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Potential of Spent Mushroom Compost from *Pleurotus Ostreatus* Strain EM-1 as Organic Soil Amendment for Growing Cowpea and Tomato Under Screenhouse Conditions

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Abstract

This study aimed to explore the impact of enriching sandy loam soil (BS) with *Pleurotus ostreatus* Strain EM-1 spent mushroom compost (SMC) on the growth and yield of tomato (Solanum lycopersicum L.) and cowpea (Vigna unguiculata L.) crops in a screenhouse environment with an average daytime temperature of 28 ± 2°C. The SMC was added to the soil in varying proportions, ranging from 5% to 100%, while the control medium consisted of unamended sandy loam soil (BS). Over a period of 14 weeks, several vegetative parameters were assessed, including plant height, leaf count, leaf area, chlorophyll content, flower count, number of aborted flowers, pod count, pod mass, pod length, fruit count, and fruit mass. The findings indicated that the different combinations of SMC and soil, used as a bio-fertilizer, had varying effects on the growth and yield of tomato and cowpea in the screenhouse setting. Generally, plant height, leaf area, flower count, pod mass, pod length, and fruit count demonstrated improved growth at lower SMC concentrations (5-20%). Among cowpea seedlings, those treated with 5% SMC exhibited the most favourable vegetative growth and yield, while tomato seedlings performed best with 10% SMC. However, leaf area, flower count, and pod count were negatively affected at the 5% SMC concentration. Concentrations exceeding 30% SMC had a variable inhibitory effect on the assessed growth parameters. This could be attributed to the presence of high levels of micro and macro-nutrients such as calcium, copper, iron, potassium, magnesium, manganese, sodium, lead, phosphorus, and zinc in the substrate. Different crops have distinct nutritional requirements, underscoring the importance of understanding a crop's specific nutrient needs before applying SMC as a soil amendment.

Keywords: Vegetative Growth; Yield, Crop; Micro and Macro Nutrient; Cowpea and Tomato Seedlings; SMC and Sandy Loam Soil

Introduction

The current global production of spent mushroom compost (SMC) is significant, with projections indicating that it will reach approximately 104 million tons by 2026. This increase is attributed to the rising global consumption of mushrooms, which currently involves more than 11 million tons of fresh mushrooms produced annually. The typical yield of SMC is about 5 kg for every 1 kg of mushrooms harvested, leading to substantial amounts of compost as a byproduct in the industry [1-3].

Therefore, meeting the growing food demand of an increasing global population with limited land resources presents a significant challenge for developing nations like Ghana. There are numerous mushroom species cultivated worldwide, offering a rich source of essential nutrients. Finally, the global mushroom market size was USD 17.25 million tonnes in 2023 and is projected to grow from USD 18.39 million tonnes in 2024 to USD 32.04 million tonnes in 2032 at a CAGR of 7.18% during the forecast period (2024-2032). The total global production of mushrooms projections for the year 2024 was estimated to be 67 million metric tonnes.

The significance and potential of fungiculture, particularly the cultivation of mushrooms, are well-recognized across various aspects of human life and ecosystem functions. Fungiculture holds the promise of addressing numerous issues, including the demand for high-quality food, environmental pollution, unemployment, and certain ecological concerns, in a constructive and substantial manner.

Mushrooms have garnered widespread popularity across the globe due to their high value as delectable, nutritious, and medicinal vegetables. Their appeal lies in their exceptional flavour, texture, and their richness in proteins, minerals, and vitamins, all while maintaining low calorie levels and containing a significant amount of unsaturated fats. Mushrooms also possess the ability to accumulate various secondary metabolites, including phenolic compounds, polypeptides, terpenes, steroids, lectins, polysaccharides, polysaccharide-peptides, and polysaccharide-protein complexes, which are recognized for their immune-regulating and anti-cancer properties [4].

Furthermore, research has demonstrated that mushrooms can reduce the risk of cancer, inhibit tumour growth, aid in stabilizing blood sugar levels, protect against viruses, bacteria, and fungi, and support the body's detoxification mechanisms. Notably, mushrooms stand out as efficient producers of high-quality protein, capable of utilizing agro wastes, which are abundant in Ghana at over one million tonnes per year, as reported by the FAO in 2013 [4].

What makes mushroom cultivation particularly fascinating is its reliance on agro-industrial residues, such as hay, straw, horse bedding, poultry litter, corn cobs, corn stover, cotton seed meal, coffee residues (including grounds, hulls, stalks, and leaves), cocoa pod husks, banana fronds, agave waste, soy pulp, and more. This diverse use of agricultural by-products underscores the significance of mushroom farming within the agri-business sector.

The mushroom industry has witnessed substantial growth, thanks to the cultivation of numerous mushroom species globally. In fact, by 2012, global production had reached a remarkable 27 billion kg [5]. Of this substantial production, a dominant 85% is attributed to five genera: Agaricus bisporus and A. subrufrescens (30%), *Pleurotus* species (27%), Lentinula edodes (17%), Auricularia species (6%), and Flammulina (5%) [6]. Notably, it has been estimated that over 10 million metric tonnes of spent mushroom compost (SMC), a by-product of Agaricus bisporus mushrooms, is generated on a global scale [4,7]. The annual projection suggests that there could be a significant production of 10 to 50 million metric tonnes of SMC worldwide from the mushroom industry [4,7]. To put this into perspective, the cultivation of just 1 kg of mushrooms results in the generation of 5 to 6 kg of spent mushroom compost [8,9]. An average mushroom farm discards approximately 25 tonnes of SMC each month. The value and production of mushrooms continue to grow, particularly with the increased awareness of the health, nutritional, and medicinal benefits associated with mushrooms. These factors collectively contribute to the ongoing expansion of the mushroom industry year after year.

Therefore, it has become imperative to identify an alternative approach for managing this extensive agro-waste problem without exacerbating existing environmental pollution. Spent mushroom compost (SMC) is characterized as the residual waste from the mushroom industry, comprising mycelium and significant levels of residual nutrients like organic substances (N, P, K) and various bio-active compounds, including extracellular enzymes, antimicrobial agents, and secondary metabolites [5,10].

