RESEARCH ARTICLE

Mineral nutrient analysis of Ginger (*Zingiber officinale* Rosc.) cultivars grown under different conditions

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Ginger is a medicinal plant with antioxidant, anti-inflammatory, anti-microbial, and anti-carcinogenic effects and has been used as a food additive. Research on the morpho-physiological differences between ginger cultivars is mostly conducted on locally produced varieties. Ginger can potentially be differentiated by rhizome color. This research explored the mineral nutrient contents of seven ginger cultivars including Bubba Blue (BB), Chinese White (CW), Hawaii Yellow (HY), Khing Yai (KY), Kali Ma (KM), Madonna (MD), and Big Kahunna (BK) in biological and edible roots, stem, and leaf under different growing conditions. The colors of ginger (yellow, white, or blue) were used to determine if mineral content was cultivar or color specific. Plants were grown under the high tunnel and greenhouse conditions with varying shade levels of 0, 40, 60, and 80%, respectively. The plant growth indicators of rhizome weight, stem diameter, stem length and mineral nutrient contents of calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), iron (Fe), manganese (Mn), Zinc (Zn), sodium (Na), and silver (Ag) were measured. The results showed that rhizome yield was the highest for all cultivars grown during 2017 under 0% shade. Nutrient amounts did not have cultivar specific responses to shade level in edible rhizomes but did in leaves. Stems and leaves produced the highest amounts of Ca, K, Fe between 60 - 80% shade, and Mg, Mn, Zn between 60 - 80% in HY and CW cultivars, 0% in KM cultivar. Biological roots had the lowest mineral contents in HY, but the highest in Fe and K in all cultivars across all growing conditions. Stems and leaves had the highest Ca, Mg, Fe, while stems and edible rhizome had K, stems had P and Zn, yellow ginger edible rhizome had Mn as the highest nutrient amounts, respectively. Besides Mn, mineral nutrient amounts and rhizome yield did not differ by ginger color. However, stem and leaf macronutrients were higher in white ginger, while stem and leaf micronutrients were higher in blue ginger and yellow ginger, respectively.

Keywords: ginger; rhizome; mineral nutrient.

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Introduction

Ginger (*Zingiber officinale Rosc*.) is a medicinal plant known for its antioxidant, anti-inflammatory, anti-microbial, and anti-carcinogenic properties, as well as other health benefits such as nausea and pain management [1- 3]. Along with ginger's medicinal properties, it is a food additive of special interest to not just North Carolina, but United States (U.S.) farmers due to its potential value as an alternate niche market cash crop. According to the Observatory of Economic Complexity, as of 2022, the USA is the top net importer of ginger with the highest trade value on imports to exports at $119 million with the main ginger producer within the U.S. being Hawaii [2]. Attempting to understand the morpho-physiological differences between ginger cultivars has become important for both researchers and growers. Previous studies, however, have run into difficulties that the transport and selling of seed ginger globally can be difficult due to ginger's susceptibility to disease [4]. Farmers and producers will not buy seeds that may be diseased upon receipt, so they emphasize buying locally grown ginger seeds, which are considered a more reliable investment. This reliance on native ginger creates a problem for ginger researchers. Because communities around the world rely on native ginger varieties, the common names associated with these varieties have changed over time to accommodate these communities. Shahrajabian *et al*. classified ginger by their geological locations and resulted that the same ginger cultivar had multiple different common names, while the different ginger cultivars were classified under the same geological classification [5]. One example of this problem is *Zingiber officinale*, which has been classified under Jamaican ginger, Nigerian ginger, Indonesia and Malaysia ginger, as well as Indian/Nepal/Bangladesh/Sri Lanka ginger. For U.S. farmers looking to buy seed from Hawaii, the issue is confusing because nearly all varieties fall under the umbrella term *Zingiber officinale* with only common names to distinguish them. That doesn't even include the existence of Hawaiian Island ginger (*Zingiber zerumbet*).

One way that researchers have attempted to differentiate ginger cultivars is by the "color" of ginger rhizome. Depending on the type of ginger, the rhizome can have different colored appearances ranging from the pale yellow to blue of *Z. officinale* Rosc. seen in most grocery stores in the U.S. [6], to bright red of *Z. officinale* var *rubrum* [7], and even the purple black of *Kaempferia parviflora* Wall. [8]. *Zingiber officinale* cultivars are characterized by a pale yellow to blue color. However, the variation of color density between cultivars is most likely due to cultivation practices and environmental conditions ginger plants were grown in [6]. Morpho-physiological studies of ginger must consider the environmental conditions that ginger plants were grown in to adequately determine the differences in ginger cultivars. One potential example of this is to determine the macro- and micro-nutrient contents of ginger plants. Ginger plants are rich in essential minerals such as calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), iron (Fe), manganese (Mn), zinc (Zn), silver (Ag), and sodium (Na) [9-11]. Not much research has been conducted on the mineral profiles of different ginger cultivars. However, some studies have been done to compare different colored gingers. Ajayi *et al*. compared the mineral profile of a yellow ginger with that of a white ginger. The results showed that the levels of potassium, phosphorus, magnesium, and sodium were markedly higher in yellow ginger, while calcium was higher in white ginger. While these variations could be due to differences in growing the two different color varieties, the fact that the samples were purchased at a local market and not grown by the researchers supported this idea [12]. Other research that looked at the change in mineral content in ginger cultivar supported that environmental conditions are the ultimate factor. Majkowska-Gadomska *et al*. reported that different growing substrates could affect the mineral contents in ginger rhizome. Specifically, the addition of coconut coir significantly increased the amount of potassium, magnesium, and calcium [13]. Another study investigated the effect of lowered pH on ginger mineral contents found that, as the pH reduced, potassium, magnesium, iron, and zinc all increased, while sodium decreased [14].

