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Research Article

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Nutrient Content of Cabbage and Lettuce Microgreens Grown on Vermicompost and Hydroponic Growing Pads

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Abstract

Current food systems, the collective processes involved in food production, distribution and consumption, create a dichotomous problem of nutritional excess and insufficiency and are not environmentally sustainable. One specific nutritional problem that needs attention is mineral (e.g., Fe, Zn) malnutrition, which impacts over two-thirds of the World's people living in countries of every economic status. Microgreens, the edible cotelydons of many vegetables, flowers, and herbs, is a newly emerging crop that is potentially a dense source of minerals that can be sustainably produced in almost any locale. In this study, the nutrient contents of lettuce and cabbage microgreens grown hydroponically (HP) and on vermicompost (C) were assessed and compared to each other as well as to the nutrient contents of store-bought cabbage and lettuce (mature vegetables). Of the 10 nutrients examined (P, K, S, Ca, Mg, Mn, Cu, Zn, Fe, Na), C cabbage microgreens had significantly larger quantities of all nutrients than HP cabbage microgreens (p-values <0.00321) with the exception of P; C lettuce microgreens had significantly larger quantities of all nutrients than HP lettuce microgreens (p-values <0.024) except for P, Mg and Cu. Compared to the mature vegetable, C or HP cabbage microgreens had significantly larger quantities of all nutrients examined (p-values <0.001) and C or HP lettuce microgreens had significantly larger quantities of all nutrients except for Ca and Na (p-values <0.0012). Results of this study indicate that microgreens grown on vermicompost have greater nutrient contents than those grown hydroponically. As microgreens can be grown easily in one's home using the methods used in this study, they may provide a means for consumer access to larger quantities of nutrients per gram plant biomass relative to store-bought mature vegetables, which had lower nutrient contents than microgreens with respect to most nutrients examined.

Keywords: Microgreens; Lettuce; Cabbage; Nutrients; Vermicompost; Hydroponic

Abbreviations: LV: Lettuce (Mature Vegetable); LC: Lettuce Microgreens Grown on Vermicompost; LHP: Lettuce Microgreens Grown Hydroponically; CV: Cabbage (Mature Vegetable); CC: Cabbage Microgreens Grown on Compost; CHP: Cabbage Microgreens Grown Hydroponically; MG's: Microgreens; s.d.: Standard Deviation

Introduction

One-third of the World's people, living in countries of every economic status, is overweight and/or undernourished [1-3]. This dichotomous problem of nutritional excess and insufficiency is the product of processes associated with food production, distribution and consumption [1]. The reliance of urban populations on long food chains that begin in distant rural areas limits accessibility to produce that has short shelf-lives and, therefore, poor transportability [4]. As a result, many urban populations reside in areas classified as "food deserts", where people do not have ready access to a complete compliment of required nutrients and depend primarily on heavily processed and packaged foods [4]. Fresh produce that does reach urban centers has usually lost substantial nutritional value during transport [5,6]. This transport consumes 10% of the total energy budget in the United States [6] and contributes to food waste as it spoils or is contaminated enroute [1]. This waste comprises the largest component of municipal waste and is responsible for a large fraction of annual methane emissions in the United States [6]. Therefore, in addition to creating problems of nutritional excess and insufficiency, current food systems are detrimental to the very environment on which the production of nutritious food depends [1].

One specific nutritional problem that is common in both developed and developing countries is mineral malnutrition with over 60% and 30% of the World's seven billion people, being Fe and Zn deficient, respectively [7]. Rates of mineral malnutrition are especially high in Asia and Africa [8], where soil degradation is especially severe and has significantly decreased the nutritional value of crops [9]. However, mineral malnutrition is considered to be one of the most important global challenges to human kind that can be prevented [10] and is one of the Millennium Development Goals [8]. Current efforts to mitigate mineral malnourishment are focused on developing biofortification methods [7] and genetically engineering crops for maximal nutrient uptake from soils [10].