While SMC is typically intended for utilization, some of the current methods for dealing with SMC globally involve burning, land spreading, burial, composting with animal manure, or, quite commonly, landfilling. Additionally, SMC finds applications in bioremediation, such as purifying air, water, soil, and contaminated substrates. It is also used in horticulture and crop production as an organic fertilizer for both greenhouse and field crops, as well as a potting mix for nursery and landscape crops [5]. In Ghana, *Pleurotus ostreatus* is currently the most cultivated mushroom variety. This study follows up on previous research conducted by Wiafe-Kwagyan M, et al. [4], who observed that spent mushroom compost from *Pleurotus eous* strain P-31 enhanced the growth and yield of Capsicum annuum L. and Solanum lycopersicum L. The primary objective of our study was to investigate the impact of *Pleurotus ostreatus* spent mushroom compost on the growth and yield quality of cowpea (Vigna unguiculata) and tomato (Solanum lycopersicum) while comparing the results with the data obtained by Wiafe Kwagyan M, et al. [4] in a similar study.

Materials and Methods

Additives used as supplements to amend soil substrate for the study

Spent mushroom compost (SMC) of *Pleurotus ostreatus* EM-1 strain was obtained from the Mycology Unit of Department of Plant and Environmental Biology.

Test crops for the study

Cowpea (Vigna unguiculata Walp. black eye variety) and tomato (Solanum lycopersicum Mill. 'Wosowoso' variety) seeds were supplied by the seed bank of the Department of Plant and Environmental Biology and Department of Crop Science, College of Basic and Applied Sciences University of Ghana, respectively.

Experimental Site

The study was conducted within the confines of the screenhouse situated at the Department of Plant and Environmental Biology, University of Ghana, Legon. To facilitate the experiment, potted plastic containers measuring 25 cm in height and 22 cm in diameter, were employed. The cowpea and tomato seeds utilized for the study were sourced from the Department of Crop Science within the School of Agriculture at the University of Ghana.

Collection of Soil Samples

Both crops thrive in sandy loam soil described as Ferric Acrisol with a pH range between 5.5 and 7. Soil samples were obtained from the University's Farm within the Legon Botanical Gardens at the University of Ghana, Legon. The soil sample was taken to the Department of Soil Science, School of Agriculture for authentication, identification, and elemental nutrient analysis.

Experimental Design

The study followed a 1x2-factorial design in which each setup was replicated three times to ensure the consistency and reproducibility of the results. Randomized Complete Block Design (RCBD) was used to arrange the cowpea and tomato seedlings grown in the different treatments ensuring that all treatment combinations are tested.

Preparation and Formulation of Soil and Spent Mushroom Compost Medium

To study the effect of the spent mushroom compost (SMC) on vegetative growth and yield quality of the two crops, a modified methods was used [5,11,12]. The SMC was first sun dried for 7 days, this was to reduce its moisture content and eliminate undesirable resident bio-deterioration organisms such as maggot, insects etc. Subsequently the dried SMC was added to sandy loamy soil to obtain the different combinations of soil and SMC in the following percentages (5, 10, 15, 20, 25, 30 and 50)% (SMC 0 = 100% soil (unamended) which served as control medium); SMC5 (5% of SMC to 95% soil); SMC10 (10% of SMC to 90% soil); SMC15 (15% of SMC to 85% soil); SMC20 (20% of SMC to 80% soil); SMC25 (25% of SMC to 75% soil) and SMC30 (30% of SMC to 70% soil); SMC50 (50% of SMC to 50% soil); SMC0 (soil medium only), SMC100 (SMC only) to obtain a total weight (w/w) of 5kg for each plastic pot of dimensions 20cm x 22cm of height and diameter respectively. The SMC0 served as the control treatment.

After thoroughly mixing the combination, the growing media were watered with 500 ml of tap water. The tomato seedlings that had been nursed for three weeks were transplanted and 3 cowpea seeds were planted per bucket for all treatments. The buckets containing the seedlings were arranged in a randomized complete-block design with three replications of all the nine treatments under screen house condition. The three cowpea seeds placed in each bucket was to ensure that at least one of the seeds would germinate. In the case where more than one seed germinated, the others were uprooted to prevent competition. Seedlings of the same height and age were used for the test.

Assessment of Vegetative Growth and Yield Parameters

The following parameters were recorded: plant height, number of compound leaves and leaf area, flowers, aborted flowers, chlorophyll content of leaves, number of fruits and pods and mass of fruits and pods. Plant height was measured using a meter rule, number of leaves, flowers, aborted flowers, and fruits were counted manually per week during the 14 weeks growing period. Leaf area in mm2 was determined using a digital leaf area meter (LI-3000C) via attaching five randomly selected leaves of same age and size. Cowpea pods and tomato fruits were measured using a digital Computing Scale (ACB plus Adams Equipment Company Limited, Milton Keynes, UK) after counting.

Total Chlorophyll Content of Leaves

Total chlorophyll content was determined using chlorophyll meter (Optic Sciences CCM-200 plus) by attaching the chlorophyll meter knob to the leaf. The values were quoted as CCI (chlorophyll content index).

Statistical Data Analysis

Data obtained were subjected to statistical analyses using the Statistical Package for Social Sciences (SPSS version 20 for Windows). Significant differences between vegetative growth and yield parameters measured among plants in treated media (SLS: SMC), SMC100 and soil only media were determined using Duncan's Multiple Range Test (DMRT) at 5% probability.

Results

Effects of spent mushroom compost (SMC) on the growth and yield parameters of cowpea (Vigna unguiculata) seedlings under screenhouse conditions

The general trend is that cowpea seedlings grown in soil amended with SMC showed superior growth and yield compared to those grown in unamended soil. Medium levels of SMC (5-30%) generally supported better plant growth and productivity than higher or lower levels. The 100% SMC (soilless medium) seedlings showed poor performance across most vegetative and reproductive parameters, indicating that a soilless medium may not be ideal for cowpea cultivation (Figures 1 & 2).

