 25: 3408-3422. https://doi.org/10.1007/s11356-017-0704-9

Chang, S.C., M.J. Lin, Y.P. Chao, C.J. Chiang, Y.S. Jea and T.T. Lee. 2016. Effects of spent mushroom compost meal on growth performance and meat characteristics of grower geese. Rev. Brasil. Zoot. 45: 281-287. https://doi.org/10.1590/S1806-92902016000600001

Chaudhari, R.D., M.T. Datar and M.R. Babookani. 2011. Municipal solid waste management through vermicomposting employing exotic species of earthworm *Eudrilus eugeniae*. J. Environ. Sci. Eng., 53(1): 129-134.

Chiang, K., H. Liu and C. Bock. 2017. A discussion on disease severity index values. Part I: Warning on inherent errors and suggestions to maximise accuracy. Ann. Appl. Biol., 171(2): 139-154. https://doi.org/10.1111/aab.12362

Cramer, C.S., 2000. Breeding and genetics of Fusarium basal rot resistance in onion. Euphytica, 115(3): 159-166. https://doi.org/10.1023/A:1004071907642

Das, I.R., M. Bhuiyan, R. Jannat, E. Kayesh, M.T. Rubayet and M. Arefin. 2019. Effect of bio-fortified compost in controlling soil-borne diseases of lentil (*Lens culinaris* L.) and enhance the crop growth and yield. Adv. Biol. Earth Sci., 4(2): 93-106.

Department of Agriculture Sri Lanka, 2021. Department of agriculture Sri Lanka.

Dominguez, J. and C.A. Edwards. 2011. Relationships between composting and vermicomposting. Vermiculture technology earthworms, organic wastes, and environmental management CRC Press, Boca Raton. pp. 11-26. https://doi.org/10.1201/b10453-3

dos Santos Pereira, T., A.G. Macêdo, J. da Silva, J.B. Pinheiro, A.M. de Paula, D. Biscaia and J.G. Busato. 2020. Water-extractable fraction of vermicomposts enriched with Trichoderma enhances the growth of bell pepper and tomato as well as their tolerance against *Meloidogyne incognita*. Sci. Hortic., 272: 109536. https://doi.org/10.1016/j.scienta.2020.109536

Ellert, B.H., H.H. Janzen, A.J.V. Bygaart and E. Bremer. 2008. Measuring change in soil organic carbon storage. Soil Sampl. Methods Anal., 2: 25-38.

Garg, P., A. Gupta and S. Satya. 2006. Vermicomposting of different types of waste using *Eisenia foetida*: A comparative study. Bioresour. Technol., 97(3): 391-395. https://doi.org/10.1016/j.biortech.2005.03.009

Jackson, M.L., 2005. Soil chemical analysis: Advanced course. UW-Madison Libraries parallel press.

Janakiram, T., V. Sharma and A. Barh. 2019. Analysis of India-China mushroom gap. A review. Curr. Hortic., 7(2): 10-14. https://doi.org/10.5958/2455-7560.2019.00013.X

Kauser, H. and M. Khwairakpam. 2022. Organic waste management by two-stage composting process to decrease the time required for vermicomposting. Environ. Technol. Innov., 25: 102193. https://doi.org/10.1016/j.eti.2021.102193

Lim, S.L., T.Y. Wu, P.N. Lim and K.P.Y. Shak. 2015. The use of vermicompost in organic farming: Overview, effects on soil and economics. J. Sci. Food Agric., 95(6): 1143-1156. https://doi.org/10.1002/jsfa.6849

Mahanta, K., D. Jha, D. Rajkhowa and Manoj-Kumar. 2012. Microbial enrichment of vermicompost prepared from different plant biomasses and their effect on rice (*Oryza sativa* L.) growth and soil fertility. Biol. Agric. Hortic., 28(4): 241-250. https://doi.org/10.1080/01448765.2012.738556

Mahmood, F., I. Khan, U. Ashraf, T. Shahzad, S. Hussain, M. Shahid, M. Abid and S. Ullah 2017. Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. J. Soil Sci. Plant Nutr., 17(1): 22-32. https://doi.org/10.4067/S0718-95162017005000002

Meng, X., B. Liu, H. Zhang, J. Wu, X. Yuan and Z. Cui. 2019. Co-composting of the biogas residues and spent mushroom substrate: Physicochemical properties and maturity assessment. Bioresour. Technol., 276: 281-287. https://doi.org/10.1016/j.biortech.2018.12.097

