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Growth and Yield of Kale, Swiss chard, Amaranth, and Arugula microgreens in response to different growing medium substrates

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Abstract

Microgreens are relatively novel food with high nutrition and dietary benefits that can be influenced by the growing medium. Two experiments were performed to develop an optimum media for microgreensfrom kale (*Brassica oleracea* L. var. acephala), Swiss chard (*Betavulgaris* var. cicla), arugula (*Eruca vesicaria* ssp. sativa), and amaranth (*Amaranthus tricolour* L.). Experiment 1 was screening of media T1 = 30% vermicast + 40% sawdust + 30% perlite; T2 = 30% vermicast + 50% sawdust + 20% perlite; T3 = 50% vermicast + 30% sawdust + 20% perlite; T4 = 30% vermicast + 40% sawdust + 30% mushroom compost; T5 = 30% vermicast + 20% sawdust + 20% perlite + 30% mushroom compost; and a negative control (NC) = 50% sawdust + 50% mushroom compost. The positive control was Promix BX™ potting mix alone. Experiment 2 was to test the efficacy of two different sources of mushroom compost (White oyster mushroom compost (MC1) and Shiitake mushroom compost (MC2)) added to media T1 to T5 above. The results showed that the media physicochemical properties varied across treatments. Higher chemical parameters were obtained for T4, T5, and media containing MC1. Porosity and water retention were increased in media containing MC2 compared to the other.Seed germination, plant height, and microgreen yield were statistically ($P>0.05$) enhanced by T2 and T4 that contained MC2 compared to the rest. Microgreens yield was approximately three times higher in T2 and 4 with added MC2, except the yield of arugula which was two times higher in these media compared to the control. Overall, T5 alone, and T2 and T4 with added MC2 were the most effective media for microgreen production. Future studies will assess microgreens' nutrients in different media.

Keywords: leafy vegetable, natural amendment, organic food, sustainable farming, healthy food

Introduction

Preharvest factors refer to management practices applied before the final harvest of crops that affect postharvest productivity and quality of the crop. Preharvest factors include 1) plant genotypic traits; 2) growing medium factors and amendments; 3) environmental factors (light quality, duration, intensity); 4) management practices (planting and harvest time, irrigation, and fertilization).[1] Natural amendments (organic natural material) are added to soil or growing media to enhance the fertility and/or the structure of soil, thereby helping plant growth and development.[2-5] Various natural amendments application was shown to differentially alter the physiochemical properties of growing media and provided higher nutrients that consequently improved the yield index of different crops.[6-8] Previous studies corroborated that adding vermicast into growing media promote aeration, porosity, capacity of holding water, and support microbial activity and antipathogenic response.[9-11]

A study by Zhang et al.[12] indicated that fresh weight and leaf area were higher in two *Plectranthus* spp treated with vermicast compared to K-humate and NPK amendments, which can be associated with more balanced nutrients in vermicast. As confirmed by Iheshiulo et al.[11] kale (*Brassica oleracea* L. var. *acephala*)growth rate, leaf elongation, and fresh weight yield were improved by the application of natural amendments compared to Pro-mix BX alone as the control. The authors found that vermicast was the most effective amendment in enhancing the growth rate of kale that may relate to the presence of higher N content.Another popular natural amendment is sawdust produced from industrial wood waste and forestry with high carbon content. It provides substantial advantages for the environment including 1) promoting water holding capacity; 2) increasing soil porosity and aeration; and 3) providing good drainage.[13] According to Singh et al.[10] sawdust and vermicompost are locally available materials and environmentally friendlier alternatives compared to traditional strategies for microgreens production. There are limited studies regarding the effects of sawdust on plant production, in particular microgreens. A study by Agboola et al.[14] revealed a delay in the initial growth response of tomato (*Solanum lycopersicum*) to sawdust but there was increase in response after 7days. The authors concluded that sawdust was economical medium substrate and an effective alternative to peat.

A research study done by Cheng confirmed that adding 30% sawdust into total soil treated with NPK (nitrogen, phosphorus, and potassium) compound fertilizer led to a significant increase in tomato yield in comparison with using sawdust alone. Mahboub Khomami et al.[15] demonstrated that the application of vermicompost-sawdust extract caused a significant increase in yield and mineral nutrients of *Syngoniumpodophyllum*. A recent study by Lin et al.[16] indicated that a combination of 60% vermicast + 40% sawdust mixed growing media noticeably enhanced growth factors including fresh/ dry weight, plant height, and leaf number in Swiss chard, pak choi, and kale microgreens. It was shown that the enhanced growth factors were linked to the positive effects of vermicast-vermicast mixed media on growing media physicochemical factors including enhanced microbial activities and nutrient mineralization. Mushroom compost is a mixture of different natural compost like chopped straw, gypsum, manure, and water used to grow mushrooms. It is known to possess potential benefits for plant growth and growing media properties including 1) supplying readily available macro and micronutrients; 2) increasing water retention capacity and drainage; 3) supporting beneficial micro-organisms. Renaldo et al.[17] reported higher germination rate and growth parameters including root/ shoot ratio, shoot/ root day mass cucumber (*Cucumis sativus*) treated with mushroom compost and biochar compared to corn stalks. It was demonstrated that the higher decomposition rate in mushroom compost, hence an increased nutrient availability may be connected to enhanced growth indices. In the work done by Hernández et al.[18] enhanced germination percentage, fresh shoot weight, and yield in red baby leaf lettuce by mushroom compost application. Interestingly, the results obtained from previous studies present obvious affirmation regarding the potential effects of mushroom compost on growth attributes and plant productivity.