However, a newly emerging crop that may be a dense source of nutrition in the absence of biofortification and genetic engineering and has the potential to be produced in just about any locale is microgreens. Microgreens (MG's) are edible seedlings of vegetables, herbs and some flowers that are usually harvested 7-14 days after germination, when they have two fully developed cotyledon leaves [11]. MG's are used to add texture and flavor to various dishes [12] and they are earning a reputation as dense sources of nutrition even though only a few studies have examined their vitamin, nutrient and carotenoid contents [11,13,14]. The potential nutritional benefits of MG's combined with their ease of cultivation in one's home has piqued consumer interest in cultivating MG's, especially given that they are not widely available for retail sale. The impact of commonly recommended cultivation methods

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on the nutritional value of MG's remains to be assessed, but could assist consumers in making educated decisions about how to grow MG's in their own homes.

This study compares the nutrient content of lettuce and cabbage MG's grown on vermicompost and on hydroponic growing pads, both of which are easily utilized in one's own home. The nutrient contents of store-bought cabbage and lettuce (mature vegetables) were also completed to determine if it may be nutritionally advantageous for people to eat home-grown MG's rather than industrially produced mature vegetables that are commonly available in supermarkets.

Materials and Methods

Growth conditions and harvest

All growing and insert trays, humidity domes and Micro-Mat Hydroponic Growing Pads used for growing MG's were obtained from Handy Pantry (Salt Lake City, UT, USA). All seeds were obtained from Mountain Valley Seeds (Salt Lake City, UT, USA). Five grams of cabbage seed ("C"; Brassica oleracea var capitata, Golden Acre) was sowed into each of eight 5 inch × 5 inch insert trays containing vermicompost (4 insert trays; "C") or Micro-Mat Hydroponic Growing Pads (four insert trays; "HP"). Similarly, 42 g of lettuce seed ("L"; *Lactuca sativa*, Parris Island Cos) was sowed into four insert trays containing vermicompost and four insert trays containing Micro-Mat Hydroponic Growing Pads. Seeds sowed on C were hydrated with sterile deionized water during the 7-day growth period (a total of 110 mL per insert tray), using sterile serological pipets in volumes of 15, 25 or 30 mL. Seeds sowed on HP were hydrated with a 0.4% solution of General Hydroponics® FloraGro® Advanced Nutrient System® 2-1-6 ("FloraGro"; GH Inc., Sebastopol, CA, USA), made in sterile deionized water, during the 7-day growth period (a total of 110 mL per insert tray); hydration was applied in 15, 25 or 45 mL volumes per insert tray using sterile serological pipets. All 16-insert trays were placed into 10 inch × 20 inch black plastic growing trays for the duration of the experiment. HP and C insert trays were maintained in separate growing trays to avoid contaminating C trays with FloraGro. Growing trays were covered with clear humidity domes and incubated under constant light produced by GE® Plant and Aquarium Ecolux Bulbs positioned approximately six inches above the surface of the growth substrate; light intensity ranged from 3,790 to 4,920 LUX across the light field and insert trays were randomly shifted to different positions within the light field each day (Figure 1). Vermicompost was generated from 0.5 bricks of Eco Earth® Compressed Coconut Fiber Expandable Reptile Substrate, vegetable and fruit waste, coffee grounds, coffee filters and shredded paper in two Worm Factories housing *Eisenia fetida*. The Worm Factories were purchased from and maintained using instructions from Uncle Jim's Worm Farm (Spring Grove, PA, USA). Vegetable and fruit waste and coffee grounds and filters were applied to the Worm Factories at a rate of approximately 0.14 kg per day. Worm Factories were kept indoors at room temperature. Compost was manually turned every two days.

MG's were harvested seven days after sowing using ethanol-cleaned scissors by cutting the cotyledon stems as close to the growth substrate as possible. Harvested biomass from each of the 16-insert trays was placed into pre-weighed foil cups and weighed. The foil cups were placed into a drying oven at 80ºC for 48 h prior to weighing again to determine the fraction dry mass. Similarly, fraction dry mass was determined for four samples of cabbage (mature vegetable; CV) and four samples of romaine lettuce (mature vegetable; LV) purchased from a local grocer.