This research aimed to provide science-based data on the nutrient contents of multiple different Hawaii-sourced ginger cultivars grown in different conditions in North Carolina, USA by measuring the mineral nutrient contents of different parts of the plant including leaf, stem, biological root, edible rhizome grown under high tunnel and greenhouse conditions. The results of this study could be used by researchers to determine if the “color” of *Zingiber officinale* rhizome is an adequate indicator to determine morpho-physiological differences between ginger cultivars and gain a better understanding of chemical composition of ginger plants.

Materials and methods

Comparation of Hawaii-sourced ginger cultivars during 2017 growing season

The seeds of three different ginger cultivars, Hawaii Yellow (HY), Kali Ma (KM), Chinese White (CW), were purchased from Plum Granny Farm (King, NC, USA) with all seeds originated from Hawaii, USA, and HY, KM, and CW were characterized as yellow, blue, and white ginger, respectively. All ginger seeds were grown under the different shade treatments of 0%, 40%, 60%, and 80% shade in a high tunnel with an additional 6-mil greenhouse grade plastic film that provided an additional roughly 12% shade to each level. The high tunnel planting applied randomized complete block split plot design with the main plot being shade level and the split plot being ginger cultivar. Each block was replicated 4 times with 12 plants per bed per cultivar for a total of 36 plants per block, and 144 plants per shade treatment. All ginger seeds were also grown in greenhouse pots with completely randomized design (CRD) and 1 ginger seedling per 10-liter pot consisting of metro mix:compost (1:1) and at least 8 pots per cultivar. The plants in both high tunnel and greenhouse were fertilized with Weaver 17-17-17 with 60 lb. N/acre for high tunnel and 10 grams slow-release fertilizer per pot in greenhouse. Ginger seedlings were transplanted into high tunnel on May 23, 2017 and into greenhouse pots on June 29, 2017, while the plants were harvested on December 7, 2017 and January 26, 2018, respectively.

Comparison of Hawaii-sourced ginger cultivars grown in a high tunnel during 2019 growing season

Seven ginger cultivars including Bubba Blue (BB), Chinese White (CW), Hawaii Yellow (HY), Khing Yai (KY), Kali Ma (KM), Madonna (MD), and Big Kahunna (BK) sourced from Plum Granny Farm (King, NC, USA) were grown in a high tunnel with 6-mil greenhouse grade plastic film that provided 12% shade to plants. Among them, HY and KY are yellow gingers, CW, MD, BK are white gingers, and BB and KM are blue gingers. All plants were grown in a completely randomized design with 12 plants per replicate and 3 replicates per cultivar for a total of 36 plants per cultivar and treated using Broiler poultry litter as fertilizer with N, P, and K of 32.4, 36, and 30.25 lb/acre, respectively. Ginger seedlings were transplanted into high tunnel on May 30, 2019, and the plants were harvested on December 5, 2019.

Data collection of ginger growth and yield

The collected plant growth data included the height of plant at maturity with number of stems for 2019 planting group, the length of stem (cm) for 2017 and 2019 groups, and stem diameter (cm) for 2017 and 2019 groups. At the end of the growing season, ginger rhizomes were harvested with the above ground vegetative parts being removed. The below ground ginger rhizomes were thoroughly washed. Average total rhizome yield (g) that included biological roots and edible rhizome were measured. The relevant plant growth and rhizome production data were compared with nutrient contents in relevant tissue samples.

Measurement of the nutrients in ginger tissues

Nutrient measurements were conducted using inductively coupled plasma optical emissions spectrometry (ICP-OES). Stems of 2019 group and leaves of 2017 and 2019 groups were collected from fully mature ginger plants, while biological (fibrous) roots of 2017 greenhouse group and edible rhizome of 2017 and 2019 groups were collected at the end of the growing season during harvest. All samples were thoroughly washed and placed in a dryer at 60°C for two days before being grounded into a fine powder between 200 - 500 um. The sample powders were measured to 0.20 (- 0.01) g and

Table 1. Stem diameter and stem length for 2017 ginger growing season in high tunnel and greenhouse.

Ginger cultivar - color	High tunnel (shade %) or greenhouse	Variable (cm)	Mean variable amount (± SD)
Chinese White white ginger	0	Stem diameter	0.74 (±0.2)[b]
		Stem length	55.3 (±23)[a]
	40	Stem diameter	0.78 (±0.2)[a]
		Stem length	73.1 (±33)[ab]
	60	Stem diameter	0.75 (±0.2)[ab]
		Stem length	71.6 (±32)[ab]
	80	Stem diameter	0.78 (±0.3)[a]
		Stem length	72.8 (±33)[b]
	Greenhouse	Stem diameter	0.90 (±0.3)[a]
		Stem length	98.4 (±38)[a]
Hawaii Yellow yellow ginger	0	Stem diameter	0.79 (±0.3)[a]
		Stem length	59.2 (±21)[b]
	40	Stem diameter	0.76 (±0.2)[ab]
		Stem length	70.9 (±29)[bc]
	60	Stem diameter	0.74 (±0.2)[b]
		Stem length	76.4 (±31)[a]
	80	Stem diameter	0.76 (±0.2)[a]
		Stem length	80.2 (±33)[a]
	Greenhouse	Stem diameter	0.70 (±0.2)[b]
		Stem length	77.9 (±35)[c]
Kali Ma blue ginger	0	Stem diameter	0.73 (±0.2)[b]
		Stem length	50.2 (±19)[c]
	40	Stem diameter	0.73 (±0.2)[b]
		Stem length	70.2 (±23)[c]
	60	Stem diameter	0.73 (±0.2)[b]
		Stem length	71.5 (±29)[b]
	80	Stem diameter	0.79 (±0.2)[a]
		Stem length	75.3 (±32)[b]
	Greenhouse	Stem diameter	0.90 (±0.2)[a]
		Stem length	86.8 (±31)[b]

placed in a labeled 50 mL centrifuge tube before being sent to the Analytical Service Lab onsite of campus for nutrients measurement. Samples were run in triplicate to determine the average contents of Ca, Mg, K, P, Fe, Mn, Zn, Ag, and Na and converted them from ppm to mg/kg using the following equation.

$$\text{Total Element Amount } (mg/kg) = \frac{\text{Total PPM of Element} \times \text{Final Solution Volume } (ml)}{\text{Initial Weight of Plant Tissue } (g)}$$

Statistical analysis

SAS OnDemand for Academics (SAS Institute Inc, Cary, NC, USA) was employed for the statistical analysis of this study. The ANOVA test was performed followed by Fisher's Protected LSD using PROC GLM procedure running at 0.05 level of significance to determine the differences of the mineral nutrient levels of ginger cultivars and tissues in response to different growing conditions. Microsoft Excel (Microsoft, Redmond, Washington, USA) was used in the process of generating all tables and figures. Tables and figures were statistically analyzed by data variables.

