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Environmental and Genetic Variation in Essential Mineral Nutrients and Nutritional Value Among *Brassica* Vegetables

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Abstract

Dietary minerals play an important role in human nutrition and proper metabolism. We grew various *Brassica* crops under field conditions in 2012 and 2013 and analyzed 8 essential minerals from edible tissues of those crops. Among the investigated crops, pak choi (*Brassica rapa*), mustard greens (*B. juncea*; *B. nigra*), and komatsuna (*B. rapa*) were generally high in most minerals, according to dry weight-based concentrations. The percentage recommended daily intake (RDA) or adequate intake (AI) values, calculated using fresh weight-based concentrations, suggest that *Brassica* vegetables are a good source of iron, calcium, and manganese, providing > 20% of %RDA/AI depending on crop. Kale (*B. oleracea*; *B. napus*) was generally higher in %RDA/AI, in particular for calcium (Ca), phosphorous (P), magnesium (Mg), and manganese (Mn). From the 2-year study, days to harvest, growing degree days, total solar radiation, and total precipitation and evaporation were found to affect the concentration of Ca, P, Ma, and Me. The results of this study provide a direct comparison of the mineral composition of various *Brassica* crops grown under the same conditions and will help consumers' food choice for better nutritional value.

Keywords: *Brassica* vegetables, dietary minerals, essential nutrients, recommended daily intake

1. Introduction

Dietary minerals are important nutrients for human health and metabolism. Minerals are present in all body tissues and fluids, and they are necessary for proper physicochemical processes (Soetan et al., 2010). Depending on their requirement, minerals can be classified as either macro- or trace minerals (U. C. Gupta & S. C. Gupta, 2014). Some minerals are classified as essential, and insufficient intake of essential minerals can result in major health problems, especially for infants and pregnant women (Gernand et al., 2016). According to the World Health Organization (WHO), over 2 billion people in the world, most in developing countries, are not meeting recommended levels of vitamins and minerals, especially vitamin A, iodine, iron (Fe), and zinc (Zn) (WHO, 2007). However, mineral deficiency is not only a problem in developing countries. More than 50% of people in the US are not getting their recommended daily allowance (RDA) of magnesium (Mg) (Bliss, 2012), and Fe deficiency is still common in industrialized countries (WHO, 2001).

It has been suggested that food-based approaches offer a sustainable means of nutrient supply, and consumption of fruits and vegetables might be more effective in chronic disease prevention than the use of supplement products such as multivitamins (Hanson et al., 2011). Therefore, a significant amount of work has been done to increase mineral levels in plant-based foods. There are multiple ways to fortify minerals in foods (Dwyer et al., 2014; Gómez-Galera et al., 2010). In the food industry, certain nutrients can be added to foods during processing, such as the addition of riboflavin to refined flour and cereal products (Dwyer et al., 2014). However, this approach has a limitation in that added nutrients may affect organoleptic properties of foods, such as changes in color for iron-added foods or flavor changes when fortified with potassium (Dwyer et al., 2014). Moreover, this may not be a suitable method for developing countries since it requires a strong food processing infrastructure and increases the food prices (Gómez-Galera et al., 2010). Biofortification is another way to elevate certain nutrient levels in foods. For instance, people have worked on developing rice with higher levels of β-carotene, Zn, or Fe via breeding or genetic engineering (Dwyer et al., 2014; Gómez-Galera et al., 2010). This approach may be more sustainable and cost effective, although trade barriers and consumers' perception to genetically modified foods may impede this effort (Dwyer et al., 2014; Gómez-Galera et al., 2010). Natural fortification, which is the addition of micronutrient-rich products to another food, can be another way to increase nutrient levels. Manipulating fertilization regimes would also be a method to elevate mineral concentrations. Although there are several ways to elevate mineral concentrations in plant-based foods, many potential limitations persist with with these approaches. Understanding mineral composition of each crop provides the baselines and establishes the starting point of mineral fortification.

