Effects of Vermicompost and Beneficial Microbes on Biomass and Nutrient Density in Purple Lady Bok Choy (*Brassica rapa var. chinensis*) in A Vertical Hydroponic Grow Tower System

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Abstract

Indoor food production in vertical hydroponic systems can be done year-round in any climate, has less negative environmental impacts compared to industrial agriculture and is a way of increasing the nutritional value of crops. Indoor hydroponic systems make it easy to control the precision of additives and amendments, such as fertilizers and vermicompost tea, to nutrient solution reservoirs. Vermicompost tea is known to contain beneficial microorganisms and can help increase the biomass, nutrient density, and overall health of the plants. Microorganisms and plants have co-evolved and is an essential relationship that deserves recognition and further research. The goal of the research presented in this paper was to better understand if vermicompost tea and its associated microorganisms, such as bacteria, fungi, nematodes, and protozoa, would increase biomass and nutrient density of Purple Lady Bok Choy (*Brassica rapa var. chinensis*) in vertical hydroponic systems. Statistical analyses were performed to compare the biomass and macro- and micronutrients of three different treatments to one another and a control. There was a significant difference between the mean leaf and root biomass among varying concentrations of vermicompost tea solutions and added inorganic hydroponic fertilizer. The nutrient density for both macro- and micronutrients also differed significantly due to different concentrations of vermicompost tea, suggesting that beneficial microbes may help plants uptake and absorb nutrients in a more efficient manner depending on the concentration of vermicompost tea and hydroponic fertilizer.

Introduction

Year-round growing of crops in a variety of climates is not possible using conventional agricultural practices. Current industrial agricultural methods can also have a negative impact on the nutritional content of food and the health of the soil and the ecosphere (6). Moreover, interest in consumption of locally grown food has risen with mounting evidence of many associated benefits. Benefits of locally grown food include but are not limited to; the reduction in overall production costs due to eliminated long-distance transportation and the need for long-term storage, increased nutrient density, taste profiles, texture, and freshness (8). Vertical hydroponic plant growth systems provide alternate means for food production and have potential to increase the amount of locally grown food in many communities. Additionally, vertical hydroponic systems could easily be integrated into the average household and provide families in any climate with healthy food. Vertical hydroponic systems demand less space, input of resources and are a more sustainable method of agriculture compared to industrial agricultural practices that are dominant in the United States (3, 7, 13). Indoor agriculture and the use of vertical hydroponic grow towers, which is soilless by nature, provides solutions to problems surrounding food production.

There are two fundamental systems for growing plants: in soil and soilless media. Plants in common horticulture/agricultural systems are typically fed with either inorganic/synthetic nutrients or organic/biological nutrients. The goal of using both inorganic and organic nutrients in horticultural/agricultural systems is to grow healthy plants with the least amount of input required and for as many months as possible. In systems in which biological nutrients are used, the nutrients are processed by living microorganisms which aids in the nutrient uptake by the plants (14). Plants and microorganisms have co-evolved and have formed an essential symbiotic relationship, whereby microbes increase mineral availability and uptake by the plants thus increasing the nutrient density. The beneficial symbiotic relationship between plants and microorganisms was the pinnacle of the research presented, as living organisms were present in the vermicompost tea used for this research which had a variety of beneficial fungi, bacteria, protozoa (flagellates, amoebae, and ciliates), and nematodes (Table 1).

Plants grown in hydroponic systems are typically isolated from their microbial partners, which would naturally be found in soil. Isolation from symbiotic microbes may be a decided disadvantage to plant growth and health. Results from animal studies have demonstrated the profound negative impact the absence of symbiotic gut microbes can have on animal health and development (9). The Fraune and Bosch study (2010) reflects the fact that symbiotic organisms, such as plants and microbes, could be negatively impacted when deprived of their symbiotic microbial partners. Additionally, microbes help plants by producing nutrients (e.g., nitrate), plant hormones, and behaving as biocontrol agents. Microbes are capable of chemically communicating with their plant host, stimulating the plant's immune system, and aiding in the defense against pathogens (4, 5).

Vermicompost Detail Summary

Organism	Result	Units	Desired Level
Flagellates	106,214.36	number/g	>10,000
Amoebae	19,181.31	number/g	>10,000
Ciliates	32.28	number/g	>1254
Nematodes	28.31	number/g	>10
Bacterial	28.31	number/g	>10
Active Bacteria	109.54	µg/g	>3
Total Bacteria	2,118.75	µg/g	>300
Active Fungi	87.76	µg/g	>3
Total Fungi	3,478.17	µg/g	>300

Table 1: Vermicompost detail summary analyzed by Soil Foodweb New York, analyzed June 17, 2019.