Microgreens are immature seedlings of edible vegetables and herbs, which are known to possess high nutritional values and biological functions.[19,20] According to literature, microgreens possess higher levels of phytonutrients such as ascorbic acid, b-carotene, a-tocopherol, and phylloquinone, vitamins, and minerals compared to their mature leaf counterparts.[20,21] Kale, Swiss chard, and pak choi have been shown to have high vitamins A, C, and K, functional lipids, carotenoids, and mineral nutrients content.[19,22] However, microgreens response to variations in growing media has not been well studied. Therefore, the objective of the current study was to determine properties exhibited by different mixed proportions of growing media and their effects on plant growth components and yield of different plant species of microgreens.

Materials and Methods

Two separate greenhouse experiments were carried out between July and December 2020 to formulate and optimize mixed growing media. Each experiment was repeated, and the data was merged due to a small coefficient of variationof less than 7%. Seeds of kale (*Brassica oleracea* L. var. *acephala*), Swiss chard (*Beta vulgaris* var. *cicla*), arugula (*Eruca vesicaria* ssp. *sativa*), pak choi (*Brasica rapa var chinensis*), and amaranth (*Amaranthus tricolour* L.); and perlite, Pro-mix BX and vermicast were purchased from Halifax Seeds, NS, Canada. Sawdust was obtained from Thermal Woods Inc., NB; and Shiitake (*Lentinula edodes*) and white oyster (*Pleurotusostreatus*) mushroom compost from Maritime Gourmet Mushroom, Great Village, NS.

Formulation and testing of media

Table 1 shows the mixture for each growing media treatment.

Table 1 Proportions of mixed growing media

Treatment	Formulation
T1	30% vermicast + 40% sawdust + 30% perlite
T2	30% vermicast + 50% sawdust + 20% perlite
T3	50% vermicast + 30% sawdust + 20% perlite
T4	30% vermicast + 40% sawdust + 30% mushroom compost
T5	30% vermicast + 20% sawdust + 20% perlite + 30% mushroom compost
Positive control	Promix BX potting medium alone
Negative control	50% sawdust + 50% mushroom compost

Physical characteristics of growing media in terms of bulk density, porosity, and field capacity were determined in triplicate as suggested by Peterson,[23] with slight modifications. Bulk density (Db) was obtained from the weight (M) and volume (V1) of the soil using a graduated glass cylinder after continuous tapping until there was not any visible change in soil volume and calculated as:

$$\text{Bulk density} = {}^{M}/_{V_1} \text{-----------------------------} \ (1)$$

The soil was air-dried under room temperature (*ca*. 22°C) after which 15.24-cm plastic pots with drainage holes were filled with known mass of the soil (Ms) and weighed (Msp). The potting soil placed in a saucer was saturated with distilled water. After 48hr, the saturated soil weight (Msat) was recorded. To drain the free water, the saucer was removed, and the drained soil (Mdrained) was weighed after 72hr under atmospheric pressure. Then, the drained soil was spread uniformly in a tray to dry at ambient temperature for 72hr and weighed (Mdried).

$$\text{Porosity} = {}^{Ms}/_{V_2} \text{-------------------------} (2)$$

$$\text{Field capacity } (F_c) = \frac{M_{drained} - M_{sp}}{M_s} \times 100 \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (3)$$

The chemical characteristics of growing media including pH, salinity, electrical conductivity (EC), and total dissolved solids (TDS) were determined by the mixture of 500g of each media and 400mL of deionized water. These chemical properties were recorded by an ExStik® II EC500 waterproof pH/conductivity meter (Extech ITM Instruments Inc., Canada).

Seeding

Seeds of kale, Swiss chard, arugula, pak choi, and amaranth were sown by broadcasting uniformly on a flat plastic tray (19cm length x 12cm width x 2.5cm deep) containing the different mixed media (200g) under high pressure sodium lamp. The temperature cycle in the growth room from seedling stage to time of harvest was 24°/22°C and 16/8hrs day/night light regime. The seedlings were irrigated every two days. No fertilizer was used.