Mohd Hanafi, F.H., S. Rezania, S.M. Taib, M.F.M. Din, M. Yamauchi, M. Sakamoto, H. Hara, J. Park and S.S. Ebrahimi. 2018. Environmentally sustainable applications of agro-based spent mushroom substrate (SMS): An overview. J. Mater. Cyc. Waste Manage., 20(3): 1383-1396. https://doi.org/10.1007/s10163-018-0739-0

Motamedi, A., M. Jafarpour and M. Oshaghi. 2022. Improving the vermicompost quality by using horticultural and agronomic residues. J. Plant Nutr., 45(5): 727-738. https://doi.org/10.1080/01904167.2021.1956534

Naguleswaran, V., K. Pakeerathan and G. Mikunthan. 2014. Biological control: A promising tool for bulb-rot and leaf twisting fungal diseases in red onion (*Allium cepa* L.) in Jaffna district. World Appl. Sci. J., 31(6): 1090-1095.

Nair, J., V. Sekiozoic and M. Anda. 2006. Effect of pre-composting on vermicomposting of kitchen waste. Bioresour. Technol., 97(16): 2091-2095. https://doi.org/10.1016/j.biortech.2005.09.020

Pakeerathan, K., G. Mikunthan and N. Tharshani. 2009. Effect of different animal manures on *Meloidogyne incognita* (Kofoid and White) on tomato. World J. Agric. Sci., 5(4): 432-435.

Pankaj, P. and A. Kumari. 2015. Vermiculture technology: An option for organic recycling. In: (eds. A.P.P.P. Kumari and P. Baskaran) recent trends in postharvest technology and management, vol 1st. Manglam Publishers, New Delhi, India, pp. 167-182.

Paredes, C., E. Medina, R. Moral, M.D. Pérez-Murcia, J. Moreno-Caselles, M.A. Bustamante and J.A. Cecilia. 2009. Characterization of the different organic matter fractions of spent mushroom substrate. Commun. Soil Sci. Plant Anal., 40(1-6): 150-161. https://doi.org/10.1080/00103620802625575

Priyantha, M.G.D.L., W.M.K. Fernando and M.S.W. Fernando. 2014. Integrated disease management of onion in Sri Lanka In: D.K.N.G. Pushpakumara *et al.* (eds.) proceedings of the international workshop on onion seed production and crop husbandry, 22-24th December 2014 at the Hotel Cinnamon Lakeside Colombo, Sri Lanka, pp. 101-118.

Rajendran, K. and K. Ranganathan. 1996. Biological control of onion basal rot (*Fusarium oxysporum* f. sp. *cepae*) by combined application of fungal and bacterial antagonists. J. Biol. Contr., 10(1 and 2): 97-102.

Rao, M., M. Kamalnath, R. Umamaheswari, R. Rajinikanth, P. Prabu, K. Priti, G. Grace, M. Chaya and C. Gopalakrishnan. 2017. *Bacillus subtilis* IIHR BS-2 enriched vermicompost controls root knot nematode and soft rot disease complex in carrot. Sci. Hortic., 218: 56-62. https://doi.org/10.1016/j.scienta.2017.01.051

SAS Institute, 1994. The SAS system for Windows. Release 6.10 SAS Inst., Cary, NC.

Singh, A. and S. Sharma. 2002. Composting of a crop residue through treatment with micro-organisms and subsequent vermicomposting. Biores. Technol., 85(2): 107-111. https://doi.org/10.1016/S0960-8524(02)00095-0

Umor, N.A., S. Ismail, S. Abdullah, M.H.R. Huzaifah, N.M. Huzir, N.A.N. Mahmood and A.Y. Zahrim. 2021. Zero waste management of spent mushroom compost. J. Mater. Cyc. Waste Manage., 23(5): 1726-1736. https://doi.org/10.1007/s10163-021-01250-3

Yusidah, I. and N. Istifadah. 2018. The abilities of spent mushroom substrate to suppress basal rot disease (*Fusarium oxysporum* f.sp *cepae*) in shallot. Int. J. Biosci., 13(1): 440-448. https://doi.org/10.12692/ijb/13.1.440-448

Zhang, R.H., D. Zeng-Qiang and L. Zhi-Guo. 2012. Use of spent mushroom substrate as growing media for tomato and cucumber seedlings. Pedosphere, 22(3): 333-342. https://doi.org/10.1016/S1002-0160(12)60020-4

Zhao, F., Y. Zhang, W. Dong, Y. Zhang, G. Zhang, Z. Sun and L. Yang. 2019. Vermicompost can suppress *Fusarium oxysporum* f.sp. *lycopersici* via generation of beneficial bacteria in a long-term tomato monoculture soil. Plant Soil, 440(1): 491-505. https://doi.org/10.1007/s11104-019-04104-y