Numerous studies of plants grown in soil demonstrate the positive impact microbes can have on influencing the plants' physiology and health (12, 15, 18). "Vermicomposting" (worm composting) is defined as a process in which earthworms play a major role in conjunction with microbes in the conversion of organic solid waste into a form of a stabilized soil conditioner. Vermicompost is a nutrient-rich compost which has macro- and micronutrients and contains high populations of diverse, beneficial microbes (1, 24). Vermicompost tea is a 'brewed' leaching process for extracting key nutrients and microbes in worm castings into a water solution. In a soil-based study done by Pant et al. (2009), they found the addition of vermicompost tea increased macro- and micronutrient uptake, phenolics, and carotenoids in the plant's tissue (20, 24). Furthermore, vermicompost is available commercially and would be relatively easy for the indoor-grow enthusiast to incorporate into their 'gardening' practices. Unfortunately, little evidence-based information exists regarding the addition of vermicompost tea and the associated benefits it may have on plant tissue in hydroponic systems.

Studies assessing the addition of beneficial microbes to hydroponic systems tend to focus on their use as biocontrol agents to combat plant pathogens (16). Could microbes be harnessed to provide benefits beyond reducing disease? The goal of the research conducted for this study was to better understand whether vermicompost tea and its associated microorganisms would increase biomass and nutrient density of Purple Lady Bok Choy (*Brassica rapa var. chinensis*) in vertical hydroponic systems. The rationale for choosing vermicompost as the source of beneficial microbes is due to its typically high populations and diversity of microbes, which has shown to benefit plants in a myriad of ways (1, 4, 15, 16, 20). Purple Lady Bok Choy was chosen due to its versatility, physiology, life cycle and stature.

It can be eaten fresh in salads, grilled, sautéed, fermented, or dehydrated. It is also known to have high levels of Vitamins C, A, B6, calcium, iron, potassium, manganese, folate and is high in antioxidants due to an abundance of anthocyanins (24, 25, 26). Not only are the anthocyanins responsible for the aesthetic purple coloration of the Purple Lady Bok Choy variety, but the pigments are also linked to the reduction of multiple diseases such as cardiovascular disease and cancer (24, 26). It has minimal heat and light requirements, was manageable within the given research space, has a quick germination rate and takes little time to reach full maturity, making this variety an ideal candidate for the indoor hydroponic research. The research tested and compared different concentrations and ratios of vermicompost teas and hydroponic fertilizer solutions. The prediction was that the addition of the vermicompost tea would increase the nutrient density and overall biomass of Bok Choy hydroponic systems.

Materials & Methods

Seedling Preparation:

A total of one hundred-twenty rockwool cubes with a two-inch diameter were used per treatment. In each cube a total of three Purple Lady Bok Choy, *Brassica rapa var. chinensis* seeds were planted surrounded by Geolite (an irregularly shaped clay medium, Hydrofarm LLC), and nestled in two-inch net pots. The net pots were placed into trays, each tray associated with a specific tower, and covered with a clear plastic dome until the seeds were germinated. The Purple Lady variety of Bok Choy is a cool weather species, is shade tolerant, germinates in 2-4 days, grows 5-7" and can grow to maturity in 60 days. All the above factors made Purple Lady Bok Choy an ideal candidate for the indoor hydroponic research because it has minimal heat and light requirements, was manageable within the given research space, has a quick germination rate and takes little time to reach full maturity.

For the first two weeks, the seedlings were watered with pH balanced tap water (pH 6.0 - 6.5). After approximately three weeks of growth, the seedlings were watered with a 1.25 grams per liter MaxiGro Hydroponic Nutrient solution (N-10, P-4, K-14). The germination took place under full spectrum LEDs on tiered "grow racks" on which the seedlings were grown for 30 days. After these 30 days of initial growth, the net pots were transferred to the vertical hydroponic grow towers (20 net pots per tower) and grew for an additional 30 days until they reached maturity and were ready to harvest.

Vermicompost Tea Preparation: The vermicompost used for the vermicompost tea was procured from Carney's Crawlers LLC, Appleton, Wisconsin. The microbial composition of the vermicompost was tested and verified by Soil Foodweb New York on June 17, 2019 (Sample # 03-12178) using direct count and the Differential Interface Contrast (DIC) microscopy technique (Table 1). DIC microscopy was also used to determine the probable number of protozoa using four replications of a serial dilution of 10-1 to 10-6. The direct count of active bacteria and active fungal organisms was done using a fluorescein diacetate stain and counted under a fluorescent light. Nematodes were identified based on morphology and the population was determined by direct count method. The total bacterial count was determined using a fluorescein isothiocyanate stain and DIC technique. The living organisms in the organic matter/soil particles were stained using fluorescein isothiocyanate, strained through a syringe filter and directly counted.

The vermicompost tea solution was prepared by using 1.5 L of the vermicompost which was "brewed" in 16 L of pH balanced water (pH 7), in 5-gallon food-grade buckets. A paint strainer was used as a "tea bag" to separate the vermicompost from the water. The solution was constantly aerated with large (4 inches long and 2 inches in diameter) air stones (Model ASC-100, Pawfly Co), which helped to oxygenate the water and encouraged the growth of the beneficial bacteria and fungi. After the vermicompost tea brewed for 24 hours, two tablespoons of unsulfured pure blackstrap molasses ('Slow As' brand) was added to feed the microorganisms that were extracted into the water from the vermicompost. The solution was aerated for an additional 24 hours before it was transferred to the vertical hydroponic towers.