Results

Growth and yield of ginger cultivars in high tunnel shade conditions and in a greenhouse

Table 2. 2019 ginger plant growth in high tunnel.

Ginger cultivar (*color*)	Variable	Mean variable amount (± SD)
Bubba Blue ***Blue***	Stem diameter (cm)	0.70 (±0.2)[b]
	Stem length (cm)	43.1 (±26.4)[c]
	Stem number	7.20 (±3.1)[bc]
Big Kahunna ***White***	Stem diameter (cm)	0.60 (±0.2)[c]
	Stem length (cm)	42.3 (±13.8)[c]
	Stem number	7.90 (±4.6)[bc]
Chinese White ***White***	Stem diameter (cm)	0.70 (±0.2)[bc]
	Stem length (cm)	36.0 (±33.1)[d]
	Stem number	5.50 (±5.0)[c]
Hawaii Yellow ***Yellow***	Stem diameter (cm)	0.70 (±0.2)[b]
	Stem length (cm)	40.1 (±15.9)[cd]
	Stem number	9.40 (±5.7)[ab]
Kali Ma ***Blue***	Stem diameter (cm)	0.80 (±0.7)[a]
	Stem length (cm)	53.8 (±15.0)[b]
	Stem number	11.5 (±3.2)[a]
Khing Yai ***Yellow***	Stem diameter (cm)	0.90 (±0.3)[a]
	Stem length (cm)	53.0 (±18.1)[b]
	Stem number	7.40 (±5.7)[bc]
Madonna ***White***	Stem diameter (cm)	0.70 (±0.2)[b]
	Stem length (cm)	58.6 (±12.1)[a]
	Stem number	11.0 (±3.6)[a]

During the 2017 growing season, the average stem diameter and length of three ginger cultivars in a greenhouse as well as under four different shading levels in a high tunnel showed that, when grown in a greenhouse, both KM and CW demonstrated significant increases of stem diameter/length as 0.90 cm/86.8 cm and 0.90 cm/98.4 cm, respectively, compared to all shade levels in a high tunnel, while HY produced the longest stem of 77.9 cm when grown under 80% shade and the thickest diameter ranged from 0.74 to 0.79 cm across all shade levels in the high tunnel. Plants grown under 0% shade produced the shortest stems across all cultivars with CW, KM, and HY showing 55.3, 50.2, and 59.2 cm, respectively (Table 1). During the 2019 growing season, the measurements of stem diameter, stem length, and number of shoots of seven ginger cultivars did not demonstrate noticeable trends between the cultivars for overall plant growth by cultivar or by ginger rhizome color. The average stem length, stem diameter, and the number of shoots ranged from 36.0 - 58.6 cm, 0.60 - 0.80 cm, and 5.5 - 11.5 cm, respectively. The stem length, stem diameter, and number of shoots ranged by colors were 40.1 - 53.0, 0.70 - 0.90, 7.40 - 9.40 for yellow; 43.1 - 53.8, 0.70 - 0.80, 7.20 - 11.5 for blue; and 36.0 - 58.6, 0.60 - 0.70, 5.50 - 11.0 for white, respectively (Table 2). The plant yields were then compared between 2017 and 2019 groups across all shade conditions in a high tunnel and greenhouse conditions. For both years, the average total rhizome yield of 0% shade was significantly the highest one with the range of 693.6 to 671.3 g followed by greenhouse groups of 378.3 to 574.6 g, while the 40 - 80% shade groups demonstrated significantly lower yields from 306.8 to 370.3 g. The 2019 high tunnel groups under 6-mil greenhouse grade plastic covering showed significant differences among individual cultivars with KY of 592.3 g as the highest yield followed by MD of 589.4 g, KM of 509.2 g, HY of 343.6 g, BK of 321.2 g, BB of 282.1 g, and CW of 206.9 g (Figure 1). The average total rhizome yields by rhizome colors were not significantly different across the same

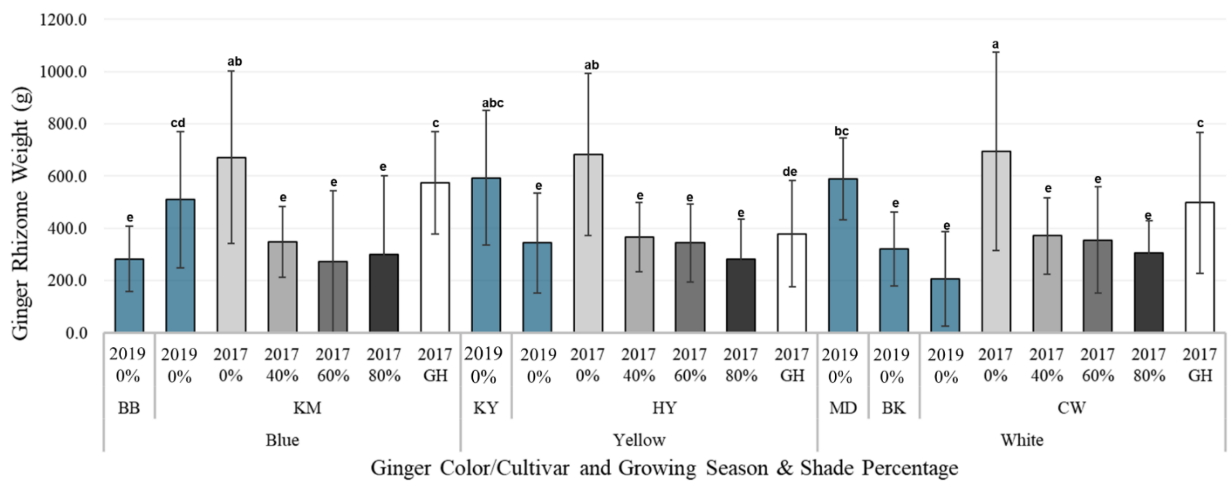

Figure 1. Comparison of average ginger rhizome weight with ginger colors and cultivars during 2017 and 2019 growing seasons in high tunnel and greenhouse.

color rhizome for all cultivars measured.