Elemental analysis

Dried MG's and vegetables (2 g per experimental replicate) were manually ground into a fine powder using a clean mortar and pestle and placed into clean scintillation vials. Ground material was sent to the Penn State Agriculture Analytical Services Program (University Park, PA) for elemental analysis. Each of the samples was subjected to standard acid digestion procedures to determine the dry mass content of the following elements: P, K, Ca, Mg, S, Na, Fe, Mn, Cu, and Zn.

Data analysis

Elemental analysis data was examined by the Shapiro Tests for normality and Fligner-Kileen Tests for homoscedasticity using R software [15]. Based on these results, a nonparametric Welch's ANOVA (α=0.05) followed by a Bonferroni Correction for multiple comparisons was utilized to determine if there were significant differences among the mean nutrient contents of LV, LC and LHP and among the mean nutrient contents of CV, CC and CHP (α=0.05).

Results and Discussion

Overall, results of this study indicate that vermicompost-grown MG's are significantly more nutrient-rich than hydroponically-grown MG's, and that MG's are relatively dense sources of nutrients relative to store-bought vegetables (Table 1). Based on nutrient mass per gram dry plant material, CC MG's had significantly larger quantities of all nutrients than CHP MG's (all p-values <0.00321) with the exception of P. LC MG's had significantly larger quantities of all nutrients (all p-values <0.024) than LHP MG's except for P, Mg and Cu. CC or CHP MG's had significantly larger quantities of all nutrients examined than CV (all p-values <0.001); LC or LHP MG's had significantly greater quantities of all nutrients than LV (all p-values <0.0012) except for Ca and Na.

The relative nutritional values of MG's to mature vegetables on a nutrient mass per gram fresh plant material are illustrated in Figure 2. Average ratios across the 10 nutrients (P, K, Ca, Mg, S, Mn, Cu, Zn, Na, and Fe) indicate that LC, LHP, CC and CHP were 2.8, 2.7, 8.1 and 2.9 times more nutrient-rich than the mature vegetable. Particularly high nutrient ratios were observed for Fe in cabbage microgreens with CC having 54.6 times the amount of Fe as the mature vegetable, while CHP had 5.4 times the amount of Fe as the mature vegetable. For Fe, lettuce microgreens still contained between 2 and 3 times the amount as the mature vegetable, but it is clear that cabbage microgreens are able to acquire far greater amounts of Fe when grown on the same substrates. For Zn, cabbage microgreens contained between 5 and 7.5 times the amount of Zn as the mature vegetable. The relatively high levels of Fe and Zn are of particular interest given the prevalence of deficiencies in these two nutrients across the globe [1,7,9].

Pinto et al. [13] found lettuce MG nutrient contents to be on par with those previously reported for "baby leaf" lettuce [16], but P, K, Fe, Cu and Zn contents of lettuce MG's in this study were between 16 and 98 times higher. This, in combination with the differences between the nutrient contents of vermicompost and hydroponically-grown MG's found in this study; highlight the significant effect of cultivation methods on MG nutrient content.

The average biomass yields (gfw) per experimental replicate (± 1 s.d.; n=4) were as follows: 35.1 g ± 7.6 g (LHP), 26.5 g ± 4.9 g (LC), 38.1 g ± 8.1 g (CC), 21.5 g ± 5.4 g (CHP). As nutritional data for MG's is still relatively scarce and MG's are not widely available products, established serving sizes do not exist. However, on the basis of serving