Seed germination, plant growth and yield

Germination data were collected after six days of sowing. Plant height was measured by using a ruler at six days interval. The microgreens were harvested and weighed as the yield (whole shoot area growing above ground) after 14days of sowing using Ohaus Navigator® XT Portable Balance (ITM Instruments Inc., Canada). The optimum proportion of mixed media was selected for the subsequent experiments.

Optimization of mixed media

In the second experiment, new formulations of different mixed growing media were made from two different mushroom composts sources i.e., White oyster mushroom compost (MC1) and Shiitake mushroom compost (MC2)as presented in Table 2.

Table 2 Proportions of mixed growing media

Treatment	Formulation
T1.1	30% vermicast + 30% sawdust + 40% White oyster mushroom compost (MC1)
T1.2	30% vermicast + 30% sawdust + 40% Shiitake mushroom compost(MC2)
T2.1	30% vermicast + 30% sawdust + 10% perlite + 30% MC1
T2.2	30% vermicast + 30% sawdust + 10% perlite + 30% MC2
T3.1	30% vermicast + 40% sawdust + 30% MC1
T3.2	30% vermicast + 40% sawdust + 30% MC2

Citation: Saleh R, Gunupuru LR, Abbey L. Growth and Yield of Kale, Swiss chard, Amaranth, and Arugula microgreens in response to different growing medium substrates. *Horticult Int J.* 2022;6(4):180–187. DOI: 10.15406/hij.2022.06.00263

Table Continued...

Treatment	Formulation
T4.1	30% vermicast + 20% sawdust + 20% perlite + 30% MC1
T4.2	30% vermicast + 20% sawdust + 20% perlite + 30% MC2
Negative control 1	50% sawdust + 50% MC1
Negative control 2	50% sawdust + 50% MC2
Positive control	Promix BX™ potting medium alone

Experimental Design and Statistical Analysis

The experiment was arranged in a completely randomized design with three replications. Plastic trays were rearranged every two days to minimize variations in microclimate of the greenhouse. Data was analyzed by 2-way ANOVA using Minitab (version 18.3), and the Fisher method was applied to compare treatment means at α = 0.05 when ANOVA showed P≤0.05. Correlation analysis was performed to identify the relationship between media quality components and plant data. Multivariate analysis by principal component analysis (PCA) was performed using GenStat. Graphs were plotted using Microsoft Excel.

Results

Experiment 1

Growing media properties

Physicochemical properties of the different growing media were significantly (P<0.05) different (Table 3). It was found that NC and T4 had a significantly (P<0.05) higher bulk density of an average of 0.184 g/cm^3 compared to an average of 0.150g/cm^3 for the other treatments. The highest porosity and field capacity were observed by T4 followed by NC and T1 but T3 recorded the least.

Table 3 Physiochemical properties affected by different proportion of mixed growing media

Treatment	Bulk density (g/cm³)	Porosity (%)	Field capacity (%)	pH	Salinity (mg/L)	Electrical conductivity (µS/cm)	Total dissolved solid (mg/L)
T1	0.139de	42.9b	34.1bc	5.8d	375.4d	1091.4d	629.5d
T2	0.161c	41.2bc	33.4bc	5.9d	481.4d	885.5d	745.0c
T3	0.165bc	34.5d	26.6d	6.3bc	355.5d	601.9e	512.8e
T4	0.181ab	45.8a	36.6a	7.2a	1938.0a	3243.3a	2365.7a
T5	0.158cd	38.0cd	29.3cd	7.3a	1369.8b	2445.9b	2295.7a
PC	0.128e	41.3bc	33.3c	6.0cd	798.0c	1521.1c	1217.5b
NC	0.187a	43.3b	34.6b	6.6ab	2039.6a	1737.6c	2585.0a
P-value	<0.001	<0.001	<0.001	0.000	<0.001	<0.001	<0.001

T1: 30% vermicast + 40% sawdust + 30% perlite; **T2:** 30% vermicast + 50% sawdust + 20% perlite; **T3:** 50% vermicast + 30% sawdust + 20% perlite; **T4:** 30% vermicast + 40% sawdust + 30% mushroom compost; **T5:** 30% vermicast + 20% sawdust + 20% perlite + 30% mushroom compost; **Positive control (PC):**Pro-mix BX™ potting medium alone; **Negative control (NC):**50% sawdust + 50% mushroom compost.

The different growing media had distinct pH ranging from 5.8 to 7.3. The pH for T4 and T5 was significantly (P<0.05) higher than the other treatments. Different trends for salinity, electrical conductivity and total dissolve solids were observed among the treatments (Table 3). The salinity, electrical conductivity, and total dissolved solids were higher in T4, T5, and NC compared to other treatments.