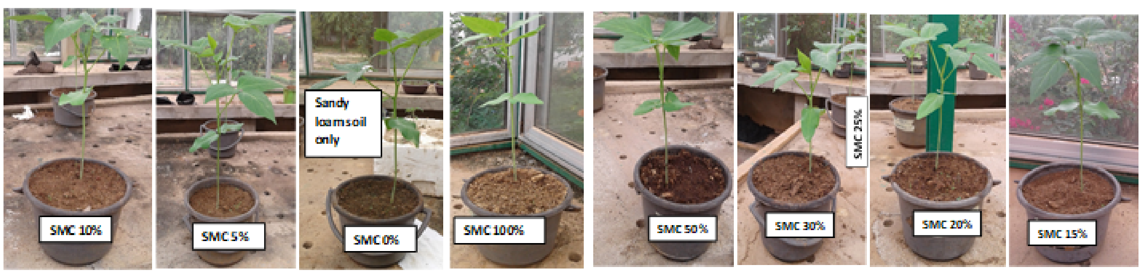
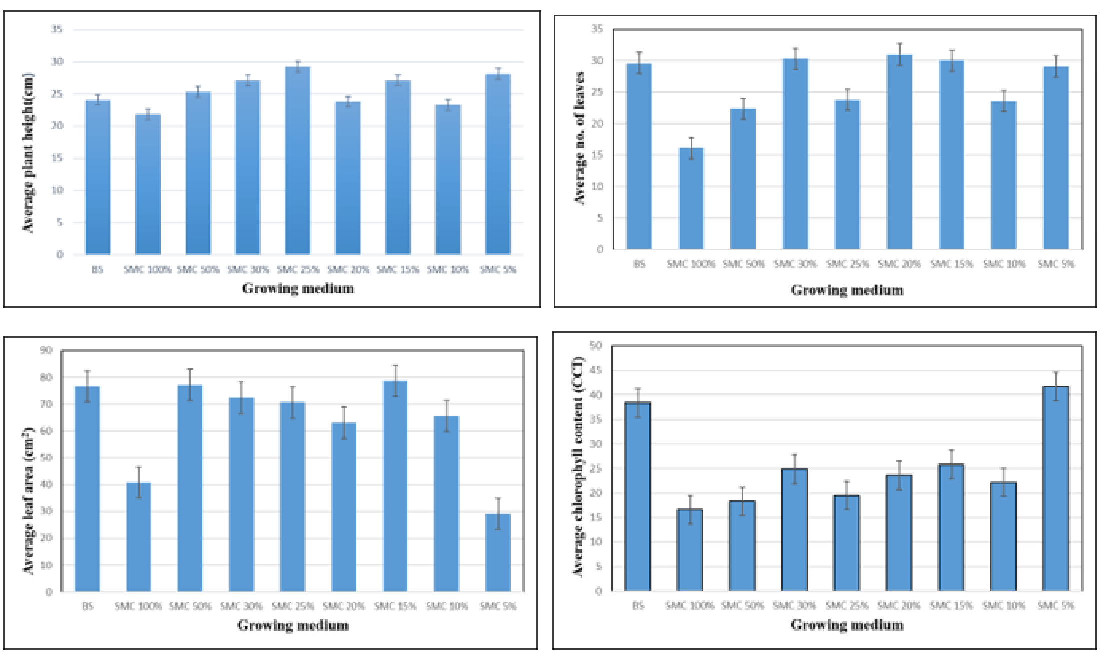


Figure 1: Effect of varying percentages of soil: SMC on the vegetative growth of cowpea seedlings under screenhouse conditions at an average temperature of 28 ± 2°C after 8 weeks of planting.



Keys *: BS - Sandy loam soil (0% SMC); 100% SMC (Soilless medium)

Figure 2: Influence of spent mushroom compost on vegetative growth of cowpea seedlings grown in the indicated proportions of soil: SMC medium after 4-10 weeks of planting.

Germination and Plant Height: Seeds germinated successfully in all treatments. The average plant heights ranged from 21.8 to 29.2 cm over a 4-week period. While plant heights were not statistically different ($p > 0.05$), the tallest cowpea plant (29.2 ± 5.3 cm) was observed in the 25% SMC treatment, and the lowest (21.8 cm) in the 100% SMC medium. Control treatment (0% SMC) produced plants 24.1 ± 2.3 cm tall (Figure 2).

Leaf Number and Area: Significant differences ($p \leq 0.05$) in leaf count were observed over 9 weeks. The optimal SMC concentration for promoting leaf growth in cowpea appears to be within the range of 5% to 20% SMC. This range is associated with increased leaf area and number of leaves compared to higher concentrations or soil-only conditions. 20% SMC growth medium recorded the highest number of leaves (31) and the lowest (16 leaves) in the 100% SMC. However, the unamended soil produced 30 leaves which was significantly higher than 100% SMC. 5% SMC supported the largest leaf area (78.9 ± 19.9 cm^2) followed by the control treatment (0% SMC) 76.7 ± 11.4 cm^2 though was not significantly different from 5% SMC) both were significantly larger than the smallest leaf area (40.8 cm^2) in the 100% SMC (Figure 2).

Chlorophyll Content: Chlorophyll content was measured over 10 weeks using Chlorophyll Content Index (CCI). The chlorophyll content in this study ranged from the lowest (6.6 ± 2.8 CCI) to the highest (41.7 ± 8.5 CCI). Significant differences were observed in chlorophyll content among treatments, with the highest recorded in the 5% SMC treatment and the lowest in the 100% SMC growing medium (Figure 2).

Flower and Pod Production: The flower counts were taken after 14 weeks. The number of flowers increased significantly in media with 5%, 10%, and 15% SMC compared to the control. No flowers formed in the 100% SMC group. Pod production was highest in the 50% SMC group, but no pods formed in the 100% SMC group. Seedlings in media with 5%, 10%, and 15% SMC produced the most flowers (11). Pod production was generally higher in amended soils, with the 50% SMC group producing the highest number of pods (5) (Figure 3).