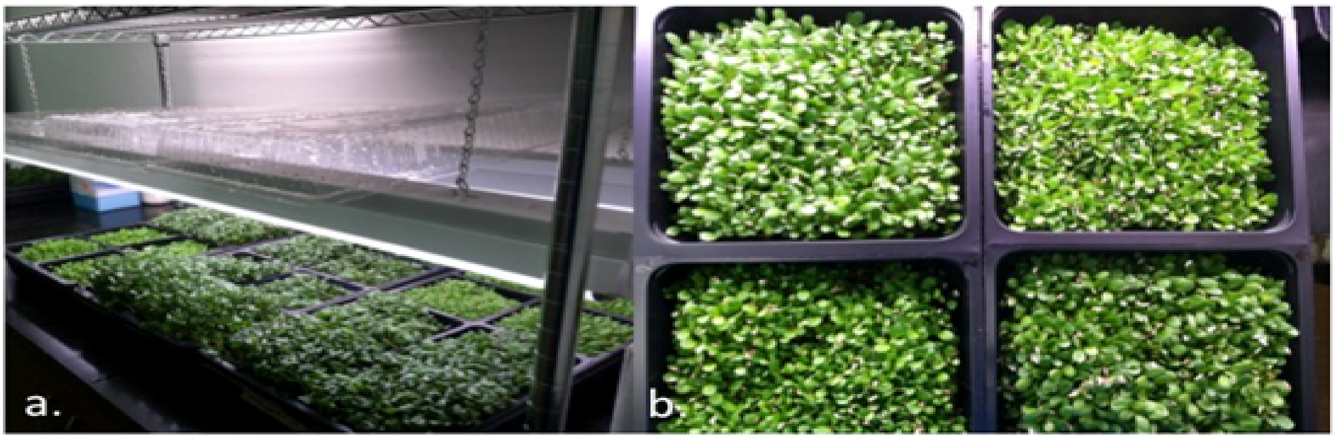

Figure 1: (a) Microgreen growing set-up. Humidity domes were removed for the purpose of taking the photo. (b) Lettuce microgreens in 5 inch × 5 inch growing trays just prior to harvest, 7-days after sowing.