Plant growth

The effects of the different mixed growing media, plant species, and the interaction of growing media × plant species on seed germination and plant height were significant (P < 0.05) (Figures 1A&B). Seed germination of Swiss chard and kale were increased by *ca.* 18% and 13% in T5 respectively, compared to their counterparts in the PC. In amaranth, T4 showed the highest germination percentage that was 25% higher than that of the control. Moreover, the different growing media did not exhibit a positive effect on arugula seedgermination as the highest rate was observed in PC (Figure 1A). Among the microgreen plant species, the overall trend for germination percentage was arugula (76.9%) > amaranth (61.5%) = kale (61.3%) > Swiss chard (55.6%) (Figure 1A). Consistently, microgreens plant height was significantly (P < 0.05) increased by T5 and PC in all the plant species (Figure 1B). Overall, the trend for the plant height was arugula (4.9cm) > kale (4.7cm) > Swiss chard (4.1cm) >amaranth (2.6cm) (Figure 1B).

The correlation analysis between physicochemical attributes of mixed growing media and plant growth factors is presented in Table 4. In general, there was a negative correlation between physical factors of mixed growing media and the plant growth factors in all tested microgreens. However, there was a significant positive correlation between pH, salinity, EC, and TDS of the mixed growing media and seed germination in amaranth.

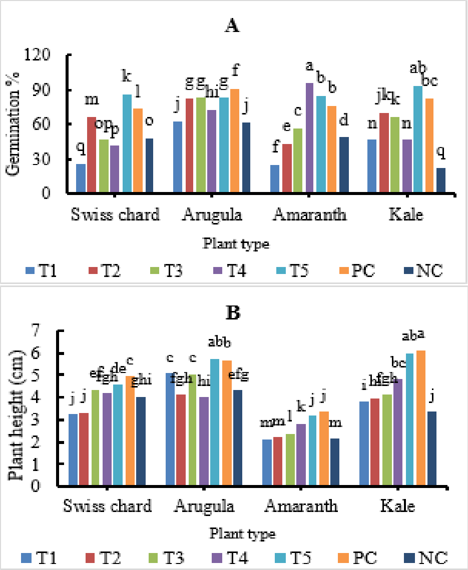

Figure 1 Germination (A) and plant height (B) of Swiss chard (*Beta vulgaris* var. *cicla*), arugula (*Eruca vesicaria* ssp. sativa), amaranth (*Amaranthus tricolour* L.), and kale (*Brassica oleracea* L. var. acephala) microgreens affected by different growing media:T1: 30% vermicast + 40% sawdust + 30% perlite; T2: 30% vermicast + 50% sawdust + 20% perlite; T3: 50% vermicast + 30% sawdust + 20% perlite; T4: 30% vermicast + 40% sawdust + 30% mushroom compost; T5: 30% vermicast + 20% sawdust + 20% perlite+ 30% mushroom compost; PC: Pro-mix BX™ potting medium alone; NC: 50% sawdust + 50% mushroom compost. (n = 3); significant at P < 0.05.

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Table 4 Correlation coefficients between growing media physicochemical factors and plant data

	Physical properties of mixed media			Chemical properties of mixed media			
	Porosity	Bulk density	Field capacity	pH	Salinity (mg/L)	EC (µS/cm)	Tds (mg/L)
Swiss chard germination	-0.352	-0.205	-0.383	0.190	0.441	0.315	0.497
Arugula germination	0.532**	-0.395	-0.521**	-0.026	0.350	0.502**	0.460
Amaranth germination	0.099	0.193	-0.003	0.689**	0.544**	0.758**	0.560**
Kale germination	0.574**	-0.566**	-0.642**	0.017	0.426	0.561**	0.661**
Swiss chard height	0.590**	-0.110	-0.324	0.409	0.279	0.326	0.343
Arugula height	0.494	-0.666**	-0.573**	0.019	-0.577**	0.461	0.519**
Amaranth height	0.404	-0.365	-0.199	0.388	0.190	0.498	0.305
Kale height	0.586**	-0.479**	-0.296	0.314	0.047	0.416	0.188

EC: Electrical conductivity; TDS: Total dissolved; ** Significant at $P < 0.05$

Association between media and plant data

A Principal component analysis (PCA) followed by a biplot was employed to examine the association between physicochemical characteristics of growing media and plant data affected by the variations in growing media (Figure 2). T5 followed by T4 are close to the origin of the axes suggesting higher stability in these treatments compared to the others that are located at the periphery. Therefore, T5 and T4 can be associated with improved physicochemical properties of the growing media and plant growth components of all the microgreen plant species. Interestingly, the chemical parameters of growing media are strongly influenced by different growing media formulations compared to that of the physical parameters. The overall trend for media chemical parameters was pH > EC> TDS> Salinity. In addition, amaranth germination and seedling height, and Swiss chard seedling height followed by kale seedling height were strongly influenced by the interaction of growing media × plant species compared to that of the arugula plant. Finally, T5 and T4 were selected as desirable media for microgreen production compared to the others irrespective plant species.