Brassica crops are important vegetables worldwide. According to the Food and Agriculture Organization (FAO, 2016), the total production of *Brassica* vegetables was ranked at 5th, following tomatoes, watermelons, onions, and cucumber. In the US, consumption of *Brassica* vegetables also ranks high among vegetable crops, after tomatoes and lettuce (USDA, 2012). The *Brassica* crops are considered nutritious, in part due to glucosinolates, which are known for their anticarcinogenic activity (Gupta & Srivastava, 2012; Ku et al., 2015, 2016). In addition, *Brassica* vegetables provide phenolic compounds, carotenoids, vitamins, and minerals (Kopsell & Sams, 2013; Ku & Juvik, 2013; Kim et al., 2017; Frazie et al., 2017). Although there are many studies reporting glucosinolate and carotenoid composition and their variation among various *Brassica* crops and different tissues (Liu et al., 2018), studies on essential minerals in various *Brassica* crops are relatively limited. Available reports on *Brassica* mineral composition are from different growing conditions and analytical methods (Hanson et al., 2011; Kim et al., 2016a; Kopsell & Sams, 2013). Considering the importance of *Brassica* crops in human diets, the mineral composition of *Brassica* vegetables needs to be more carefully investigated. Therefore, the objective of this study was to determine the mineral composition of edible tissues of *Brassica* vegetables. *Brassica* vegetables (N = 13) were grown at the same field under identical cultural conditions for the purpose of making direct comparisons. Multiple varieties of each crop were grown, when available, to better characterize each crop. Additionally, all crops were grown in two growing seasons, so that environmental impact on mineral content could be estimated.

2. Materials and Methods

2.1 Plant Materials

Seeds of *Brassica* crops were obtained from the USDA Germplasm Resources Information Network (GRIN) database or purchased from seed companies: Burpee (Warminster, PA) and Sakata Seeds (Morgan Hill, CA). Two experimental broccoli varieties were also included; a landrace called 'Broccolette Neri E Cespuglio (BNC)' and a doubled haploid line called 'VI-158' were provided by Dr. Mark Farnham at the USDA-ARS U.S. Vegetable Laboratory in Charleston, South Carolina. Crops and cultivars investigated in this study are listed in Table 1. Details of growing condition and harvesting methods are described by Becker (2015), and Becker et al. (2016). Seeds of all *Brassica* crops were germinated in flats in the greenhouse facility at the University of Illinois at Champaign-Urbana filled with Sunshine® LC1 professional soil mix (Sun Gro Horticulture, Vancouver, British Columbia, Canada) and were allowed to grow in the greenhouse for three weeks under a 25 °C/15 °C day/night temperature regime and 14 hr/10 hr photoperiod with supplemental lighting. After three weeks, the flats were moved to raised beds outside for acclimation to the outdoor environment before being transplanted into the field at the University of Illinois Vegetable Research Farm (40°04′38.89″ N, 88°14′26.18″ W). Transplanting was carried out 15 days after sowing. Varieties were grown in a randomized complete block design with three replicates in 2012 and 2013. All plants were supplied with supplemental water via aerial irrigation as needed in the first 30 days after transplanting. Mechanical and hand weeding was done as needed. Various weather factors were calculated using data from the Illinois State Water Survey (ISWS; http://www.isws.illinois.edu) Champaign, IL station. Days to harvest (DTH) were calculated using the transplant date as day 0. Growing Degree Days (GDD) were calculated using the formula $(\text{Temp}_{\text{max}} + \text{Temp}_{\text{min}})/2 - 7.2$ °C with a ceiling on Temp_{max} of 29.4 °C (Dufault, 1997). Average air temperature at harvest was calculated using the average air temperature data from the ISWS for the day of harvest. All other weather variables (*i.e.* total solar radiation, total precipitation, total evaporation, and total precipitation-total evaporation (estimate of soil moisture)) were aggregated from daily data from the ISWS for the period of time from transplant to harvest. After harvest, edible tissues (leaves, roots, stems, or stems/florets without soil contamination) were collected from five plants for each biological replication, flash-frozen in liquid N_2, transported on dry ice from the field to -20 °C storage, and kept until those samples could be lyophilized and ground to a powder. Freeze-drying of samples was done within two months after sample harvest.