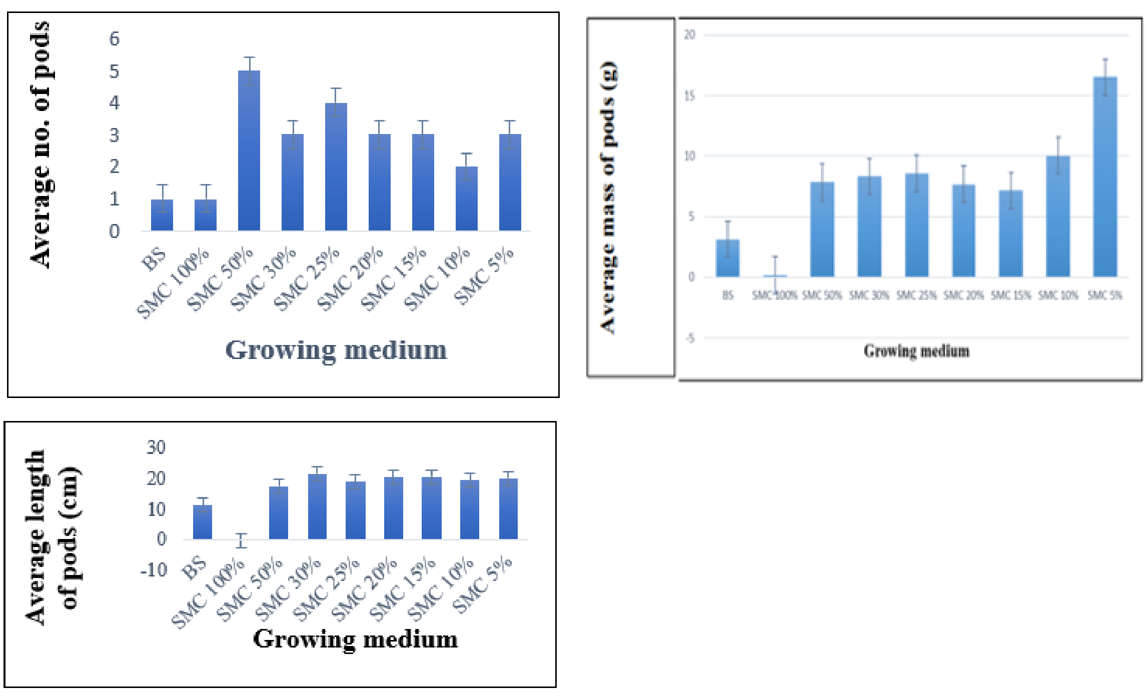


Figure 3: Effect of spent mushroom compost on reproductive growth of cowpea seedlings grown in the indicated proportions of soil: SMC medium after 14 weeks of planting.

Pod Characteristics: Overall, amended soil generally supported better growth and yield than unamended soil. 5% SMC treatment obtained the highest pod mass 16 g per seedling and followed closely by the 10% SMC medium. Control treatment (0% SMC) produced the lowest pod mass (3g per seedling). Longest pods (21.7 ± 5.2 cm) were observed in 30% SMC whereas the shortest pods (11.4 cm) were observed in unamended soil (control treatment) (Fgure 4).

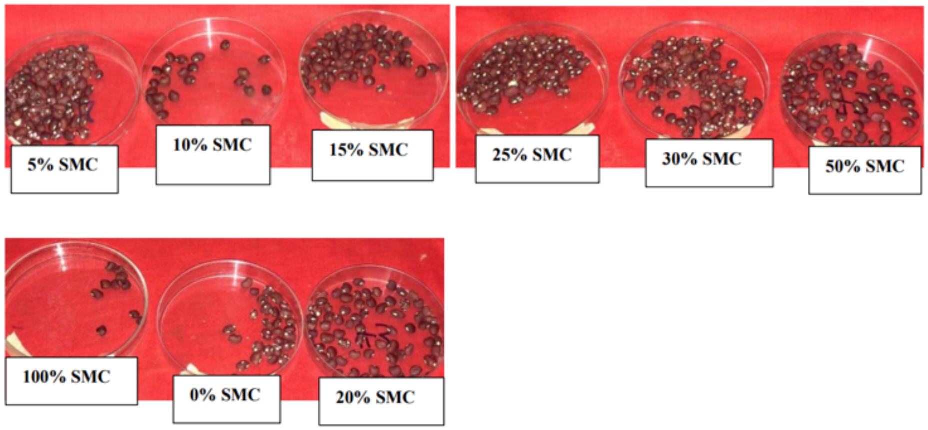


Figure 4: Seeds from pods harvested from cowpea plants grown in the varied indicated soil: SMC media under screenhouse conditions after 14 weeks of planting.

Influence of P. ostreatus strain EM-1 spent mushroom compost SMC on the growth development and yield quality of tomato (Solanum lycopersicum) seedlings under screenhouse conditions. Plant Height: Tomato seedlings grown in a mixture of soil and spent mushroom compost (SMC) showed varying heights, ranging from 10.8 ± 2.2 cm (100% SMC) to 52.9 ± 10.3 cm (10% SMC). Increasing SMC proportions generally reduced plant height. Significant differences ($p \leq 0.05$) were observed between: Soil only (0% SMC) and 5-20% SMC treatments and between 25-100% SMC treatments. No significant differences ($p \geq 0.05$) were found within the 25-100% SMC treatments (though numerical differences existed) and within the soil only (unamended soil) and 5-15% SMC treatments though numerical differences existed). 10% SMC promoted the growth of tomato plant height. Unamended soil produced taller plants (44.1 cm) than all tomato plants grown in 15-100% SMC (Figures 5-7).

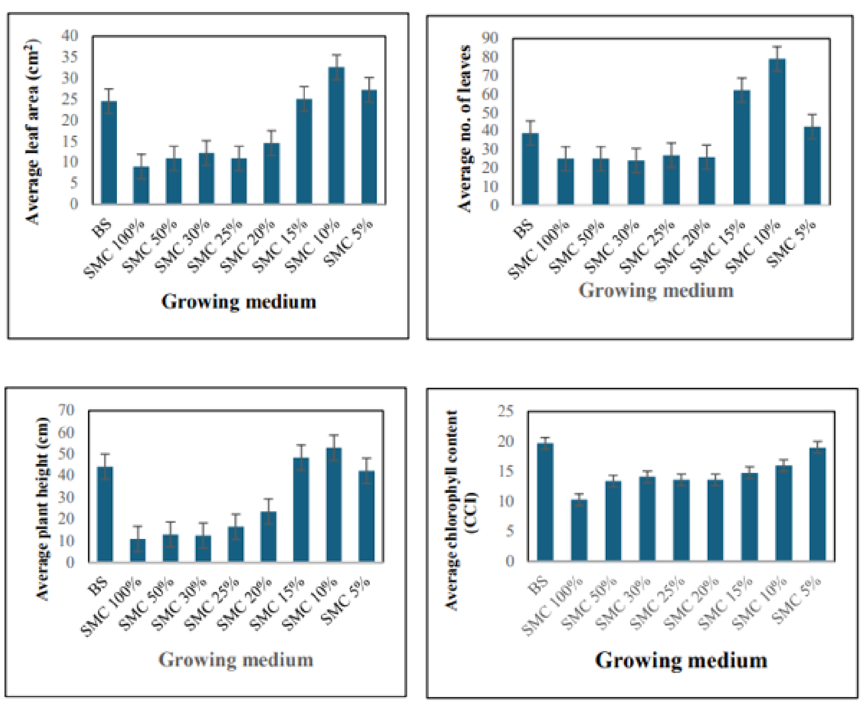


Figure 5: Effect of spent mushroom compost on vegetative growth of tomato seedlings grown in the indicated proportions of soil: SMC medium after 2-14 weeks of planting.