Hydroponic Tower Design:

There were three modular units, each supporting two grow towers (made from PVC pipes and PVC fence posts), for a total of six grow towers. Two of the modules (with two towers each) were placed parallel to each other, while the third unit (with two towers) was placed perpendicular to the parallel modules which all together covered approximately 32 square feet (Figure 1). One grow tower housed 20 plants, for a total of 120 plants for all three modular units. The towers were equipped with a water pump (Bayite BYT-7AO15 DC 12V Solar Hot Water Heater Circulation Pump with DC Power Supply Adapter) that moved the solutions to the small reservoirs at the top of the towers. The solutions trickled down via gravity feed and subsequently covered ('showered') the roots of the plants in a consistent manner. PVC pipes were used as vertical support poles for each of the 6 LED strips (T8 LED Grow Lights, 4 feet, providing full-spectrum sunlight replacement at 400 nm - 800 nm, Monios-L Co.) and provided overall support for the units.

Experimental Treatments:

Each treatment was executed consecutively through implementation of all 6 towers at once. The utilization of all six towers for each treatment at the same time helped maintain efficiency and consistency of said treatment. The number of towers, 6, provided the minimum number of repetitions necessary for proper statistical analysis. Each tower had a 16 L solution reservoir (5-gallon bucket). The control was prepared with 1.25 grams of mineral solution (General Hydroponics, MaxiGro hydroponic nutrients) per liter of water. Treatment one consisted of 0.625 grams of mineral nutrients per liter and ~25% by volume vermicompost tea. Treatment two was made with 1.25 grams of mineral nutrients per liter and ~25% by volume vermicompost tea solution. Treatment three was a solution composed of 0.625 grams of mineral nutrients per liter and ~50% by volume vermicompost tea. The temperature

Fig 1: Design layout of the three modular units which housed the six vertical grow towers that were surrounded by six strips of LEDs each. The photo was taken in Weston Hall, room 1208, at Northern Michigan University, in Marquette, Michigan, where the experiment was conducted from September 2020 - March 2021.

of the reservoir solutions was periodically measured and recorded. The solutions of each treatment were added alternately when the reservoirs were approximately 4-6 liters depleted. The reservoirs were completely emptied and refilled with fresh solutions approximately halfway through each growth cycle, which was ~15 days, except for treatment three. During treatment three an experimental error occurred where the reservoirs were refilled on day 28 rather than the 15-day time that had been previously done in all the other treatments. The pH was regularly checked and adjusted to ~6.0-6.5 by using General Hydroponics pH adjustment chemicals. The plants were grown in the towers for 30 days, at which point they were mature and harvested. The plant biomass was dehydrated at 60°C (140°F) in dehydration ovens. The dehydrated biomass was used to determine the dry weights of the leaves/petioles and roots (the initial weight of the rockwool was deducted from the weight of the roots) which was used as a 'dry weight method' to perform proper statistical analysis. All equipment was cleaned with hydrogen peroxide solution (using ~2 tablespoons of 3% hydrogen peroxide per 1 gallon of water) and set up for the next treatment.

Plant Nutritional Analysis & Sample

Preparation:

Before the plants were harvested, six leaves were taken from each tower at random (as per the laboratory technician's instructions) and immediately sent to A & L Great Lakes Laboratories (Fort Wayne, IN) where the nutritional density of the plant tissue was analyzed. The samples were shipped via UPS, unrefrigerated. Once the plant tissue was received by the laboratory, the samples were dried overnight at 100-105°C. The dried tissue was ground with a Wiley Mill Grinder and sieved through 20 mesh screens. The plant tissue was tested for a variety of macro- and micronutrients (Tables 2 and 3). Total nitrogen was analyzed using the Dumas method (using an Elementar rapid-N cube), while mineral analysis was conducted using Inductively Coupled Argon Plasma (ICAP) run on a Thermo iCAP 6500.

Environmental Measurements: The windowless room in which the research was conducted was on the campus of Northern Michigan University in Weston Hall, room 1208. A Govee Bluetooth hygrometer thermometer tracked the room humidity (14-42.5 g kg-1) and ambient room temperature (68.36-72.86°F). There were no significant changes in room and reservoir temperature or humidity while the research was being conducted. The average temperature of the solutions in the tower reservoirs was 21-22°C (69.8-71.6°F) and was measured periodically with a submerged thermometer.

Statistical Analysis:

The variance among the towers was tested using a linear mixed model. The data was analyzed with R-studio using analysis of variance (one-way ANOVA). First, the data was checked for normality with histograms and a Shapiro-Wilk test. Homogeneity of variance was tested with Levene's test.