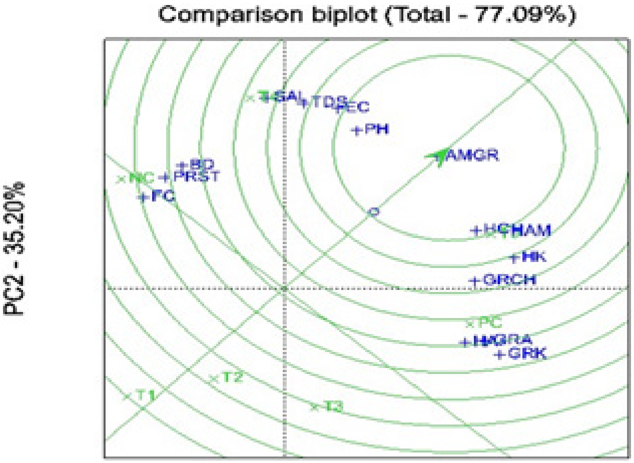

Figure 2 Ranking total × total biplot for comparison of treatment × plant species interaction effects on all growth and physicochemical growing media properties variations in all microgreens. PRST: Porosity; BD: Bulk density; FC: Field capacity; SAL: Salinity; EC: Electrical conductivity; TDS: Total dissolved solid; GRCH: Swiss chard germination; GRA: Arugula germination; GRK: Kale germination; AMGR: Amaranth germination; HCH: Swiss chard height; HA: Arugula height; HK: Kale height; HAM: Amaranth height.T1: 30% vermicast + 40% sawdust + 30% perlite; T2: 30% vermicast + 50% sawdust + 20% perlite; T3: 50% vermicast + 30% sawdust + 20% perlite; T4: 30% vermicast + 40% sawdust + 30% mushroom compost; T5: 30% vermicast + 20% sawdust + 20% perlite+ 30% mushroom compost; PC: Pro-mix BX™ potting medium alone; NC: 50% sawdust + 50% mushroom compost.

Experiment 2

Growing media properties

The physicochemical properties of the growing media were significantly ($P<0.05$) different from each other, possibly due to the distinct composition of each growing media (Table 5). It was found that PC had the highest bulk density among treatments. However, treatments formulated with White oyster mushroom compost (MC1) had a higher bulk density of an average of 0.095g/cm^3 compared to an average of 0.087g/cm^3 for treatments formulated with Shiitake mushroom compost (MC2).

The highest porosity was observed in PC followed by T4.2 and the least were T2.1. Field capacities of media PC, T3.2 and T1.2 were the highest compared to the others. Consistently, field capacity was increased in growing media formulated with MC2 compared to MC1.Moreover, T4.1 and NC1 had higher pH of an average of 7.4 compared to an average of 6.2 for T1.2 and PC. The overall trend for salinity, EC and TDS of the growing media parameters were different among treatments. The highest salinity, EC, and TDS were observed in NC1 followed by T3.1 and T1.1 (Table 5).

Plant growth

The ANOVA showed that seed germination, plant height, and yield indexin all tested microgreen species were significantly ($P<0.05$) influenced by the different growing media, plant species, and their interaction (Figure 3A-C). Swiss chard, arugula, and pak choi seed germination were increased by *ca.*9% in T2.2 and T4.2, *ca.*59% in T2.2 and T3.2, and *ca.*25% in T2.2, respectively, compared to their counterparts that were grown in the PC. The different mixed growing media did not exhibit positive effect on seed germination of arugula as the highest rate was observed in the PC (Figure 3A).

Similarly, the different growing media did not have a positive effect on seed germination of kale as the highest rate was observed in PC (Figure 3A). Moreover, microgreens plant height was significantly ($P < 0.05$) increased by T2.2, T4.2, PC in all the plant species (Figure 3B). Contrary to this, T1.1, NC1, NC2 followed by T4.1 reduced plant height of all the microgreen plants. The yield index was significantly ($P < 0.01$) increased by T2.2 and T4.2 in all the plant species (Figure 3C). The yield of Swiss chard, arugula, and kale increased by 31%, 17%, and 43% in T2.2 respectively compared to their PC counterparts. However, pak choi yield was enhanced in T4.2 by 35% compared to PC (Figure 3C).

Positive correlation between porosity and yield of most microgreen species, while there was significant negative correlation between bulk

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density and field capacity and the measured growth parameters of the microgreens. Furthermore, there was significant ($P<0.05$) negative correlation between pH, salinity, EC, and germination of pak choi and kale. There was no significant ($P>0.05$) correlation between TDS and the measured traits in all the microgreens (Table 6).