Table 1. Cultivars and plant introduction (PI) numbers used in this study

Crop	Species	Cultivar	PI number/or source
Broccoli	*oleracea*	BNC	USDA lab
		Marathon	Commercial
		Maximo	Commercial
		Patron	Commercial
		Pirate	Commercial
		Sultan	Commercial
		VI158	USDA lab
Brussels sprout	*oleracea*	Jersey	209942
		-1/57	243050
Cabbage	*oleracea*	-	214148
		-	229747
		Snow Resisting (Vilmorin)	245023
		Jotunka	330396
		Kilis, Anatolia Local	344065
		Baylo Lykorishko	662573
Cauliflower	*oleracea*	Perfection (De Massy)	204782
Chinese broccoli	*oleracea*	Bhug-Gana	249556
		-	435900
		G28307	662520
Collard greens	*oleracea*	No. 9809	181720
Kale	*napus*	Red Russian	Commercial
		Red Winter	Commercial
	oleracea	Vates	662768
		Dwarf Blue Curled Vates	Commercial
Kohlrabi	*oleracea*	Roggli's Freiland	188610
		Weide Biata	662560
		White Vienna	662563
		Early White Vienna	662671
Komatsuna	*rapa*	Okiyo F1	662627
Mustard greens	*juncea*	Grey Leaf Root Mustard	662736
	nigra	114-0049-67	597829
Pak choi	*rapa*	Peng Pu Chang Chsai	430484
Savoy cabbage	*oleracea*	Roi de L'hiver	245022
		Late Drumhead Savoy	280068
		3800005	507856
		Cavolo Verza Grosso Delle	662660
Turnip	*rapa*	Kuuziku	633172
		Crawford	662695

2.2 Determination of Mineral Concentration

Mineral concentration was determined following the method of Kim et al. (2016a) with slight modifications. Freeze-dried powder of each sample (0.5 g) was placed in a porcelain crucible and ashed at 550 °C overnight. The ashed sample was dissolved in 5 mL of 1 N nitric acid. Then, the sample was transferred to a 25 mL volumetric flask. All crucibles were rinsed with deionized distilled water and the rinse was combined with nitric acid extract. Each sample was adjusted to 25 mL with deionized distilled water. All flasks were shaken well and the samples were filtered through a filter paper (Grade 2, Fisher Scientific, Waltham, MA) and stored at 4 °C until analysis. Mineral content was analyzed using inductively coupled plasma (Optima 2100DV, Perkin Elmer Corp., Waltham, MA). The plasma, auxiliary, and nebulizer gas flows were 15, 0.2, and 0.65 L/min, respectively, and the pump flow rate was 1.5 mL/min. Mineral concentration in the sample was determined based on a standard curve of each mineral. Additionally, the National Institute of Standards and Technology standard reference material peach leaves 1547 were used for analytical quality assurance.

Mineral concentration was calculated based on dry weight, and then converted to values based on fresh weight to calculate % recommended daily intake (RDA) or adequate intake (AI) (Kim et al., 2016b). The conversion was done based on the moisture content according to the USDA nutrient database (USDA, 2015), except for komatsuna. The moisture content information of komatsuna was not available from the USDA nutrient database, so the moisture content of pak choi was used, as it is the same species with similar morphology.

2.3 Statistical Analysis

Each sample was analyzed in triplicate (3 biological replications). Univariate analysis of variance (ANOVA) and Tukey's honest significant difference (HSD) were conducted using JMP Pro 12 (SAS Institute, Cary, NC, USA) to determine the variation in mineral composition among different crops.

3. Results and Discussion

A total of 8 minerals were analyzed from the edible tissues of the 13 *Brassica* crops grown in 2012 and 2013; the 2-year average is shown in Table 2. Pak choi, mustard green, and komatsuna were found to be generally high in minerals compared to other crops, but we also found a significant difference in mineral composition among the 13 *Brassica* crops. Additionally, a significant effect of crop and growing year, as well as their interaction on mineral concentration, was found (Table 2). Minerals Fe, Zn, P, and Mn were significantly affected by both main effects (growing year and genetic difference) and their interaction, but K was only affected by crop. In contrast, only growing season was significant for Na. Our results indicate that both genetic difference (crop) and environment have significant influence on uptake and accumulation of most minerals analyzed in this study. However, crop effect was significant for all minerals except for Na, suggesting that crop selection is very important for better mineral-based nutritional value of *Brassica* vegetables. Our result also implies that breeding can be an effective way to elevate essential minerals.