Mineral contents of stem and leaf tissue

Leaf and stem tissues were only collected and analyzed under high tunnel growing conditions in this study. In the 2017 growing season, interaction plots comparing shade levels with ginger cultivars were generated for each element measured and determined that cultivar specific reactions were occurring, which meant that each ginger cultivar measured produced a specific element (Ca, Mg, K, Fe, Mn, Zn, Ag and Na) at different amounts under different shade conditions. The results showed that all three cultivars produced the highest amounts of Ca, K, Fe, while HY and CW produced the most amount of Mg, Mn, and Zn between 60 - 80% shade and KM produced the highest amount at 0% shade. All three cultivars produced the highest amount of Ag and Na between 0 - 60% shade. HY and CW produced the least amount of Ca, Mg, K, Fe, Mn, and Zn between 0 - 40% with KM producing the lowest amount between 0 - 60% shade. HY and CW produced the lowest amount of Ag and Na at 80% shade and KM at 0% shade (Figure 2). During 2019 growing season, leaf tissue was analyzed for ginger plants growing under high tunnel conditions with 6-mil greenhouse grade plastic covering. There were no significant differences between ginger rhizome colors. However, in general, macronutrients (Ca, Mg, K, P) were produced in the highest amounts in white gingers and the lowest amounts in blue gingers except for phosphorus which produced the least amount in Hawaii Yellow, while micronutrients (Fe, Mn, Zn, Na) produced in the highest amount in yellow gingers and the lowest amounts in both white and blue gingers. In the 2019 growing season, the highest and lowest amounts of each nutrient in leaves demonstrated that the highest Ca of 18,125.9 mg/kg was shown in BK and the lowest Ca of 3,807.4 mg/kg was seen in KY. The highest Mg of 11,467.5 mg/kg was found in CW and the lowest Mg of 5,550.0 mg/kg in KM. The highest K of 5,320.2 mg/kg was in CW and the lowest K of 2,446.7 mg/kg was in BB. The highest P of 3,485.8 mg/kg was found in MD, while the lowest P of 1,746.8 mg/kg was found in HY. The highest Fe of 176.0 mg/kg was in KY and the lowest one of 101.5 mg/kg was in HY. The highest Mn of 52.0 mg/kg was found in HY, while the lowest Mn of 8.5 mg/kg was seen in CW. The highest Zn of 32.5 mg/kg was in KY and the lowest one of 26.0 mg/kg was in CW. The highest Na of 33.7 mg/kg was shown in MD, while the lowest Na of 0.8 mg/kg was observed in KY. The stem tissues showed no significant differences among ginger rhizome colors, while the macronutrients were generally the highest in white ginger except K was the highest in BB and the micronutrients were