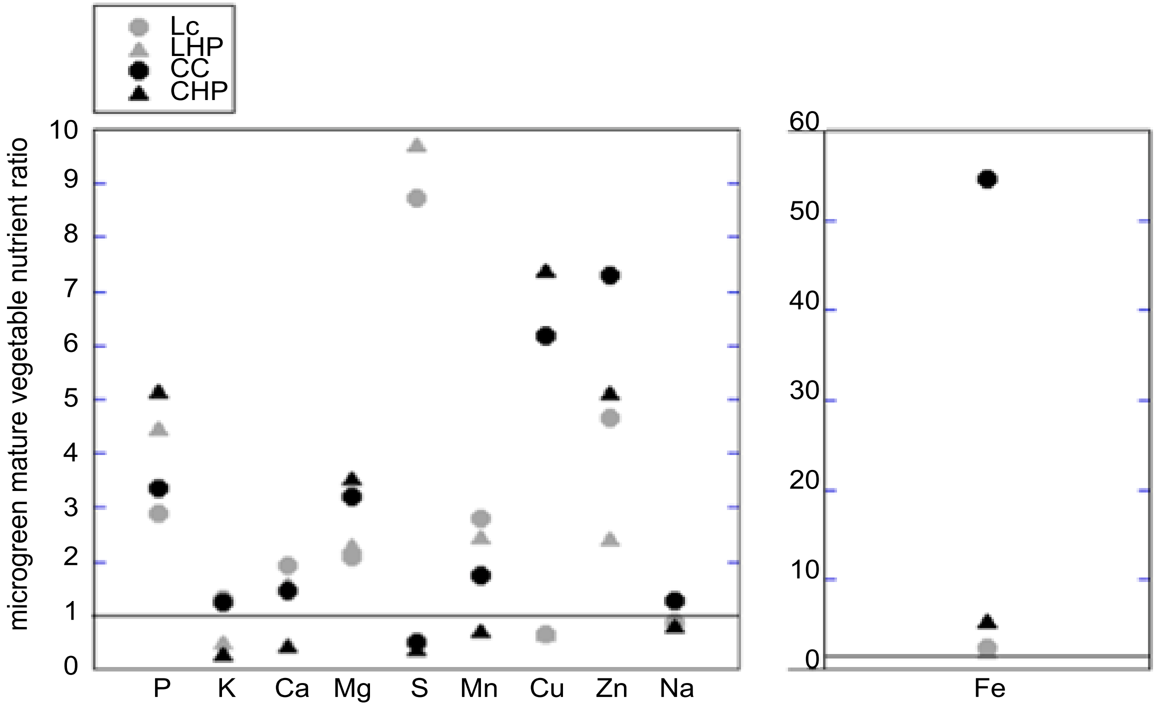

Figure 2: Microgreen: mature vegetable nutrient ratio based on mass of nutrient per gfw plant material for P, K, Ca, Mg, S, Mn, Cu, Zn, Na (left) and Fe (right). Note the different scale on the y-axis for the two graphs. For both graphs, horizontal lines at a microgreen: mature vegetable ratio: 1 indicate where nutrient values of microgreens and mature vegetables are equivalent. LC: Lettuce microgreens grown on vermicompost; LHP: Lettuce microgreens grown hydroponically; CC: Cabbage microgreens grown on vermicompost; CHP: Cabbage microgreens grown hydroponically. Symbols plotted are listed on the legend on the graph.

sizes for lettuce and cabbage vegetables and the relative nutrient contents of MG's to these mature vegetables, estimates of serving sizes can be made. The serving sizes for mature lettuce and cabbage are 91 g and 89 g, respectively [17]. On the basis of the average microgreen: vegetable nutrient ratios for LC, LHP, CC and CHP (2.8, 2.7, 8.1 and 2.9, respectively), microgreen serving sizes that are nutritionally equivalent to the mature vegetable servings can be calculated as: 32.5 g (LC), 33.7 g (LHP), 11 g (CC), 30.7 g (CHP). This indicates that a single 5 inch × 5 inch growing tray produces the following number of MG servings based on fresh mass yields in this study: 1 (LHP), 0.8 (LC), 3.5 (CC), 0.7 (CHP).

MG's can be grown easily in one's home via the methods used in this study. Therefore, results presented here indicate that MG's could provide a means for consumer-access to larger quantities of nutrients per gram plant biomass relative to store-bought mature vegetables. The hydroponic mats utilized are compostable and may be especially convenient for consumers who wish to grow MG's in relatively small urban dwellings and avoid purchasing or working with a soil matrix.

Element	Lettuce			Cabbage		
	LV	LHP	LC	CV	CHP	CC
	mg (gdw)$^{-1}$					
P	5.58 (0.43)^{a}	13.34 (0.43)^{b}	8.66 (1.24)^{c}	1.28 (0.07)^{a}	14.76 (0.42)^{b}	12.95 (0.27)^{c}
K	41.06 (2.63)^{a}	13.92 (1.77)^{b}	60.14 (6.23)^{c}	24.22 (1.04)^{a}	12.34 (0.99)^{b}	42.99 (2.55)^{c}
Ca	8.48 (1.67)^{a}	2.61 (0.19)^{b}	8.50 (0.88)^{a}	2.93 (0.36)^{a}	7.88 (0.11)^{b}	13.22 (0.27)^{c}
Mg	3.49 (0.50)^{a}	6.48 (0.25)^{b}	5.78 (0.08)^{c}	0.90 (0.02)^{a}	4.75 (0.09)^{b}	5.82 (0.05)^{c}
S	2.76 (0.23)^{a}	4.48 (0.16)^{b}	5.89 (0.72)^{c}	5.74 (0.19)^{a}	15.77 (0.49)^{b}	19.39 (0.69)^{c}
Na	5.02 (0.47)^{a}	1.80 (0.41)^{b}	2.71 (0.21)^{c}	1.07 (0.02)^{a}	2.61 (0.25)^{b}	3.49 (0.12)^{c}
	µg (gdw)$^{-1}$					
Mn	28.99 (3.64)^{a}	48.61 (3.10)^{a}	118.03 (38.59)^{b}	34.34 (1.36)^{a}	41.84 (1.16)^{b}	64.96 (2.77)^{c}
Fe	99.59 (12.57)^{a}	232.75 (46.50)^{a}	2327.45 (916.94)^{c}	21.83 (3.03)^{a}	121.35 (9.02)^{b}	187.19 (32.72)^{c}
Cu	9.44 (1.24)^{a}	21.22 (0.92)^{b}	17.49 (0.74)^{c}	1.42 (0.30)^{a}	3.69 (0.21)^{b}	5.07 (0.10)^{c}
Zn	42.65 (4.69)^{a}	143.49 (7.15)^{b}	200.97 (31.95)^{c}	13.84 (0.71)^{a}	60.78 (2.79)^{b}	160.02 (4.97)^{c}