Table 2. Mineral composition of *Brassica* crops grown in 2012 and 2013

Crop	Fe	Zn	Na	K	Ca	P	Mg	Mn
	---------------------- µg/g DW ----------------------			-------------------------- mg/g DW ----------------------------				-- µg/g DW --
Broccoli (n=7)	64.70±2.72b	37.53±1.92b	152.27±32.24a	24.08±1.14b	4.45±0.64g	5.35±0.45a	2.41±0.17cd	18.12±0.99d
Brussels sprouts (n=2)	98.64±9.36ab	38.27±10.11ab	99.04±29.48a	25.18±1.53ab	3.02±0.32g	4.10±0.35a-c	1.76±0.16d	20.48±2.75cd
Cabbage (n=6)	64.21±3.19b	28.67±4.20b	102.62±17.18a	27.94±1.36ab	6.40±0.34fg	3.48±0.21bc	2.10±0.11cd	20.36±1.68d
Cauliflower (n=1)	84.78±13.38ab	43.45±10.00ab	182.97±77.20a	27.67±2.56ab	3.56±1.47fg	4.60±0.97a-c	2.58±0.09b-d	19.53±2.18cd
Chinese broccoli (n=3)	96.69±10.86ab	39.89±10.11ab	100.86±27.78a	27.19±1.75ab	10.83±1.03c-e	5.44±0.83a	2.87±0.15bc	42.02±4.36ab
Collard greens (n=1)	112.34±37.58ab	36.05±4.57ab	83.68±24.71a	32.93±7.32ab	17.22±1.21a-c	3.99±2.35a-c	3.71±0.001ab	30.92±2.36b-d
Kale (n=4)	90.33±4.72b	30.68±2.62b	154.06±31.06a	28.24±0.99ab	15.56±1.27b	2.93±0.37bc	3.86±0.28a	31.08±2.02bc
Kohlrabi (n=4)	129.34±43.11ab	21.52±4.28b	105.04±10.27a	33.96±1.89a	4.36±0.21fg	3.17±0.19bc	2.02±0.21cd	15.84±1.26d
Komatsuna (n=1)	174.73±23.27ab	17.73±17.26b	108.46±30.33a	34.94±2.09ab	18.59±3.56ab	4.09±1.33a-c	3.08±0.54^{a-d}	45.31±2.53ab
Mustard greens (n=2)	203.47±82.06a	29.10±12.46b	132.96±32.69a	29.53±4.51ab	18.86±0.89ab	3.62±1.02a-c	4.37±0.41a	52.81±9.65a
Pak choi (n=1)	175.89±70.19ab	73.41±41.08a	74.52±24.39a	37.44±0.32a	15.78±2.94a-d	5.62±2.41ab	3.05±0.26a-d	54.60±17.88a
Savoy cabbage (n=4)	81.43±4.21b	31.08±5.35b	86.64±10.31a	31.95±0.97a	7.62±0.33e-g	4.71±0.39ab	2.55±0.11b-d	23.02±1.73cd
Turnip root (n=2)	134.63±23.44ab	25.02±6.32b	178.52±105.44a	29.34±0.78ab	9.32±2.47d-f	2.09±0.28c	2.66±0.22b-d	16.52±1.16d
Turnip greens (n=2)	136.42±25.91ab	28.30±5.14b	75.55±52.23a	29.37±4.73ab	22.11±4.28a	2.35±0.19c	4.02±0.47a	42.67±4.49ab
Significance (*p* value)								
Crop (C)	0.0003	0.0017	0.5380	0.0011	<0.0001	<0.0001	<0.0001	<0.0001
Growing year (Y)	0.0232	0.0132	0.0069	0.4596	0.0863	<0.0001	0.4240	0.0355
C × Y	0.0065	0.0005	0.4830	0.2000	0.0008	0.0053	0.0002	0.0377

Note. "n" indicates the number of cultivar of each crop. Different letters indicate a significant difference among crops by Tukey's HSD at $p \leq 0.05$. Data are expressed as mean ± standard error.