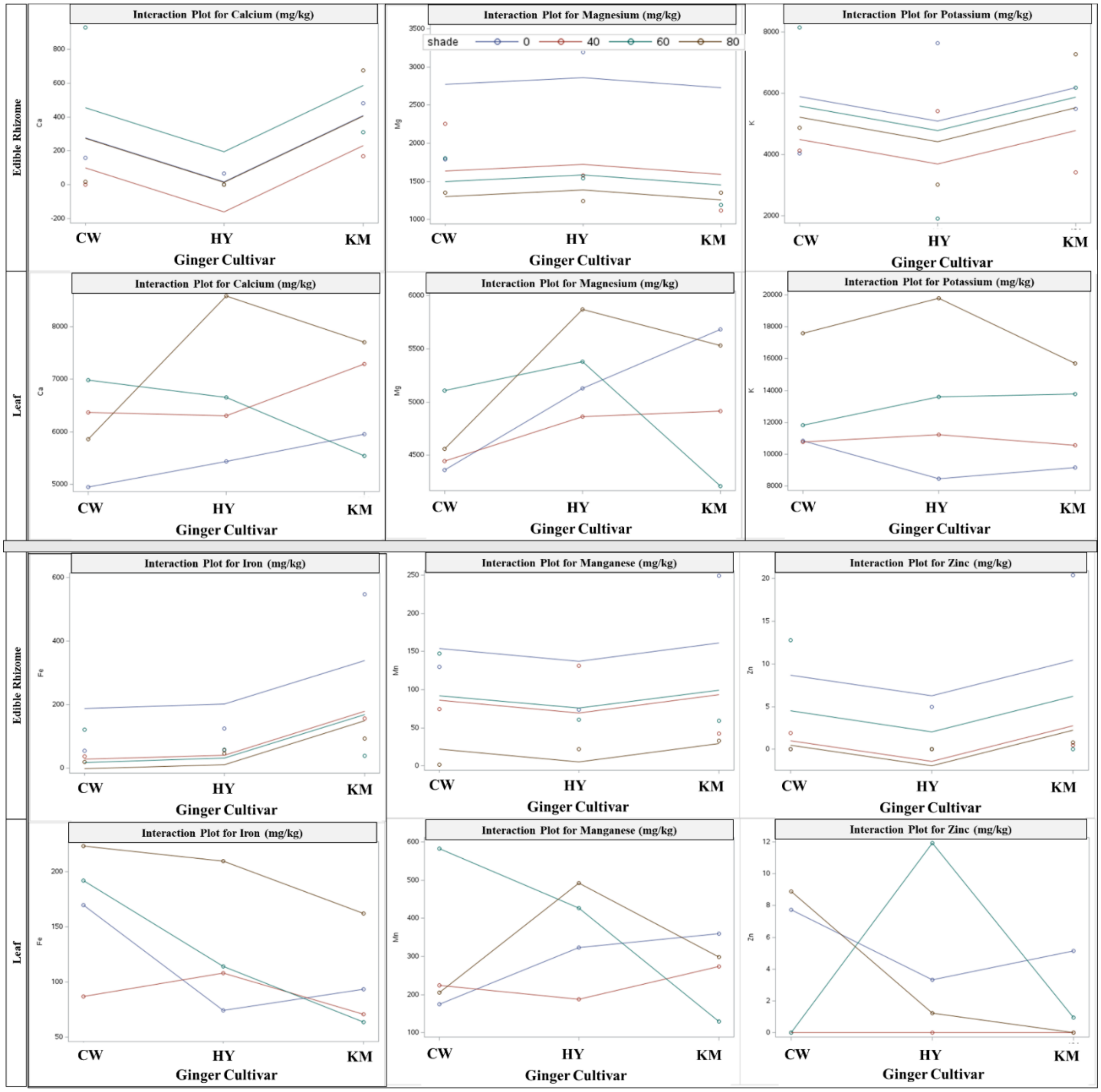

Figure 2. Interaction plots of edible rhizome and leaf nutrient compositions under multiple high tunnel shade treatments of 0%, 40%, 60%, 80% in the 2017 growing season. Lines that crossed indicated the cultivar specific reactions to shade levels. Lines that did not cross indicated no cultivar specific response to shade levels.

the highest in blue gingers except Na was the highest in HY (Figure 3). All micronutrients were the lowest in the stem of CW. The highest and lowest amounts of each nutrient demonstrated that the highest Ca of 16,769.7 mg/kg was observed in BK, while the lowest Ca of 3,700.8 mg/kg was seen in BB. The highest Mg of 8,795.8 mg/kg was found in CW and the lowest Mg of 5,278.9 mg/kg was shown in HY. The highest K of 23,680.6 mg/kg was in BB, while the lowest K of 10,097.0 mg/kg was in BK. The highest P of 4680.8 mg/kg was seen in BK and the lowest P of 1,746.8 mg/kg was in HY. The highest Fe was found in KM as 193.2 mg/kg, while the lowest Fe of 33.9 mg/kg was found in CW. The highest Mn of 17.6 mg/kg was observed in KM and the lowest

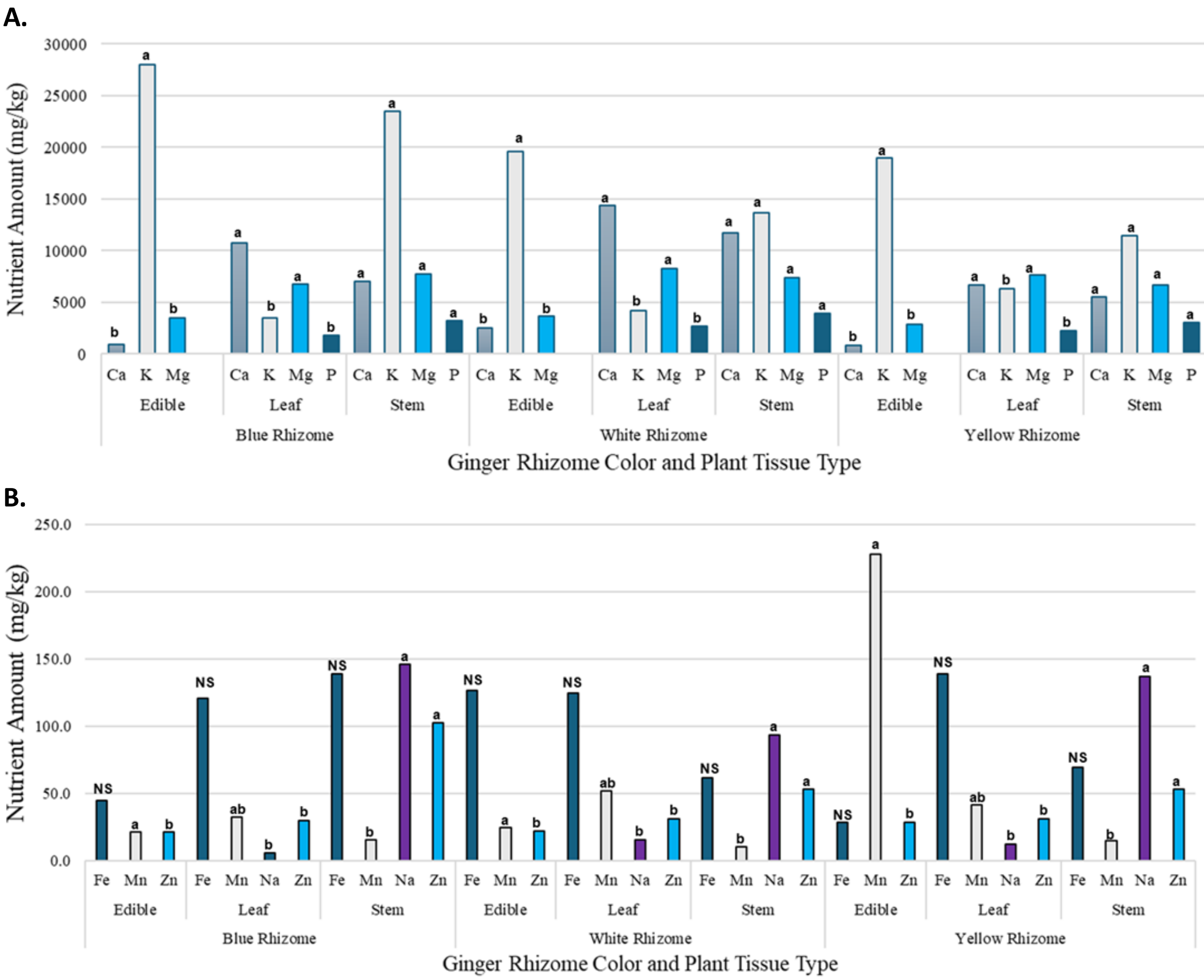

Figure 3. The macronutrients (**A**) and micronutrients (**B**) of edible rhizome, leaf, and stem from ginger plants based on ginger rhizome color during the 2019 growing season in high tunnel. NS meant not significant.