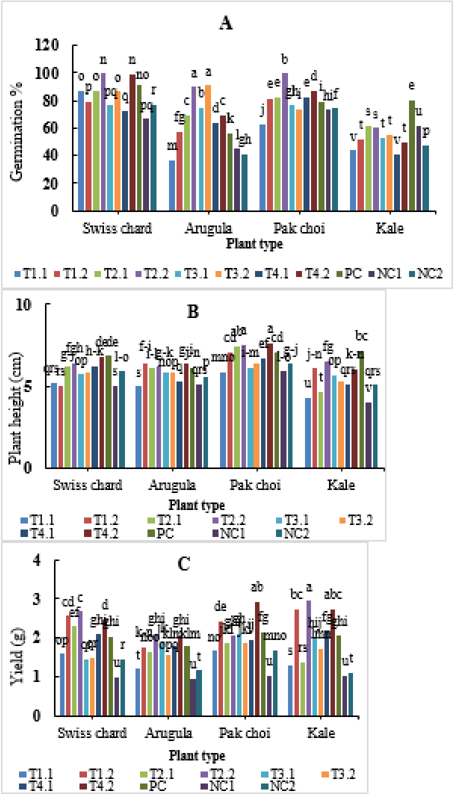

Figure 3 Germination (A); plant height (B); yield (C) of Swiss chard (Beta vulgaris var. cicla), arugula (Eruca vesicaria ssp. sativa), pak choi (Brasica rapa var chinensis.), and kale (Brassica oleracea L. var. acephala) microgreens affected by different growing media including T1.1: 30% vermicast + 30% sawdust + 40% MC1; T1.2: 30% vermicast + 30% sawdust + 40% MC2; T2.1: 30% vermicast + 30% sawdust + 10% perlite + 30% MC1; T2.2: 30% vermicast + 30% sawdust + 10% perlite + 30% MC2; T3.1: 30% vermicast + 40% sawdust + 30% MC1; T3.2: 30% vermicast + 40% sawdust + 30% MC2. T4.1: 30% vermicast + 20% sawdust + 20% perlite + 30% MC1; T4.2: 30% vermicast + 20% sawdust +20% perlite + 30% MC2. NC1: 50% sawdust + 50% MC1; NC2: 50% sawdust + 50% MC2; Positive control: Pro-mix BX™ potting medium alone. ***, significant at $P<0.001$

Association among media and plant components

The PCA demonstrated the association among physicochemical parameters of growing media and seed germination and growth parameters affected by the variations in growing media formulations (Figure 4). T4.2 showed a high association and stability compared to the other treatments located at the periphery of the axes. Thereby, the enhanced growth traits in all the microgreens can be attributed toT4.2. Seed germination, plant height and yield were strongly influenced by the interaction between growing media × microgreen plant species.

Discussion

In the present work, the effects of different natural amendments on the physicochemical attributes of formulated growing media and the response of different microgreens plant species were studied in indoor cultivation system. The results indicated that T4 and T5 growing media had considerable effect on seed germination while T5 and PC growing media had the greatest effect on plant height of all the microgreen species (Figure 1A). Physicochemical properties of the growing media play a significant role in seed establishment and consequently, plant growth.