Mean Macronutrients (%)

Nutrients:	N	S	P	K	Ca	Mg
Control	7.87	1.31	0.73	7.72	3.22	0.72
Treatment 1	6.27(-)	2.07(+)	0.95(+)	7.07	3.02	0.66
Treatment 2	7.02(-)	1.16	0.77	5.61(-)	2.71	0.39(-)
Treatment 3	5.85(-)	1.62(+)	0.93(+)	7.21	2.86(-)	0.53(-)

Table 2: Mean macronutrient (%) for the control and each treatment with a (+) or (-) indicating a statistically significant increase or decrease in mean nutrient density compared to the control. No symbol indicates no significant change (n= 6).

Mean Macronutrients (ppm)

Nutrients:	Fe	B	Na	Zn	Cu	Al	Mn
Control	73.83	60.00	0.15	35.17	56.83	5.83	253.33
Treatment 1	72.50(+)	89.50(+)	0.14	18.00(-)	5.50	8.83	277.50
Treatment 2	85.50	59.50	0.08(-)	43.17(+)	5.17(-)	8.17	232.33
Treatment 3	73.83	82.17	0.11(-)	38.83	9.00(+)	4.33	287.33

Table 3: Mean micronutrients (ppm) for the control and each treatment with a (+) or (-) indicating a statistically significant increase or decrease in mean nutrient density compared to the control. No symbol indicates no significant change (n= 6).

The normality and variance assumptions were met, and the ANOVA was run. A post hoc Dunnett's and Tukey's test was used to determine if the leaf and root biomass of the treatments were significantly different from the control and each other. The nutritional analysis from the labs was also tested for significance using one-way ANOVA and Dunnett's test, examining the overall mean macro- and micro-nutrient densities compared to the control. Furthermore, each macro- and micro mean nutrient density was comparatively analyzed among each treatment via a one-way ANOVA. Some macronutrients failed the Levene's test of homogeneity of variance ($P > 0.05$), thus a Welch's corrected one-way ANOVA was run for those nutrients.

Results

According to Soil Food Wed New York Lab, the vermicompost analysis resulted in above desired population levels for all organisms (Table 1). Importantly, the active bacterial and fungal populations were very high (109.54 µg/g, 87.76 µg/g respectfully). A linear mixed model showed that the variance among the towers was estimated at zero, meaning the growing conditions for each tower was the same. Treatment two had the highest mean leaf biomass of 444 grams, followed by the control (404.8 g), treatment one (300.1 g), and treatment three (197 g). Using a one-way ANOVA, the mean leaf biomass was found to be significantly

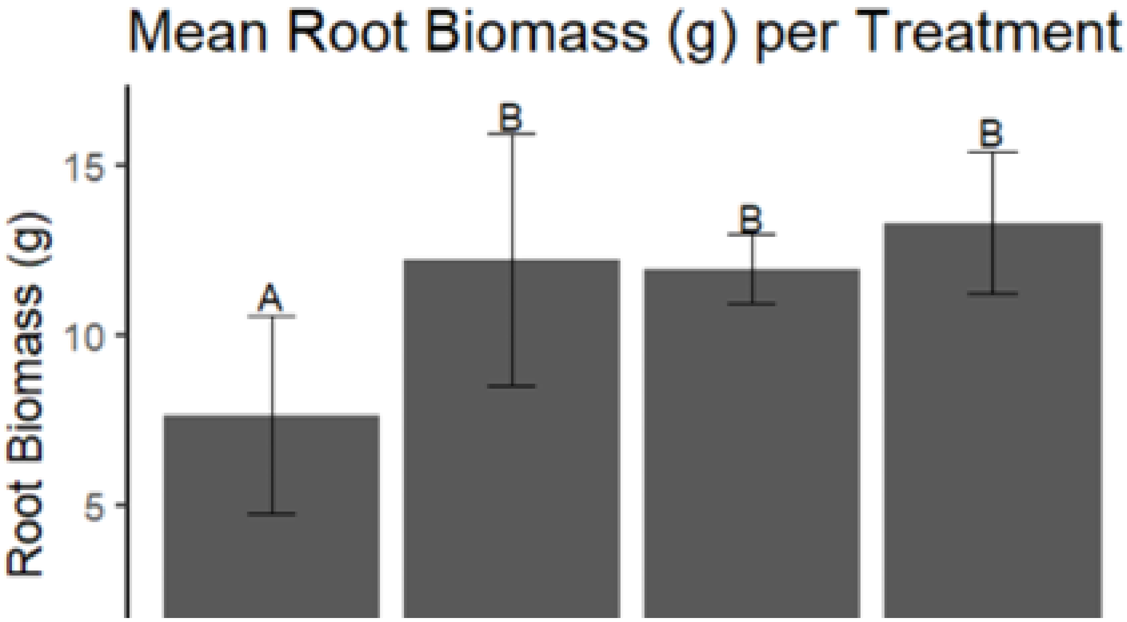

Fig 2: Results from ANOVA, Dunnett's and Tukey's tests of the mean leaf biomass showed a significant difference among treatments (F= 235.4; df= 6, 21; n= 6; P< 2e-16). Treatments one and three were significantly different from the control (Dunnett's: P= 0.0058 and P= 3.7e-06, respectively) and from each other (Tukey's: treat1-treat2 P= 0.0005; treat1-treat3 P= 0.011; treat2-treat3 P= 3.0e-7). Letters indicate significant differences. Bars indicate standard error.