one of 8.5 mg/kg was found in CW. The highest Zn of 149.6 mg/kg was seen in KM, while the lowest amount of 29.4 mg/kg was found in CW. The highest Na of 228.5 mg/kg was shown in HY and the lowest Na of 32.1 mg/kg was observed in CW (Table 3).

Mineral content of edible rhizome and biological roots

Edible rhizomes of the ginger plants were analyzed for both 2017 and 2019 growing season groups under greenhouse and high tunnel growing conditions. The results showed that, for 2017 groups in high tunnel group, all nutrients of edible rhizomes had consistent reactions to each shade level with no cultivar specific responses occurring in the presence of differing amounts of shade (Figure 2). Noticeable trends occurred in 0% shade, which produced the most amount of Mg, K, Fe, Mn, Zn in all three cultivars with only Ca being produced the most at 60% shade. All nutrients, except Ca, produced the least amount when exposed to shade of 40 - 80%, while Ca produced the least amount at 40% shade. There was also no significant change between the three cultivars, although in general, HY had the lowest amount of all nutrients except Mg. By comparing ginger rhizomes grown in greenhouse to that in high tunnel shading, Ca and K were significantly higher in greenhouse groups than that in high tunnel groups with all shade conditions, while the other nutrients demonstrated neither the

Table 3. Analysis of micro- and macronutrients of edible rhizome, stem, and leaf of multiple ginger cultivars grown in high tunnel during the 2019 growing season.

Cultivar	Tissue	Ca	Mg	K	P	Fe	Mn	Zn	Na
Big Kahunna white ginger	Edible rhizome	4,114.7	5,325.5	14,696.3	X	219.6	43.8	37.5	x
	Stem	16,769.7	7,193.2	10,097.0	4,680.8	36.0	10.5	43.7	48.8
	Leaf	18,125.9	6,833.6	2,559.4	2,304.2	105.5	29.8	32.1	1.8
Peruvian Yellow yellow ginger	Edible rhizome	897.6	2,912.3	17,207.7	X	28.4	343.9	46.1	X
Hawaii Yellow yellow ginger	Edible rhizome	594.6	2,325.0	15,440.2	X	23.7	19.3	9.1	X
	Stem	7,228.8	5,278.9	X	2,254.9	55.5	15.6	57.6	228.5
	Leaf	9,500.0	8,007.5	7,675.0	1,746.8	101.5	52.0	30.0	23.5
Kali Ma blue ginger	Edible rhizome	891.5	3,519.1	27,977.9	X	45.0	21.3	21.3	X
	Stem	10,321.9	7,014.6	23,274.6	2,623.2	193.2	17.6	149.6	162.2
	Leaf	13,017.5	5,550.0	4,550.0	1,782.0	135.0	30.5	31.3	8.5
Khing Yai yellow ginger	Edible rhizome	1,083.1	3,473.8	24,189.3	X	33.7	319.9	30.0	X
	Stem	3,768.4	7,977.1	22,916.0	3,877.9	84.0	14.5	48.3	45.8
	Leaf	3,807.4	7,323.2	4,963.9	2,731.0	176.0	30.5	32.5	0.8
Chinese White white ginger	Edible rhizome	985.0	2,054.5	24,466.0	X	33.1	5.5	6.8	X
	Stem	9,132.0	8,795.8	17,034.6	2,920.2	33.9	8.5	29.4	32.1
	Leaf	15,012.6	11,467.5	5,320.2	2,216.8	130.9	8.5	26.0	10.3
Madonna white ginger	Stem	9,208.9	6,175.1	13,745.5	4,180.7	114.4	12.0	86.5	199.2
	Leaf	10,032.5	6,576.7	4,580.2	3,485.8	138.4	46.2	36.0	33.7
Bubba Blue blue ginger	Stem	3,700.8	8,403.1	23,680.6	3,811.8	84.3	12.9	55.0	129.9
	Leaf	8,537.9	7,972.2	2,446.7	1,755.1	106.3	34.8	29.0	3.3

Note: The units for Ca, Mg, K, Fe, Mn, Zn, Na, Ag were mg/kg. BDL indicated the data below detection limit. X indicated the measurement not viable or not available.

highest nor the lowest in both greenhouse and high tunnel groups (Table 4). During 2019 growing season, the ginger edible rhizomes showed no significant differences of all nutrients by rhizome color, while Mn was generally much higher in yellow ginger compared to the other ginger colors (Figure 3). Biological roots were only measured for the plants of 2017 growing season in greenhouse (Table 4). The general trends of the data analysis suggested that HY had the lowest amount of all nutrients in biological roots when grown in a greenhouse, except Mg where there was no noticeable difference between the three cultivars. CW and KM had comparable nutrients in this study. While biological roots were not analyzed in high tunnel conditions, Fe and K were the highest nutrients in biological roots compared to the other types of tissues in both studies.

Discussion

Macronutrients and micronutrients serve specific roles in plant biochemical processes. Macronutrients are nutrients within a plant that are required in large amounts, while conversely micronutrients are required in smaller quantities within a plant but are still considered necessary for plant growth [15]. Most of the research on plant nutrient content focused on how they affected plants at the cellular level. This research analyzed the total amount of specific macronutrients and micronutrients by plant organs, specifically leaf, stem, rhizome, and roots. In addition, Ag was also measured although it is not required for plant growth and development. In general, Ca, Mg, Fe, Na accumulates mainly in plant leaves that have the highest number of cells in comparison to other organs. The number of cells is important in determining the total nutrients amount. Ca is

Table 4. Analysis of micro- and macronutrients in edible rhizome, leaf, biological root of ginger cultivars during the 2017 growing season.