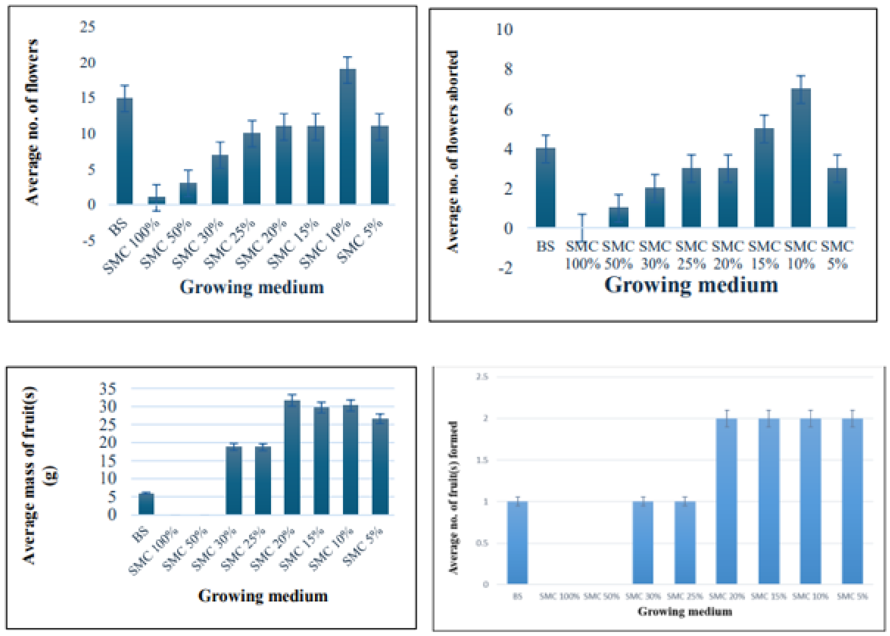


Figure 6: Effect of spent mushroom compost on reproductive growth of tomato seedlings grown in the indicated proportions of soil: SMC medium after 14 weeks of planting.

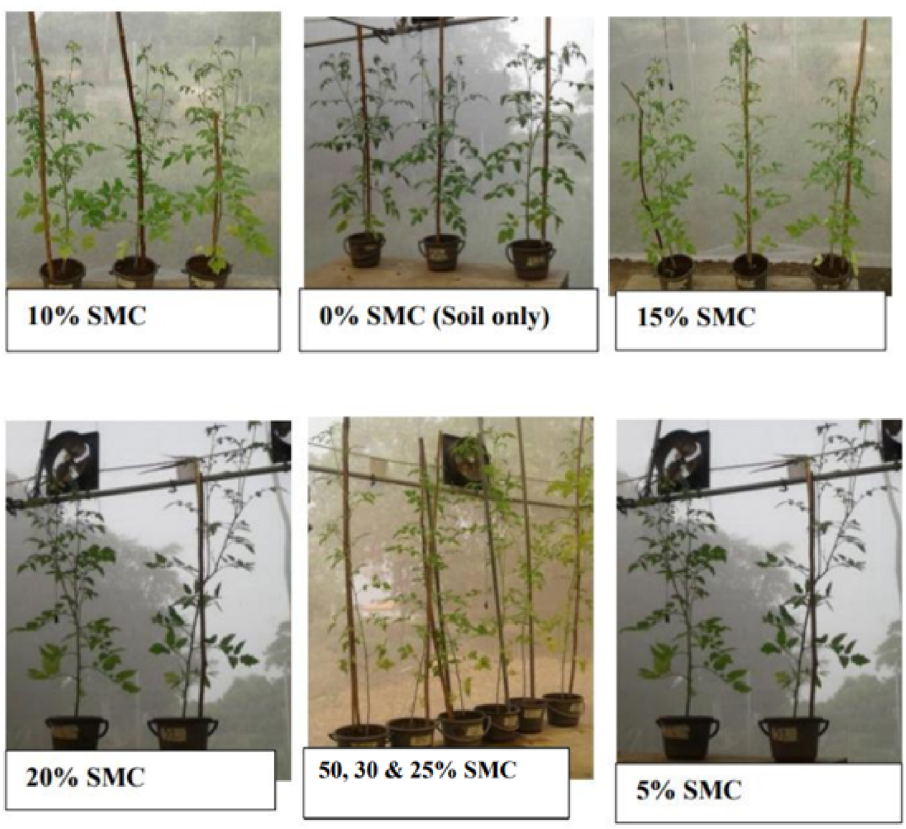


Figure 7: Growth of tomato seedlings in response to different soil: SMC compositions under screenhouse conditions.

Leaf Number: The highest number of leaves counted after two weeks of transplanting was observed in seedlings grown in 10% SMC (79 leaves), while the lowest was in 30% SMC (24 leaves). There were no significant differences among seedlings grown in 20-100% SMC. Tomato plants in the unamended soil recorded higher number of leaves (39) than all plants grown in 20-100% SMC.

Leaf Area: The highest leaf area was recorded in 10% SMC (32.6 ± 6.4 cm^2), while the lowest was in 100% SMC (9.0 ± 1.8 cm^2). Soils treatments above 15% SMC produced smaller leaf areas than control (i.e., 20 – 100 SMC percentages. They were significantly lower than those with lower percentages and than plants in the unamended soil (24.5± 3.9 cm^2). Significant differences ($p \leq 0.05$) existed between lower (5-15%) and higher (20-100%) SMC treatments.

Chlorophyll Content: Chlorophyll levels decreased as SMC percentages increased. The lowest chlorophyll content was observed in 100% SMC (10.3 ± 1.0 CCI) and this was significantly different ($p \leq 0.05$) from the control treatment (unamended soil). Unamended soil recorded the highest chlorophyll content (19.7 ± 2.2 CCI) followed by 5% SMC (19.0± 2.5 CCI). Amended soil treatments recorded chlorophyll content ranging from 13.4 ± 1.5 to 19.0 ± 2.5 CCI.

Flower Production: Flower counts ranged from 1 to 19 per seedling after 14 weeks. 10% SMC enhanced flower formation and accounted for the highest flower count (19). Control treatment recorded 15 flowers, with the lowest in 100% SMC (1 flower). There were no significant differences among most treatments except for 50% and 100% SMC.