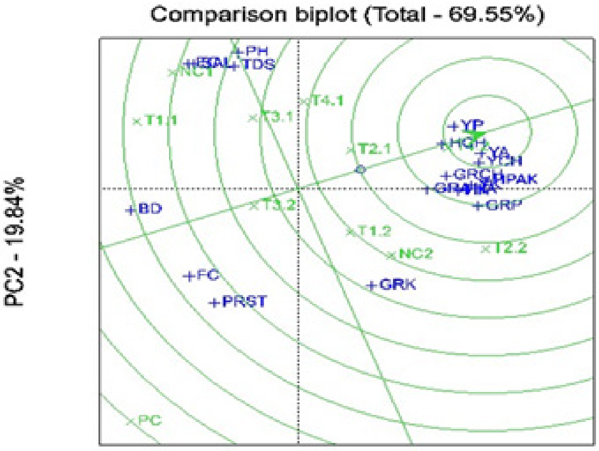

Figure 4 Ranking total × total biplot for comparison of treatment × plant species interaction effects on all growth and physicochemical growing media properties variations in all microgreens. PRST: Porosity; BD: Bulk density; FC: Field capacity; SAL: Salinity; EC: Electrical conductivity; TDS: Total dissolved solid; GRCH: Swiss chard germination; GRA: Arugula germination; GRP: Pak choi germination; GRK: Kale germination. HCH: Swiss chard height; HA: Arugula height; HPAK: Pak choi height; HK: Kale height. YCH; Swiss chard yield; YA: Arugula yield; YP: Pak choi yield; YK: Kale yield. T1.1: 30% vermicast + 30% sawdust + 40% MC1; T1.2: 30% vermicast + 30% sawdust + 40% MC2; T2.1: 30% vermicast + 30% sawdust + 10% perlite + 30% MC1; T2.2: 30% vermicast + 30% sawdust + 10% perlite + 30% MC2; T3.1: 30% vermicast + 40% sawdust + 30% MC1; T3.2: 30% vermicast + 40% sawdust + 30% MC2. T4.1: 30% vermicast + 20% sawdust + 20% perlite + 30% MC1; T4.2: 30% vermicast + 20% sawdust +20% perlite + 30% MC2. NC1: 50% sawdust + 50% MC1; NC2: 50% sawdust + 50% MC2; Positive control: Pro-mix BX™ potting medium alone.Correlation analysis results indicated that there was a significant ($P<0.05$)

Amendments are considered one of the major strategies to improve the physical features of growing media such as drainage, water retention capacity, and porosity, which in turn affect plant growth factors.[24-26] In this experiment, it seems that the structure and physicochemical traits of media T4 and T5 were ameliorated, mostly by the presence of the mushroom compost and as a result, germination and plant height of all microgreens were increased.

In agreement with current results, Vahid Afagh et al. attributed improved crop productivity to increased aeration and water holding capacity by adding 15% mushroom compost into a growing medium. It has been shown that high bulk density reduces root growth and yield of lettuce. However, the bulk density of T5 was about 0.158 g/cm^3, which was below root-restriction threshold bulk density (1.66g/cm^3). This results, together with the average value of porosity in T5, could be responsible for the improved plant height in this media. In contrast, decreased plant height of arugula in T4 can be ascribed to high level of salinity (Figure 1B), as confirmed by significant negative correlation between arugula plant height and media salinity (Table 4). Similar to our results, Warrence et al. explained that root penetration and root growth can be negatively influenced by the higher level of salinity and EC. Addition of perlite and wood-based substrates into growing media can diminish the negative effects of high EC and salinity levels.[27,28] Accordingly, the more positive effects of T5 on plant height compared to T4 can be explained by the presence of high portions of perlite in the former compared to the latter. Moreover, the presence of mushroom compost in T4 and T5 may supply more

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nutrients for plants that may explain the observed higher germination and plant height in these media.[29] PCA analysis results validated T4 and T5 enhancement of microgreens plant performance compared to other treatments (Figure 2). As a result, T4 and T5 were selected for further investigation in the Experiment 2.

Mixed media with added White oyster mushroom compost (MC1) had higher bulk density and lower porosity, field capacity, and recorded low plant growth (Table 5).Given that the optimum range of pH for leafy greens is 5.5 to 6.5,[30] the lower growth rate in the mixed media made from MC1 can be attributed to the high pH, which negatively affects plant nutrients availability.[31] It is well known that salinity adversely affect water and nutrient uptake by reducing osmotic potential and leading to nutrient imbalance in plants,[32,33] in addition to a negative relationship between EC and TDS and soil nutrients availability.[34,35] In the present study, a high salinity and EC levels were observed in growing media made from MC1 (Table 5). Therefore, a reduction in plant growth in T1.1 and NC1 can be attributed to high EC and salinity levels in these media. Like our results, Zhang et al.[12] reported negative effects of high EC levels on plant growth and productivity. These results were further confirmed by correlation data analysis in which there was a negative relationship between germination, plant height, yield factors on one hand, and high salinity, EC, and TDS levels on the other hand (Table 6).

Consequently, there was high germination rate, plant height, and yield of microgreens grown in mixed media added with Shiitake mushroom compost (MC2), particularly T2.2 and T4.2 (Figure 3).These results could be due to the improved physical factors such as porosity and field capacity in these media. Moreover, the presence of MC2 in the media may provide more readily available nutrients for the plants compared to MC1. In support of this, higher levels of nutrients including N, C, P, Ca have been reported in Shiitake mushroom compost compared to White oyster mushroom compost by Hernández et al.[18] and Kumar et al.[29] In addition, PCA results suggested that growing media made from MC2 were better for the improvement of plant growth and yield performance in all tested microgreens (Figure 4). In agreement with our results, it previously shown that application of mushroom compost enhanced germination rate and seedling growth in cucumber and lettuce plants.[17,18] Furthermore, Lin[16] demonstrated that growth parameters including plant height, leaf number, fresh and dry mass of Swiss chard, pak choi, and kale were drastically enhanced when grown in the mixed media formulated with 60% vermicast + 40% sawdust.[36-43]

Table 5 Physiochemical properties of growing media affected by different proportion of mixed amended