different among the treatments (F= 235.4; df= 6,21; P< 2e-16; Figure 2). In treatments one and three, the mean leaf biomass was significantly less compared to the control (Dunnett's: *P*= 0.0058 and *P*= 3.7e-06, respectively). Treatment two showed no significant difference in leaf biomass compared to the control (*P*= 0.56). All treatments were significantly different from one another, excluding the control (Tukey's: treat1-treat2 *P*= 0.0005; treat1-treat3 *P*= 0.011; treat2-treat3 *P*= 3.0e-7). The mean root biomass was significantly increased in all treatments compared to the control (F= 5.932; df= 3,20; *P*= 0.00458; Figure 3). The control had the lowest root biomass with a weight of 46 grams. Treatment three had the highest root biomass of 79 grams, followed by treatment one (73.3 g), and treatment two (71.7 g). Root mass did not differ significantly among treatments one, two and three (Tukey's: P> 0.05).

The mean nutrient densities for micro- and macronutrients were tested separately with a one-way ANOVA and Dunnett's post hoc test. These tests revealed that there were significant differences between nutrient levels among the treatments compared to the control for both macro- (F= 107.5; df= 5; *P*= 9.27e-13; Figure 4; Table 2) and micronutrients (F= 235.4; df= 6; P< 2.16e-16: Figure 5; Table 3). The macronutrients that were significantly greater than the control occurred in treatments one and three, which included sulfur (trmt1 *P*= 1.3e-08, trmt3 *P*= 0.002) and phosphorus (trmt1 *P*= 0.0007, trmt3 *P*= 0.002). The macronutrient, nitrogen, was significantly decreased compared to the control in all treatments (trmt1 *P*= 1.2e-07, trmt2 *P*= 0.0004, trmt3 *P*= 6.0e-12). Treatment two had significantly decreased levels of potassium (*P*= 1.6e-07), calcium (*P*= 0.0008) and magnesium (*P*= 2.9e-11) compared to the control. Treatment three had significantly decreased levels of calcium (*P*= 0.016) and magnesium (*P*= 3.0e-05) compared to the control. On the other hand, the micronutrients that were significantly greater than those in the control occurred in treatment one with boron (*P*= 4.7e-06), treatment two with iron (*P*= 0. 016), and zinc (*P*= 0.014), and treatment three with copper (*P*= 0.0018). The micronutrients which were significantly lower than the control occurred in treatment one with zinc (*P*= 5.8e-06), treatment two with sodium (*P*= 2.3e-08) and copper (*P*= 0.014), and treatment three with sodium (*P*= 0.0009).

Moreover, each individual nutrient underwent a one-way ANOVA test, comparing the mean nutrient density of each treatment among the same nutrient in different treatments. Macronutrients nitrogen, phosphorus, and magnesium failed the Levene's test for homogeneity of variance (*P*< 0.05), thus these macronutrients underwent a Welch's corrected ANOVA instead, which doesn't assume equal variances. The ANOVAs resulted in all nutrients, both macro and micro, amidst each treatment to have a significant difference in mean nutrient density (P< 0.05; Table 4; Table 5).

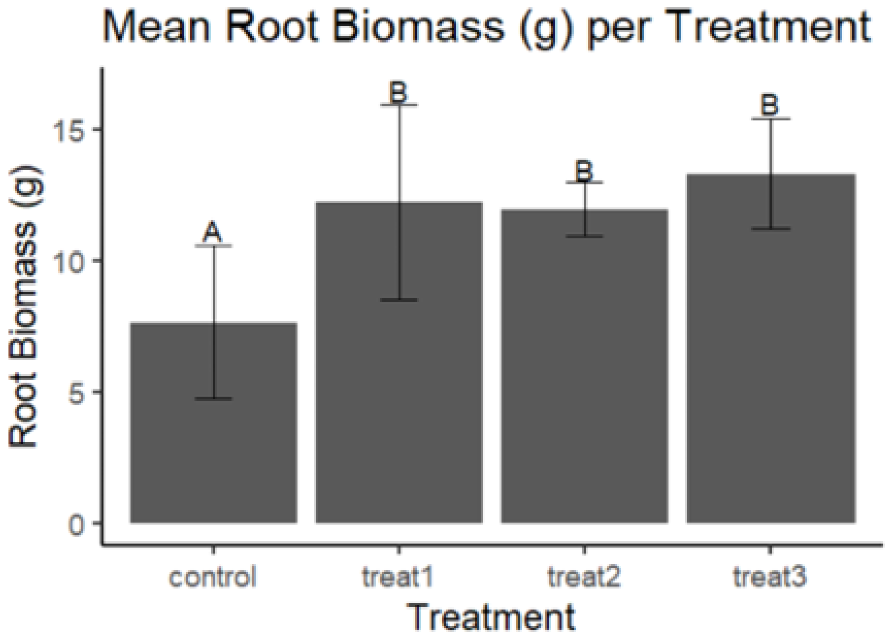

Fig 3: Results from ANOVA, Dunnett's, and Tukey's tests of the mean root biomass showed a significant difference among the treatments (F= 5.932; df= 3, 20; n= 6; P= 0.00458). The three treatments were significantly increased compared to the control (Dunnett's: treat1 P= 0.023, treat2 P= 0.035, treat3 P= 0.004), but did not significantly differ among one another (Tukey's: P> 0.05). Letters indicate significant differences. Bars indicate standard error.