We found that some minerals were significantly correlated with environmental conditions (Table 3). From the 2-year study, we found that Mn was negatively correlated with days to harvest, growing degree days, total solar radiation, total precipitation, and total evaporation, and Mg and Ca negatively correlated with all of those except for total precipitation. In contrast, P was positively correlated with all environmental variables except for days to harvest. These results indicate that environmental effect on uptake and accumulation differed among minerals. Additionally, correlations between different minerals indicate that there might be a synergistic or antagonistic effect on mineral uptake and accumulation (Rietra et al., 2015).

Table 3. Pearson's correlation between mineral concentration and environmental condition from *Brassica* crops grown in 2012 and 2013 (n = 80)

	Fe	Mn	Mg	Ca	K	Na	P	Zn	DTH	GDD	TSR	TP
Mn	0.48***											
Mg	0.41**	0.60***										
Ca	0.39**	0.71***	0.81***									
K	0.18	0.23*	0.14	0.11								
Na	-0.05	-0.04	-0.04	-0.16	-0.29**							
P	-0.09	0.01	-0.07	-0.27*	0.13	-0.14						
Zn	0.03	0.26*	0.04	-0.05	-0.14	0.30**	0.35**					
DTH	-0.12	-0.42***	-0.37**	-0.41***	-0.14	-0.03	0.22	-0.04				
GDD	-0.18	-0.46***	-0.40**	-0.46***	-0.23*	-0.02	0.33**	0.004	0.92***			
TSR	-0.14	-0.45***	-0.37**	-0.42***	-0.18	-0.06	0.30**	-0.02	0.97***	0.97***		
TP	-0.03	-0.24*	-0.10	-0.10	-0.01	-0.25*	0.27*	-0.08	0.72***	0.59***	0.74***	
TE	-0.11	-0.43***	-0.30**	-0.35**	-0.17	-0.13	0.34**	-0.03	0.91***	0.93***	0.97***	0.83***

Note. DTH, days to harvest; GDD, growing degree days; TSR, total solar radiation; TP, total precipitation; TE, total evaporation. Askterisks *, **, and *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively.

The crops investigated in this study were from several *Brassica* species; *juncea*, *napus*, *nigra*, *oleracea*, and *rapa*. Similar to a significant variation among crops discussed earlier, we also found that mineral composition differed among species (Table 4). Among five species analyzed in this study, *juncea* and *nigra* were, in general, higher in mineral concentration compared to other species. This result is in agreement with the observation that mustard greens were generally high in minerals (Table 2), since the mustards surveyed belong to either *juncea* or *nigra*. Although pak choi was also high in dietary minerals, other crops belonging to the species *rapa*, such as turnip, were comparatively lower than mustard. Species effect was significant for Fe, Ca, Mg, and Mn whereas Zn and P were more affected by growing year. However, we had fewer cultivars for some crops, such as cauliflower and komatsuna, and therefore, increased number of cultivars will need to be evaluated for those crops. Additionally, we found that mineral composition differed among tissues (Table 5). Leaf tissues were the highest in Ca, Mg, and Mn while stems were the highest in K. The level of P was the highest in stems/florets. Tissue effect was significant for minerals K, Ca, P, Mg, and Mn but Fe, Zn, and Na were more greatly affected by growing year. The result of this study indicates that mineral composition differs among *Brassica* crops as well as species and edible tissues. Although there are a few studies reporting variation in secondary metabolites in different tissues of *Brassica* crops, to our knowledge, information of mineral composition in different edible tissues of *Brassica* crops is relatively limited.