Cultivar	Condition	Tissue	Ca	Mg	K	Fe	Mn	Zn	Na	Ag
Chinese White white ginger	0% shade	Edible rhizome	158.2	1790.4	4,037.8	55.2	129.5	BDL	X	X
		Leaf	4947.6	4363.1	10,841.7	170.1	174.1	7.7	142.9	28.7
	40% shade	Edible rhizome	X	2,252.8	4,133.6	36.9	74.7	1.9	X	X
		Leaf	6,372.5	4,444.2	10,755.7	86.8	223.8	BDL	166.3	11.5
	60% shade	Edible rhizome	927.9	1,801.0	8,145.6	122.0	147.6	12.8	X	X
		Leaf	6,987.8	5,105.0	11,805.0	192.3	582.0	BDL	163.3	26.3
	80% shade	Edible rhizome	18.6	1,350.8	4,885.4	19.3	1.5	BDL	X	X
		Leaf	5,862.6	4,557.6	17,592.7	223.4	205.1	8.9	75.6	BDL
	Greenhouse	Biological roots	3,136.1	2,551.7	26,050.1	570.7	93.0	8.4	X	X
		Edible rhizome	516.4	1,148.8	9,053.0	13.6	37.1	1.0	X	X
Kali Ma blue ginger	0% shade	Edible rhizome	480.1	3,373.8	5,491.0	547.2	248.9	20.4	X	X
		Leaf	5,953.6	5,679.7	9,151.6	93.4	359.7	5.1	114.4	2.4
	40% shade	Edible rhizome	167.0	1,116.0	3,426.5	156.4	42.1	0.5	X	X
		Leaf	7,287.4	4,912.0	10,559.6	70.6	274.2	BDL	164.0	19.3
	60% shade	Edible rhizome	308.8	1,190.7	6191.2	39.4	59.2	BDL	X	X
		Leaf	5,539.9	4,209.3	13,779.3	63.6	129.0	1.0	137.9	6.7
	80% shade	Edible rhizome	675.2	1,350.1	7,279.1	92.8	33.0	0.8	X	X
		Leaf	7,704.6	5,531.6	15,705.5	162.4	297.9	BDL	137.9	2.9
	Greenhouse	Biological roots	3,282.6	2,880.6	25,663.8	855.4	114.6	11.0	X	X
		Edible rhizome	646.8	1,297.1	10,774.6	15.6	66.4	0.7	X	X
Hawaii Yellow yellow ginger	0% shade	Edible rhizome	65.3	3,191.9	7,641.9	125.3	73.8	5.0	X	X
		Leaf	5,440.9	5,126.3	8,448.5	73.4	323.4	3.3	150.8	1.7
	40% shade	Edible rhizome	X	1,580.0	5,418.5	55.6	131.5	BDL	X	X
		Leaf	6,304.6	4,862.7	4,862.7	108.4	187.6	BDL	166.7	34.3
	60% shade	Edible rhizome	X	1,538.3	1,914.8	58.5	60.3	BDL	X	X
		Leaf	6,659.5	5,379.1	13,609.9	114.5	426.6	11.9	159.5	4.1
	80% shade	Edible rhizome	X	1,238.3	3,022.2	46.4	21.7	BDL	X	X
		Leaf	8,582.6	5,867.6	19,794.7	209.9	491.9	1.2	75.0	BDL
	Greenhouse	Biological roots	1,531.6	2,608.1	20,749.7	853.6	62.7	6.4	X	X
		Edible rhizome	814.6	1,721.5	12,876.8	29.6	78.9	5.1	X	X

Note: The units for Ca, Mg, K, Fe, Mn, Zn, Na, Ag were mg/kg. BDL indicated the data below detection limit. X indicated the measurement not viable or not available.

mainly found in the plant cell wall and membrane [16], while Mg is in chlorophyll molecules and K associates with enzyme activation that mainly occurs during photosynthesis [17]. Fe is found in the highest amounts in the cytoplasm of cells, while Na has been found to accumulate mainly in the vacuoles of plant cells [18, 19]. In comparison to these general trends, the results of this study demonstrated the differences in mineral nutrient contents in different ginger plant organs. The results showed that Ca accumulated the most in leaves of all cultivars. Na was the highest in the stems of ginger cultivars during the 2019 growing season in high tunnels. Fe was found to be the highest in biological roots of ginger plants grown in greenhouse during 2017 growing season. Mg showed cultivar specific reactions with HY, CW, and BB and had the highest amounts in leaves, BK and KM were the highest in the stems of plants and KY had no discernable difference in leaves and stems during the 2019 high tunnel growing conditions. Meanwhile, there is a general trend that Mn and K will accumulate in either shoots or leaves of plants. Mn amounts are determined by the age of the plant with movement of Mn through the xylem of the stem towards the leaves. The older the plants, the more likely the highest amount of Mn will be found in the leaves versus in the stem [20, 21]. The resulting data indicated that K was the highest in the stems of all ginger cultivars grown under high tunnel conditions in 2019, while Mn was the highest in the leaves of all cultivars grown under high tunnel conditions in both 2017 and 2019 except for KY cultivar in 2019, which was the highest in the edible rhizome of plants. In contrast to the other elements, P does not accumulate in a primary organ but focuses in young meristematic tissues, which are mainly new points of growth on a plant such as root and shoot tips with their DNA and RNA in the highest amounts [22, 23]. When comparing the leaf and stem in this research, P was found to have the highest amount in the stems of all cultivars. Past research found Zn to accumulate mainly in the roots of plants [24]. However, the results of this study identified the highest Zn amounts in the stem of all ginger cultivars in high tunnel condition in 2019. There is little research on where Ag accumulates in plants. Some studies reported that Ag accumulated in roots, which has been heavily debated [25]. The results of this study found that the highest amount of Ag was in the stem of ginger plants grown under high tunnel conditions in 2019. Research on the mineral content of ginger has mainly focused on the edible rhizome as this is the main part of ginger plant harvested for consumption with very little if no focus given to the other parts of the plant, *i.e*., the leaf, stem or biological roots. Mineral nutrient contents in ginger rhizomes have been known to decrease as the planting season continues, where the amount of Zn, copper and molybdenum decreased as number of days after planting increased, which was theorized due to the translocation of micronutrients to metabolic sinks [26]. Also, use of a Zn based spray significantly increased the rhizome yield in comparison to ginger grown with no Zn.