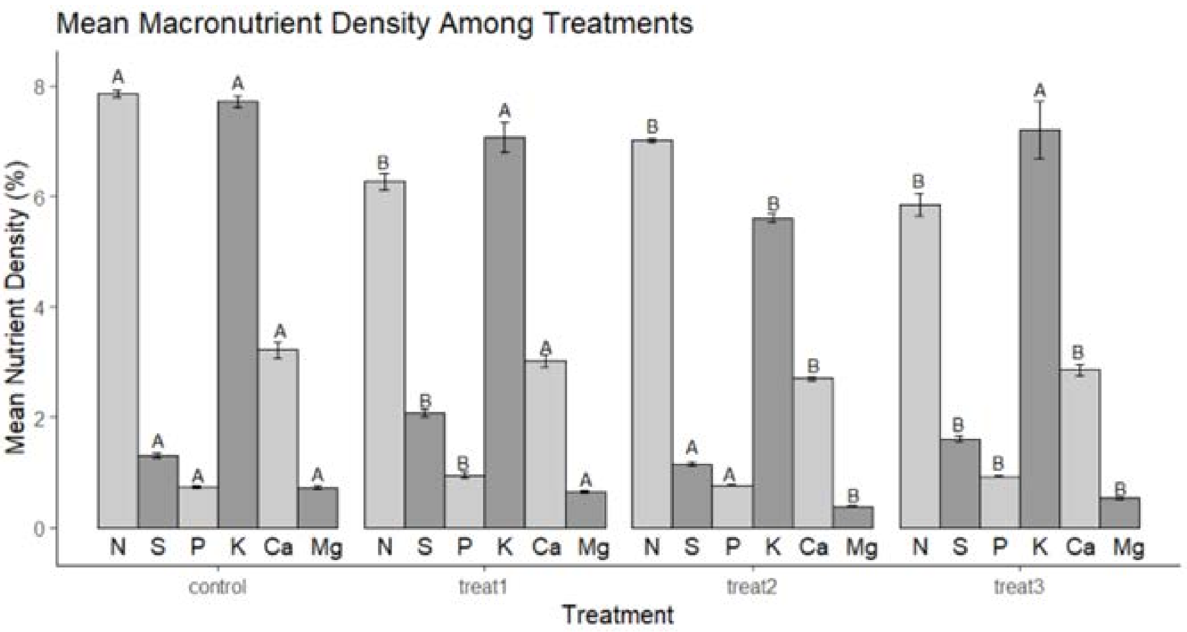

Fig 4: The mean macronutrient (%) per treatment was significantly different compared to the control (F= 107.5; df= 5; n= 6; P= 9.27e-13). Letters indicate significant differences. Bars indicate standard error.