Flower Abortion: The highest number of aborted flowers was in 10% SMC (7). The number of aborted flowers declined with increasing SMC percentages 10% > 15% > 20% > 30% > 50% > 100%. Plants in 100% SMC had no flower abortion. Control treatment (0% SMC) had 4 aborted flowers. Percentage of flower abortion was higher in control (73.3%) than in 5% SMC (63.2%). Lower SMC percentages (except 10% and 15%) generally showed lower flower abortion rates than control.

Fruit Formation: No fruits formed in 50% and 100% SMC due to total flower abortion and no flower production respectively. The highest number of fruits was observed in 5-20% SMC, with the lowest in unamended soil and higher SMC percentages. Fruit counts ranged from 1 to 4 per seedling. 5-20% SMC produced the highest fruit count (4). 0%, 25%, and 30% SMC produced the lowest fruit count (1) (Figure 8).

Figure 8: Samples of tomato fruits harvested from tomato plants grown in the indicated soil: SMC media under screenhouse conditions after 14 weeks of planting.

Fruit mass: It ranged from 6.0 ± 2.7 g to 31.69 ± 10.8 g. Seedlings in all amended soil produced significantly ($p \leq 0.05$) heavier fruit than those in unamended soil (control treatment). The highest tomato fruit mass peaked at 20% SMC (31.69 ± 10.8 g), followed by 10% SMC (30.3 ± 7.5 g).

Control treatment produced the lightest fruits (6.0 ± 2.7 g). Overall tomato plants grown in soil amended with moderate levels of spent mushroom compost (5-20% SMC) demonstrated superior growth and yield compared to unamended soil, with optimal results generally occurring at 10-20% SMC.

Analysis of Mineral Elements in Soil and SMC Samples

Atomic absorption spectrometry (AAS)- Flame Atomic Emission Spectrometry (FAES) analysis of soil and SMC samples revealed varying concentrations of Zn, Cu, Mn, Pb, Ca, Mg, Mg, Fe, Na, P, K and N. Spent mushroom compost recorded the higher concentration of Cu, Ca, Mg, Fe, Na, K and N whilst soil contained high concentration of Zn, Mn, Pb, and P. The pH of the soil and SMC were pH 6.8 and 7.10 respectively (Table 1). These pH ranges fall within the favourable range for growth of cowpea and tomato 6.6 – 7.6 and 5.5 – 6.8, respectively (Table 1).

Growing Medium	Zn (mg/kg)	Cu (mglkg)	Mn (mg/kg)	Pb (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	Na (mg/kg)	P (mg/kg)	K (mg/kg)	N (mg/kg)
Soil	0.018	0.002	0.135	0.016	0.473	0.446	0.002	0.215	0.892	0.12	0.82
Spent Com post only	0.015	0.005	0.011	0.013	0.595	0.775	0.019	0.198	0.797	0.283	0.98

Table 1: Elemental content of sandy loam soil and spent compost used as growing medium for cowpea and tomato seedlings.

Discussion

The constant-increasing human demand for protein-rich food and the inefficiency of conventional methods have resulted in the need to explore alternatives for low-cost production of unconventional protein-rich food. Mushroom industries are such alternatives, mushrooms are cultivated on organic substrates, naturally suitable for agricultural crops. The production of any mushroom species results in significant residual material after cultivation. Spent mushroom compost (SMC) is defined as a bulky waste byproduct of mushroom industry [5,6,13]. The current disposal methods involving landfills or incineration, causing environmental problems [1]. It has necessitated the need for environmentally conscious management of this coproduct of mushroom cultivation. The situation is same in Ghana and currently SMC is disposed of as residual waste and constitutes an environmental problem in Ghana [4]. However, when extensive research is conducted its application as soil conditioner or organic fertilizer for crop production in greenhouse, and field would be harnessed.

There have been some reports on the use of SMC as bio-fertilizer by Wiafe Kwagyan M, et al. [4,5,14-22]. Their findings revealed that spent mushroom substrate mixed with loamy soil produced greater vegetative growth and yields of crops such as cowpea and tomato than same crops in unamended loamy soil (control treatments). Studies by Ogbonna Det al. [23] demonstrated that SMC could be used to improve growth and yield of maize (Zea mays) in Nigeria. These studies reported that SMC is an attractive material for improving soil structure in tilled soils and increasing dry matter production in grassland soils, owing to its high organic matter content and availability of essential plant nutrients. It is also an effective source of K and P and provides trace elements for plant growth and as well as contribute to nitrogen nutrition. Other researchers have also shown that SMC can be used with beneficial effect in field crop production. Segun GJ, et al. [24] also reported that four vegetables Abelmoschus esculentus, Lycopersicum esculentum, Capsicum annum and C. chinense responded well to the SMC treatment whereas seedlings planted on 6 kg of depleted garden soil only, without the application of SMC, showed stunted and poor growth, with few or no flower and fruit production.

Their assertion was that the poor growth of seedlings in depleted soil may be because the depleted garden soil alone lacks the essential mineral elements which plants needed to retain leaves. The sandy loam soil ferric acrisol used in this study as the control treatment contained minerals such Zn, Cu, Mn, Pb, Ca, Mg, Fe, Na, N, P and K (Table 1). Similarly, the SMC also contains the same minerals but at significant concentrations and this could have accounted for better and optimum growth and yield of cowpea and tomato seedlings grown in soil: SMC combination as these nutrients were available in the SMC applied. Önal and Topcuóglu investigated the effect of SMC as an organic fertilizer for pepper grown in screenhouse soil in Turkey. Pepper plants grown in pots containing different amounts of SMC i.e., 0, 15, 30 and 60 t/ha had effect on the fruit yield and N, P, K, Fe and Zn contents were found statistically significant. The best result for yield as was obtained at 30 ton/ha SMC applications whereas fruit yield decreased at 60 ton/ha of SMC applications, possibly by the increased salinity [25,26].

SMC application on dry matter and N, P, K, Ca, Mg, Fe, Zn, Cu, Ni, Cd, and Pb content of pepper were determined. SMC application caused statistically ($p<0.05$) important effects on dry matter yield and N, P, K, Fe and Zn contents in the pepper plant. As an organic fertilizer, the spent compost was mixed at 1, 3, 5% (w/w) and added to the soil. SMC-containing sets showed early germination of Spinacia oleracea than pure soil. The time of germination decreased with an increasing proportion of SMC and recorded minimum in 5% (w/w) SMC. Their findings also revealed that composted spent mushroom substrate mixed with loamy soil produced greater vegetative growth and yields of both vegetables than loamy soil (controls).