The changes in growing conditions may potentially influence ginger mineral contents, which is supported by a few studies. Majkowska-Gadomska *et al*. confirmed that different growing substrates could affect the mineral contents in ginger rhizome, especially, the addition of coconut coir significantly increased the amount of K, Mg, and Ca [13]. Other research investigated the effect of lowered pH on ginger mineral content, finding that, as the pH lowered, K, Mg, Fe, and Zn all increased while Na decreased. The results of this study indicated that mineral contents of ginger leaves and stems were cultivar specific with no significant differences among the different rhizome colors. Leaf mineral content was influenced by the level of shade when ginger cultivars were grown in a high tunnel. However, this was only for micronutrients, specifically for Mg, Mn, and Zn, with KM producing the highest amount in leaves when grown under 0% shade. Elizabeth *et al*. reported similar results with both nitrogen (N) and K being significantly different between shade levels in the haulm, the entire top part of the ginger plant including stems and leaves [27]. Between the 2017 and 2019 growing seasons, only nutrient amounts of both leaf and edible rhizome in HY, CW, and KM under 0% shade in a high tunnel were compared. A noticeable pattern occurred with nutrient amounts of both leaf and edible rhizome much higher during the 2019 growing season. The results were particularly interesting because yields for all cultivars were significantly lower in 2019 compared to that in 2017. It was hard to determine why such nutrients increase occurred. The exceptions of the results were Mn that was higher in both leaves and edible rhizome during the 2017 season and Fe that was higher in edible rhizomes during 2017. Both Fe and Mn are mineral nutrients involved in redox reactions along with Zn. The lower amounts of them can occur when adverse soil conditions occur, lessening their uptake by plants [28]. Other outliers that were higher during 2017 growing season were edible rhizomes with higher Mg in HY and Zn in KM, while higher Mg was shown in KM, Fe in CW, and K in both HY and KM leaves. One potential reason that Fe, Mn, and Zn for KM cultivar were lower during 2019 growing season might be the excessive weed growth that occurred during the entire month of June and first one third of July, which was the most likely reason for the decreased yield for all cultivars during this growing season. However, it was not certain why nutrient amounts were still so much higher in 2019 ginger edible rhizomes and leaves in comparison to 2017.

Multiple ginger plants were analyzed based on their common “color” designation to determine if there was any difference in elemental composition in different parts of the plant. Three different colored ginger plants were grown in various light and environmental conditions during the 2017 growing season to analyze the total element composition in their leaves and edible rhizomes. For edible rhizome, it was determined that, within high tunnel conditions, there were noticeable differences among the three cultivars. HY (yellow cultivar) had the lowest amount of Ca, K, Mn, and Zn at all shade levels compared to CW (white cultivar) and KM (blue cultivar). KM had the highest amount of Fe across all shade levels in a high tunnel, while CW and HY both had the lowest one. CW and KM had the highest amounts of all other nutrients. The shade level that produced the highest amounts of individual elements in edible rhizomes in all cultivars was 0% shade with the only exception of Ca that was the highest at 60% shade. In contrast, leaf samples demonstrated cultivar specific reactions to each shade level with each cultivar accumulating different elements in leaves at different shade levels. The 60 - 80% shade produced the most elements with HY specifically producing the highest amounts of elements under 80% shade except for Zn at 60% shade. In contrast, KM produced the highest amount of Zn, Mn, and Mg at 0% shade. Comparing the different shade levels in the high tunnel to greenhouse conditions, a significant change with edible rhizome was noticed although no cultivar specific reaction in the greenhouse *vs*. the shade levels were observed. Ca and K were significantly higher in edible rhizomes when grown in pots in the greenhouse, while Fe was significantly lower. Mg, Mn, and Zn were not significantly different between the greenhouse and high tunnel conditions. Biological roots were measured for their mineral element contents and compared to edible roots. Biological roots, in general, had higher contents for all elements than edible roots except for Mn in HY. HY demonstrated unique amounts in comparison to CW and KM for Ca, K, Mg, Mn, Zn with this yellow cultivar having the lowest amount of single element in the biological roots and the highest amount of the same element in the edible rhizome. These findings suggested that the elemental composition of ginger plants was potentially dependent on the color of the ginger rhizome. However, this could simply be a cultivar specific reaction. To further determine if there was a difference by ginger rhizome color, mineral nutrient contents of ginger plants grown under high tunnel conditions were analyzed by ginger rhizome color during 2019 growing season. The results showed that mineral element amount did not significantly differ among the ginger rhizome colors. Further analysis focused on tissues of leaf and stem edible rhizome found that all elements were significantly differ across all ginger cultivars except for Fe. K and Mn both accumulated the highest amounts in the edible rhizome of ginger plants which was understandable as other research had determined that potassium was an element that accumulated in the ginger rhizome in large quantities [10]. In general, Ca, Mg, Mn, and Fe accumulated the most in the leaves of ginger plant, while Ca, Na, P, and Zn were the highest in the stem of ginger plant. Across all ginger colors, the edible rhizome consistently had higher levels of K than that in the stem and leaf samples. Blue ginger had the highest amount of K compared to that in white and yellow ginger.

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