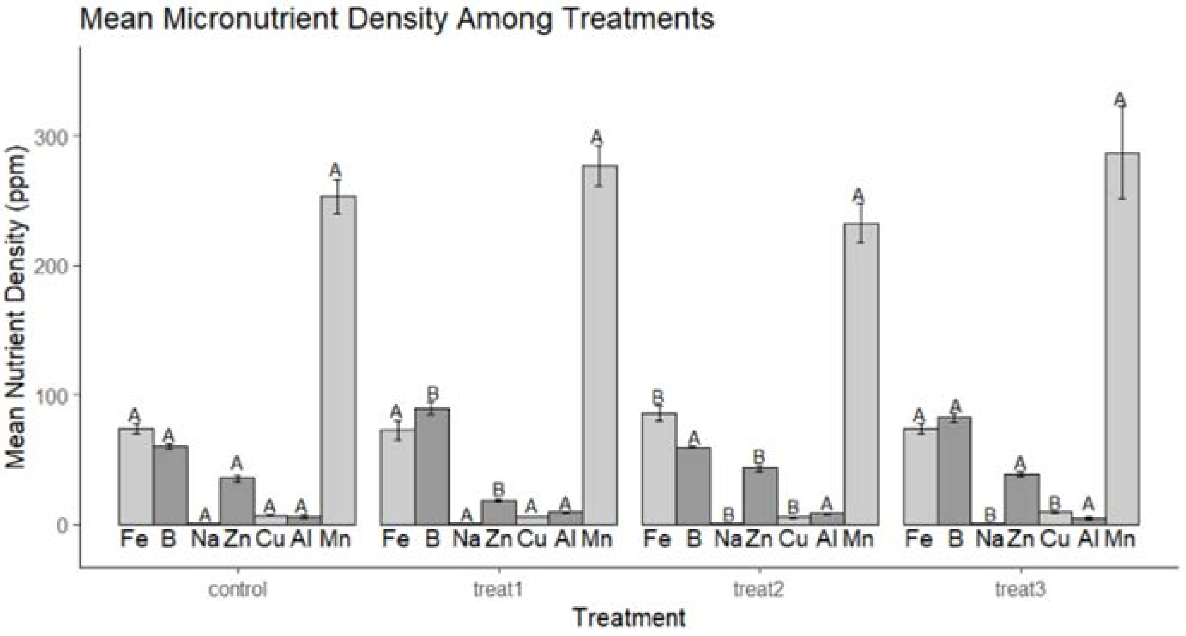

Fig 5: The mean micronutrient (ppm) per treatment was significantly different compared to the control (F= 235.4; df= 6; n= 6; P< 2.16e-16). Letters indicate significant differences. Bars indicate standard error.

Discussion

In the presented research, treatment two (1.25 grams of mineral nutrients per liter and ~25% by volume vermicompost tea) had the highest leaf biomass (Figure 2), the second highest root biomass (Figure 3) and increased concentrations of micronutrients iron and zinc compared to the control (Table 3). These two micronutrients are very important to human health yet are recognized to be deficient in many crop species and are part of the phenomenon of 'hidden hunger' that impacts significant portions of the human population (11, 21, 23). In contrast, treatment two had the greatest decrease in macronutrients compared to the other treatments, but the lab nutrient analysis showed that this decrease was not enough to drop the macronutrients into an unacceptable nutrient density level. There was no uniform gain or loss of nutrients among the treatments, although the lab analysis of leaf nutrient density showed that the control and all treatments were deficient in the micronutrient zinc except for treatment two, which had the highest level recorded. This may suggest that the concentrations of nutrient mineral solution and beneficial microbes in the vermicompost tea used in this treatment were the most effective in increasing overall health and biomass of Bok Choy (B. *rapa var. chinensis*). In Abul-Soud's et al. study (2015), they found that optimal plant growth responses occurred with the addition of 10 - 20% vermicompost by volume, along with the addition of mineral nutrients (for the majority of crops in their research) (1).

Plants need nutrients to maximize their biomass in the form of ions (a positively or negatively charged compound), regardless of whether a system is synthetic or biological. The use of artificially based nutrients (inorganic salts/minerals) does not typically include living microorganisms, is unsustainable and is an attempt to mimic what natural biological systems have been successfully performing over eons of time (14). Treatment one and three experienced a significant decrease in the mean leaf biomass compared to the control. These two treatments also had the least amount of mineral nutrient additives (0.625 grams per liter), which could have led to nutrient stress, reducing leaf biomass. In a similar study by Aini et al. (2019), they found that the reduced nutrient content added to their hydroponic system led to smaller plants that took two weeks longer to reach maturity and had significantly less biomass due to nutrient stress (2). While treatment three did have the least amount of leaf biomass, it had the highest amount of root biomass. Additionally, treatment three's reservoirs were not emptied and refreshed with new solutions halfway through the growing process, which could have increased the bacterial concentration even further. The increase in root biomass and not leaf biomass may be due to a stress response caused by an overgrowth of microbes on the roots, resulting in an increase of root growth but limiting nutrient uptake to the rest of the plant (17). No visual evidence of plant disease was present in this treatment (or any of the other treatments). Similar results were found in a study by Li et al. (2018) where shoot growth was limited while root growth increased due to the lack of water micro

One-Way ANOVA Summary for Macronutrients

Nutrients:	N	S	P	K	Ca	Mg
df	3, 9.55*	3, 20	3, 10.17*	3, 20	3, 20	3, 8.72*
F-value	57.56	55.78	42.43	23.38	7.10	89.17
p-value	p<0.001	p<0.001	p<0.001	p<0.001	0.002	p<0.001

Table 4: One-way ANOVA summary outputs for macronutrients when assessed individually, resulting in all nutrients having significantly different mean nutrient densities among each treatment (P< 0.05, n =6). Welch's corrected ANOVA was run on nutrients N, P, and Mg due to unequal variances, hence the changes in the denominator df (*).

One-Way ANOVA Summary for Micronutrients

Nutrients:	Fe	B	Na	Zn	Cu	Al	Mn
df	3, 20	3, 20	3, 20	3, 20	3, 20	3, 20	3, 20
F-value	5.13	25.36	30.32	37.32	21.15	5.32	3.68
p-value	0.009	p<0.001	p<0.001	p<0.001	p<0.001	0.007	0.029

Table 5: One-way ANOVA summary outputs for micronutrients when assessed individually, resulting in all nutrients having significantly different mean nutrient densities among each treatment (P< 0.05, n= 6).

droplets and nutrient availability caused by aeroponic misting intervals and droplet size (17). Comparatively, the increase in root growth found in treatment three and the Li et al. research could reflect a stress response due to a lack of nutrients. The effects of treatment three may coincide with the study conducted by Abul-Soud et al. (2015), using vermicompost in soilless culture wherein they found increasing the vermicompost concentration to 15% was the plateau at which the plants received positive effects (1). Beyond this limit, significant negative effects in yield, quality and nutrient density occurred with certain crops.