Treatment	Bulk density (g/cm^3)	Porosity (%)	Field capacity (%)	pH	Salinity (mg/L)	Electrical conductivity (µS/cm)	Total dissolved solid (mg/L)
T1.1	0.099abc	27.0de	20.4b	7.2ab	2135.0ab	4551.5a	2524.7bc
T1.2	0.091abc	30.5bc	22.9ab	6.2b	1714.1bc	2619.5cd	1711.6e
T2.1	0.078bcd	25.5e	15.5d	6.8ab	1499.2cd	3176.4bc	1993.6de
T2.2	0.076d	30.6bc	20.8b	6.4ab	836.8e	1508.4e	1381.3f
T3.1	0.105ab	29.1cd	20.1bc	7.1ab	2132.9ab	4238.2a	2574.4bc
T3.2	0.103abc	30.5bc	24.3a	6.7ab	1881.7bc	2935.7c	2431.5bc
T4.1	0.087abc	27.1de	14.7d	7.4a	1486.6cd	2758.3cd	2286.6bcd
T4.2	0.077cd	32.4b	16.1cd	7.0ab	1328.6d	2325.9d	2191.5cd
PC	0.108a	38.0a	24.4a	6.2b	798.5e	1560.5e	1275.0fg
NC1	0.106a	27.2de	19.9bc	7.4a	2523.2a	3797.7ab	3434.7a
NC2	0.089 abc	28.4cd	20.2b	6.5ab	830.2e	1685.1e	2603.4b
P-value	<0.003	0.000	0.000	0.008	<0.001	<0.001	0.000

T1.1: 30% vermicast + 30% sawdust + 40% MC1;T1.2: 30% vermicast + 30% sawdust + 40% MC2;T2.1: 30% vermicast + 30% sawdust + 10% perlite + 30% MC1; T2.2: 30% vermicast + 30% sawdust + 10% perlite + 30% MC2;T3.1: 30% vermicast + 40% sawdust + 30% MC1;T3.2: 30% vermicast + 40% sawdust + 30% MC2. T4.1: 30% vermicast + 20% sawdust + 20% perlite + 30% MC1;T4.2: 30% vermicast + 20% sawdust + 20% perlite + 30% MC2. NC1: 50% sawdust + 50% MC1; NC2: 50% sawdust + 50% MC2; Positive control: Pro-mix BX™ potting medium alone.

Table 6 Simple correlation coefficients between growing media physicochemical parameters and plant characteristics

	Physical properties of mixed media				Chemical properties of mixed media		
	Porosity	Bulk density	Field capacity	pH	Salinity (ppm)	EC (µs)	Tds (mg/L)
Swiss chard GR	0.318	-0.577**	-0.242	-0.191	-0.299	-0.267	0.001
Arugula GR	0.298	-0.361	-0.209	-0.191	-0.227	-0.270	-0.276
Pak choi GR	0.324	-0.681**	-0.519**	-0.591**	-0.531**	-0.614**	-0.457
Kale GR	0.048	-0.158	0.236	-0.589**	-0.646**	-0.592**	-0.219
Swiss chard height	0.489	-0.601**	-0.578**	0.116	-0.330	-0.319	0.200
Arugula height	0.329	-0.553**	-0.216	-0.414	-0.236	-0.360	-0.172
Pak choi height	0.418	-0.858**	-0.605**	-0.261	-0.437	-0.488	-0.279
Kale height	0.534**	-0.406	-0.096	-0.306	-0.330	-0.425	0.023
Swiss chard Yield	0.688**	-0.823**	-0.617**	-0.188	-0.309	-0.331	-0.304
Arugula Yield	0.537**	-0.676**	-0.314	-0.067	-0.279	-0.269	-0.168
Pak choi Yield	0.506**	-0.574**	-0.440	0.029	-0.011	-0.073	0.086
Kale Yield	0.618**	-0.575**	-0.348	-0.262	-0.333	-0.407	-0.334

EC: Electrical conductivity;Tds:Total dissolved solids; GR: Germination; ** Significant at$P < 0.05$.

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Conclusion and recommendation

The results of this study demonstrated variations in physicochemical parameters and the effectiveness of different proportions of mixed media and their impact on the growth and yield of microgreens. The media containing Shiitake mushroom compost substantially promoted plant growth and yield in all microgreen plant species due to improved physicochemical parameters of the growing media and possibly superior nutrient status. In contrast, the reduced plant growth in media containing White oyster mushroom compost may be attributed to the higher salinity, EC, and TDS levels. Overall, it was found that T2.2 and T4.2 were the most effective treatments in improving germination rate, plant height, and yield in all microgreens. We concluded that adding Shiitake mushroom compost and perlite into a growing media will enhancemedia physical featuresand make nutrients more available to microgreen plants. Future studies will evaluate the effect of different mixed growing media on the chemical composition of microgreens.

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Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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