Studies by Ogbonna D, et al. [23] demonstrated that SMC could be used to improve growth and yield of maize (Zea mays) in Nigeria. Poole RT, et al. [27] proposed that Agaricus bisporus spent substrate be used as a potting soil and since then SMS has been evaluated for the production of various greenhouse flowers and vegetables such as chrysanthemum, Easter lilies, marigolds, Helleborus, marigolds, cucumbers, tomatoes, lettuce, okra, eggplant, asparagus, beetroot, cauliflower, cabbage, capsicums, celery, cucumber, lettuce, green gram, mustard, onion, potato, radish, snap bean, spinach, sugar beet Male, Wang, Maynard, Maher, Rathier, Richter, Verdonck [5]. Stoknes K, et al. [28] reported the use of pasteurized spent mushroom compost (SMC) of Agaricus subrufescens in a sustainable plant growing lettuce, tomatoes, and cucumber under greenhouse conditions. These findings confirmed previous reports that SMC promoted growth and yield performance of agricultural crops. The present study also corroborated these findings and that there was a significantly better plant growth in treatments with added SMC of *Pleurotus ostreatus*.

In addition, their data indicated in several experiments when full fertigation was not used, the amendment of SMC to compost substrates significantly increased available nutrients, especially N, but also available K and S and improved plant growth. This also supported the present study when cowpea and tomato were used as test crops. Results presented in this study indicated that cowpea and tomato seedlings grown in soil amended with spent mushroom compost from *Pleurotus ostreatus* strain EM-1 performed better than same plants raised in unamended soil (i.e., soil only or 0% SMC) and spent compost only (100% SMC or soilless medium). Cowpea plants which developed in 50% SMC obtained the highest number of pods although the maximum mass of pods was recorded for cowpea plants raised in 5% SMC.

The findings showed that while higher proportions of SMC (25% to 50%) promoted the formation of a greater number of pods, it had an adverse impact on the mass of these pods. On the other hand, lower proportions of SMC (ranging from 5% to 20%) enhanced the mass of the pods, even though the number of pods formed decreased (Figures 3 and 4). A contrasting trend was observed for tomato plants cultivated in various amended soil-SMC mixtures. For tomatoes, a positive correlation was observed between the number and mass of fruits produced in the different formulated media. The highest number and mass of fruits were on lower concentrations of SMC (5% to 20%), recording two fruits per plant, each with corresponding masses ranging from 26.6 ± 5.5 to 31.8±10.8 g. In contrast, higher concentrations of SMC (50% and100%) did not produce any fruit per seedling. The unamended soil (0% SMC, control); the 25% and 30% SMC treatments recorded the lowest number of fruits, with just one fruit per seedling.

Remarkably, the mass of the fruit harvested from the (25% and 30%) SMC treatments was not only statistically significant but also superior to that of the control tomato fruit. However, seedlings cultivated in (50% and 100%) SMC did not yield any fruit. SMC is rich in nutrients, including nitrogen, phosphorus, and potassium, which are essential for plant growth. However, excessive nutrient levels can disrupt the balance of plant hormones such as auxins, cytokinins, and gibberellins, which regulate growth and development. For example, Auxins promote cell elongation and root growth, while cytokinins promote cell division and leaf growth. An imbalance in these hormones, potentially influenced by SMC, can affect plant morphology and productivity. This suggests that SMC applications increased yield up to the point where SMC constituted 50% of the growing medium. Consequently, it can be inferred that higher SMC application rates had a detrimental effect on plant growth and the corresponding quality of the yield. Another possibility is that the time constraints of the project might have hindered seedlings grown in higher concentrations of SMC (ranging from 25% to 50%) from developing flowers and, consequently, forming pods and fruits. It's also plausible that the mineral concentrations in the combined soil-SMC treatments were elevated, affecting the physiological processes, including photosynthesis. Photosynthesis unfolds in two distinct phases, involving light and dark reactions in what is termed photosystem I and II within the chloroplasts. The reaction sites for both light and dark reactions might have been influenced by the levels of mineral elements, nutrients, as well as chlorophylls 'a and b'. Therefore, it can be conjectured that the overall growth of the plant could be influenced by the efficiency of the coordinated reactions within photosystems I and II.

Furthermore, as the soil received higher levels of SMC amendments, it likely led to an increase in cation exchange capacity, pH levels, and the concentrations of extractable K, Ca, and Mg in the soil. Given that there is a notable connection between these three ions in the soil, an excess of any of these ions could lead to competitive interactions for uptake by plants or exchange with one another, potentially hastening the leaching of these exchanged ions [29-31].

Conclusion

The utilization of spent mushroom compost derived from *Pleurotus ostreatus* strain EM-1 yielded significant enhancements in both the vegetative growth and yield quality of cowpea and tomato seedlings when incorporated into soil treatments at lower concentrations (5-30%) of SMC. However, the introduction of higher concentrations (50-100%) of SMC into the soil had an adverse effect on the growth and development of these plants, potentially due to an excessive concentration of mineral elements within the compost. It is important to note that the absence of fruit formation in plants subjected to higher SMC concentrations during this study required further studies on the elucidation of the factors accounting for this occurrence. For instance, in a real-world field trial with longer growth periods, it is plausible that cowpea and tomato seedlings could still yield fruits, even in the presence of higher concentrations of soil-SMC mix (50-100%). Another aspect to consider is the specificity of nutrient requirements for each crop, leading to varying responses of cowpea and tomato seedlings to the different SMC formulations examined in this study. Further research may shed more light on these intriguing observations. In all, the use of spent mushroom compost in vegetable production is an environmentally sustainable means of agriculture and an excellent example of permaculture.

Recommendation

Application and the use of *Pleurotus ostreatus* strain EM-1 SMC in the growing of other vegetables should be investigated since adding SMC to compost substrates significantly increased available nutrients, especially N, but also available K and S which will reduce full fertigation in agriculture. However, it is important field trials are conducted to establish the feasibility and effect of the use of spent mushroom compost for commercial farming. Further studies should also investigate the effect of SMC on the production of different plant hormones as high SMC levels might influence ethylene production, impacting fruit development and senescence.

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Declaration Statement

The authors reported no known conflict of interest.

References

1. Londoño CR, Giraldo AG, Moreno A, Alvarado PN (2024) Valorization of Spent Mushroom Compost Through a Cascading Use Approach. Energies 17(21): 5458.

2. Poudel P, Duenas AEK, Di Gioia F (2023) Organic waste compost and spent mushroom compost as potential growing media components for the sustainable production of microgreens. Front Plant Sci Sec Crop and Product Physiology 14: 2023.