Table 1: Average nutrient content (n=4, (standard deviation)), for lettuce vegetable (LV), hydroponically grown lettuce microgreens (LHP), vermicompost-grown lettuce microgreens (LC), cabbage vegetable (CV), hydroponically-grown cabbage microgreens (CHP) and vermicompost-grown cabbage microgreens (CC). The average fraction dry masses (standard deviation) were as follows: 0.059 (0.009), LHP; 0.060 (0.007), LC; 0.056 (0.002), LV; 0.096 (0.016), CHP; 0.070 (0.006), CC; 0.120 (0.002), CV. Small letters denote significance (α=0.05) of statistical comparisons among LV, LC and LHP nutrient contents and comparisons among CV, CC and CHP nutrient contents.

However, compostable waste is produced by every household and includes "unavoidable waste" from fruit and vegetables that is nutrient rich, but comprises a large amount of fresh mass that goes uneaten. An example of such unavoidable food waste is banana peels, which make up about 40% of the fruit's fresh weight [18], and contain 45,000 and 64,000 mg potassium (Kg dry mass)-1 [19]. Growing MG's in the vermicompost generated from such unavoidable food waste provides a mechanism for recapturing some of these nutrients in plant biomass for human consumption rather than having it lost to a landfill. The MG ability to acquire micronutrients from vermicompost that had been made bioavailable via decomposition of nutrient rich-food wastes is likely responsible for the higher levels of some nutrients in the compost-grown MG's than in the hydroponically-grown MG's. The hydroponic fertilizer solution used in this study was an N, P, K-based fertilizer; although it contains trace elements, their availability for plant uptake was not as great as it was in the vermicompost utilized. The ability of vermicompost to improve plant growth when added to growth matrix has been documented previously, but its impact can vary tremendously depending on the materials being composted (e.g., fruits and vegetables, manure, sewage sludge; [20]). Additionally, the microbial community composition and activity in vermicompost can also dramatically affect plant growth [20]. Nutrient quantities and microbial properties of the vermicompost were not assessed in this study, as the focus was to examine whether or not the two growing methods yielded MG's with different nutrient contents. However, given the differences in the nutrient contents of MG's grown hydroponically or on vermicompost, a more detailed study that examines the nutrient and microbial properties of the vermicompost is warranted. The ability of microbial communities to enhance MG growth is intriguing because the HP treatment in this study likely contained far fewer microbes than the vermicompost treatment [21].

Conclusion

Results of this study indicate that, on average, MG's grown on vermicompost had greater nutrient contents than those grown hydroponically. However, MG's, irrespective of growing method, had greater average nutrient contents than store-bought mature vegetables. As microgreens can be grown easily in one's home using the two methods used in this study, they may provide a means for consumer access to larger quantities of nutrients per gram plant biomass relative to store-bought mature vegetables. Simultaneously, growing and consuming MG's could reduce consumer need to rely on industrialized food systems, which involve environmentally damaging processes (i.e., fertilizer application, high water use, long transport chains [1]).

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