Though treatment three in the presented research had the greatest root biomass, the exact mechanisms for this result are not clear; it may be worth further investigation for applications when an increased root biomass is desired. Increased root biomass in medicinal root crops cultivated in a greenhouse, using an aeroponic or hydroponic system, could make medicinal roots more readily available to the public (17, 19). According to a study conducted by Pagliarulo et al. (2004), there is a multibillion-dollar market for medicinal botanical products, such as purple coneflower (*Echinacea purpurea)*, burdock (*Arctium lappa*), ginseng (*Panax ginseng*) and St. John's wort (*Hypericum perforatum*) (19). In their study, they found that *E. purpurea* had a significantly greater root biomass when grown in an aeroponic setting versus in soil (19). This suggests the use of indoor aeroponic systems can be very advantageous when operated properly. Aeroponic and hydroponic systems function similarly and may have some of the same benefits. The experimental results of the research conducted for this paper showed that adding microorganisms via compost tea increased the root biomass of Bok Choy in a hydroponic system. The addition of beneficial microbes to indoor cultivation systems has great potential to increase biomass and reduce the need for synthetic fertilizers and pesticides conventionally used for crop production.

A study done by Giurgiu et. al (2018), showed that certain medicinal plants (*Hypericum perforatum*) treated with *Trichoderma spp*., (a known beneficial fungus) in rockwool substrate in a hydroponic system had a two-fold increase in foliar biomass and enhanced root development compared to plants treated with a pathogenic microbe (10). Their research highlights the complexity of plant-microbe interactions regarding the impact on plant growth and nutrient levels. The research conducted in this paper demonstrated variable plant responses with the different levels of inorganic fertilizer and vermicompost tea solutions.

Overall, research results indicate there may be no “one size fits all” when it comes to the implementation of amendments to hydroponic systems to reach the goals of improvements in plant biomass and nutrient profiles. Similarly, Sheridan et. al. (2017), investigated how plant growth promoting microorganisms (PGPMs) affect the root zone microbiome of four common food crops (durum, potato, bread wheat and soybean) in recirculating hydroponic cultivation systems for the whole life cycle of each plant (22). They concluded crops inoculated with a mixture of commercial PGPMs (with a composition of microbial communities associated with root rhizosphere, rhizoplane, and endosphere with a recirculating nutrient solution) were more stable in a plant based biological life support system over time, depending on the specific crop (22). However, more research is needed to better understand this dynamic and to fine tune experimental protocols to achieve desired results.

Vermicompost is a PGPM, is available commercially and would be relatively easy for the indoor-grow enthusiast to incorporate into ‘gardening’ practices. Based on the results of the experimental study, the addition of vermicompost tea in a hydroponic system can result in an enhancement to the plant biomass and nutrient density of Bok Choy when applied at specific concentrations. A thorough analysis of the microorganism species which were present, persisted, or died off, on plant roots at the beginning and end of the experiment would provide more insight as to how the species of plants, amendments and microorganisms interacted and would enhance the continuation of the presented research. Modifying the current experiment to include a second control consisting of 0.625 g of mineral nutrients in future studies may give further insight to how the beneficial microorganisms in the vermicompost tea influences the growth and nutrient density of Bok Choy. Investigating the specific species of microbes’ and deciphering their impact on plant growth, biological and chemical properties, such as antioxidants and polyphenols, would be valuable. Research conducted by Chandra et al. (2014) suggested that aeroponically grown crops may provide an environment in which plants produce higher levels of antioxidant activity (10). Moreover, hydroponic systems might offer a higher level of reproducibility for influencing the concentrations of vitamins and phenolic compounds within a crop (10). These findings should be studied further using larger data sets and total environmental and nutrient input controls. With a greater understanding of the specific microbes and their impacts on plants, it would provide better insight as to how to adjust and fine-tune the percent solutions to achieve the specific desired results for certain plant species. The incorporation of beneficial microbes into hydroponic systems holds promise for improving plant growth and nutritional characteristics and could play an important role in the transition from conventional agriculture to indoor hydroponic systems which may lead to significant advancements in the future of farming.

Acknowledgements

We would like to extend our sincerest gratitude to Dr. Donna Maki for her unrelenting support and help with the overall execution of this research. We would also like to thank Dr. Alan Rebertus for his generosity and abundant knowledge regarding R-studio and statistical analysis. Much thanks to Regan Doran for his expertise and build of the vertical towers. Additionally, we would like to thank Sarah Kunister for her help throughout the research and Michael Fishman for his assistance with the initial installation of the modular units. We would also like to extend our gratitude to Mrs. Marilyn Scheidemantel, as our research was supported in part by a grant from the Scheidemantel Research Fund for undergraduate students.

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