3. Jasińska A (2018) Spent mushroom compost (SMC)-retrieved added value product closing loop in agricultural production. 150th Anniversary of the Foundation of Agricultural University in Debrecen pp: 185-202.

4. Wiafe Kwagyan M, Odamtten GT (2018) Use of Pleurotus eous Strain P-31 Spent Mushroom Compost (SMC) as Soil Conditioner on the Growth and Yield Performance of *Capsicum annuum* L. and *Solanum lycopersicon* L. Seedlings under GreenhouseConditions in Ghana. Trop Life Sci Res 29(1): 173-194.

5. Rinker DL (2017) Spent Mushroom Substrate Uses: Technology and Applications. University of Guelph, Guelph, ON, Canada, pp: 29.

6. Royse DJ (2014) A global perspective on the high five: Agaricus, Pleurotus, Lentinula,Auricularia & Flammulina. In: Singh M (Ed.), Proceedings of the 8th International Conference on Mushroom Biology and Mushroom Products. New Delhi. India, pp: 1-6.

7. Gonani Z, Riahi H, Sharifi K (2011) Impact of using leached spent mushroom compost as a partial growing media for horticultural plants. J Plant Nutr 34(3): 337-344.

8. Jasińska AJ, Wojciechowska E, Stoknes K, Krzesiński W, Spiżewski T, et al. (2016) Mushroom cultivation on substrates with addition of anaerobically digested food waste. Acta Horticulturae pp: 199-206.

9. Ma Y, Wang Q, Sun X, Wang X, Su W, et al. (2014) A study on recycling of spent mushroom substrate to prepare chars and activated carbon. Bioresources 9(3): 3939-3954.

10. Roy S, Barman S, Chakraborty U, Chakraborty B (2015)

Evaluation of spent mushroom substrate as biofertilizer for growth improvement of *Capsicum annuum* L. Journal of Appl Biol and Biotechnol 3(3): 22-27.

11. Wiafe Kwagyan M (2014) Comparative bioconversion of rice lignocellulosic waste and its amendments by two oyster mushrooms (Pleurotus species) and the use of the spent mushroom compost as bio-fertilizer for the cultivation of tomato, pepper, and cowpea. Unpublished Ph.D thesis, Department of Plant and Environmental Biology, University of Ghana, Legon, Ghana, pp: 326.

12. Çayci G, Baran A, Bender D (1998) The effects of peat and sand amended spent mushroom compost on growing of tomato. Journal of Agricultural Sciences 4(2): 27-29.

13. Phan CW, Sabaratnam V (2012) Potential uses of spent mushroom substrate and its associated lignocellulosic enzymes. Appl Microbiol Biotechnol 96: 863-873.

14. Marques ELS, Martos ET, Souza RJ, Silva R, Zied DC, et al. (2014) Spent mushroom compost as a substrate for the production of lettuce proceedings. J Agric Sci 6(7): 138.

15. Idowu OO, Kadiri M (2013) Growth and yield response of okra (Abelmoschus esculentusMoench) to spent mushroom compost from the cultivation of *Pleurotus ostreatus* an edible mushroom. Aca J Agric Res 1(3): 039-044.

16. Kadiri M, Mustapha Y (2010) The use of spent mushroom substrate of Lentinus subnudus (Berk) as a soil conditioner for vegetables. Bayero J Pure and Appl Sci 3(2): 16-19.

17. Polat E, Uzun HI, Topçuoglu B, Önal K, Onus AN, et al. (2009) Effects of spent mushroom compost on quality and productivity of cucumber (*Cucumis sativus* L.) grown in greenhouses. Afri J Biotechnol 8(2): 176-180.

18. Peksen A, Uzun S (2008) Effect of chemical compositions of seedling media prepared by spent mushroom compost on seedling growth and development of kale and broccoli (Brassica oleracea L. var. italic L.). Asian J Chem 20(4): 3002-3008.

19. Uzun I (2004) Use of spent mushroom compost in sustainable fruit production. Journal of Fruit and Ornamental Plant Research 12: 157-165.

20. Maher MJ, Smyth S, Dodd VA, McCabe T, Magette WL, et al. (2000) Managing pent mushroom compost. Teagasc, Dublin, Ireland, pp: 1-4.

21. Chong C, Rinker DL (1994) Use of spent mushroom compost for growing containerized woody ornamentals: an overview. Compost Science and Utilization 2(3): 45-53.

22. Dallon J (1987) Effects of spent mushroom compost on the production of greenhouse-grown crops. Combined Proceedings of the International Plant Propagators Society 37: 323-329.

23. Ogbonna D, Nnaemeka N, Isirimah O, Ekanim P (2012) Effect of organic waste compost and microbial activity on the growth of maize in the utisoils in Port Harcourt Nigeria. Afri J Biotechnol 11(62): 12546-12554.

24. Segun GJ, Muritala ML, Olusola JO (2011) Effect of Spent Mushroom Compost of *Pleurotus* pulmonarius on Growth performance of four Nigerian vegetables. Mycobiology 39(3): 164-169.

25. Chong C, Cıne RA, Rnker DL, Allan AO (1991) Growth and mineral nutrient of containerized woody species in media amended with spent mushroom compost. J Amer Soc Hort Sci 116(2): 242-247.

26. Wisniewska GH, Pankiewicz T (1989) Evaluation of the suitability of spent mushroom substrate for tulip cultivation. Prace Instytutu Sadownictura W Kwiaciarstwa Skerniewicack 14: 7-13.

27. Poole RT, Conorer CA (1974) Spent compost: a possible ingredient of potting soil. Florida Foliage Grower 11(7): 7.

28. Stoknes K, Wojciechowska E, Jasinska A, Noble R (2019) Amelioration of composts for greenhouse vegetable plants using pasteurized Agaricus mushroom substrate. Sustainability 11(23): 6779.

29. Wang SHL, Lohr VI, Coffey DL (1984) Growth response of selected vegetable crops to spent mushroom compost application in a controlled environment. Plant and Soil 82: 31-40.

30. Adhikari D, Kobashi Y, Kai T, Kawagoe T, Kubota K, et al. (2018) Suitable Soil Conditions for Tomato Cultivation under an Organic Farming System. Journal of Agricultural Chemistry and Environment 7: 117-132.

31. Kamara AY, Omoigui LO, Kamai N, Ewansiha SU, Ajeigbe HA (2018) Improving cultivation of cowpea in West Africa.