Table 4. Mineral composition of five *Brassica* species grown in 2012 and 2013

Species	Fe	Zn	Na	K	Ca	P	Mg	Mn
	---------------------- μg/g DW	--------------------		----------------------- mg/g DW	-------------------------			-- μg/g DW --
juncea (n=1)	99.51±8.83bc	28.26±8.08a	156.11±60.72a	26.42±6.55a	19.57±0.87a	2.63±0.33a	4.47±0.19a	38.09±9.10a-c
napus (n=2)	87.06±6.90bc	33.81±1.71a	202.75±41.80a	27.01±0.67a	12.95±0.64ab	3.41±0.59a	3.82±0.53a	29.51±2.56bc
nigra (n=1)	307.43±136.79a	29.94±29.42a	109.81±40.66a	32.64±7.72a	18.16±1.72a	4.61±2.05a	4.28±0.98a	67.52±6.57a
oleracea (n=30)	85.10±6.43c	32.53±1.90a	114.21±9.84a	28.38±0.70a	7.10±0.58b	4.26±0.20a	2.47±0.09b	22.91±1.21c
rapa (n=6)	148.79±15.03b	32.96±8.19a	115.19±38.43a	31.63±1.77a	16.20±2.26a	3.10±0.53a	3.25±0.24a	36.38±5.13b
Significance (*p* value)								
Species (S)	<0.0001	0.9951	0.2913	0.2654	<0.0001	0.0915	<0.0001	<0.0001
Growing year (Y)	0.0987	0.0310	0.2442	0.9349	0.6530	0.0166	0.9753	0.0842
S × Y	0.0002	0.2976	0.3853	0.1017	0.3351	0.6719	0.0686	0.6527

Note. "n" indicates the number of cultivars of all crops analyzed for each species: *juncea* includes mustard greens; *napus* includes kale; *nigra* includes mustard greens; *oleracea* includes broccoli, Chinese broccoli, cauliflower, cabbage, Brussels sprout, kohlrabi, savoy cabbage, kale, and collard green; *rapa* includes komatsuna, pak choi, and turnip. For the species *rapa*, both leaves and roots were counted. Different letters indicate a significant difference among crops by Tukey's HSD at $p \leq 0.05$. Data are expressed as mean ± standard error.

Table 5. Mineral composition in different tissues of *Brassica* crops grown in 2012 and 2013

Tissue	Fe	Zn	Na	K	Ca	P	Mg	Mn
	---------------------- µg/g DW		--------------------	-------------------------- mg/g DW			------------------------	-- µg/g DW --
Leaf (n=23)	104.88±9.74a	32.07±2.78a	106.97±9.59a	29.65±0.82a	11.77±1.01a	3.71±0.21b	2.97±0.15a	30.49±2.10a
Root (n=2)	134.63±23.44a	25.02±6.32a	178.52±105.44a	29.34±0.78ab	9.32±2.47ab	2.09±0.28b	2.66±0.22ab	16.52±1.16ab
Stem (n=4)	129.34±43.11a	21.52±4.28a	105.04±10.27a	33.96±1.89a	4.36±0.21b	3.17±0.19b	2.02±0.21b	15.84±1.26b
Stem/floret (n=11)	75.25±4.59a	38.71±2.95a	141.04±22.75a	25.25±0.92b	6.11±0.80b	5.31±0.36a	2.55±0.12ab	24.77±2.64ab
Significance (*p* value)								
Tissue (T)	0.0737	0.0625	0.1473	0.0006	0.0003	<0.0001	0.0269	0.0078
Growing year (Y)	0.0037	0.0157	0.0004	0.7794	0.2032	0.1199	0.0876	0.2514
T × Y	0.0088	0.6586	0.0663	0.6909	0.6108	0.1286	0.3973	0.9936

Note. "n" indicates the number of cultivar of each tissue analyzed. Different letters indicate a significant difference among crops by Tukey's HSD at $p \leq 0.05$. Data are expressed as mean ± standard error.

Mineral concentration is presented based on dry weight. This representation is useful for comparing mineral concentration in different leafy vegetables and crops, including *Brassica* crops, though they are often consumed fresh or with slight cooking, where most of the water remains in the tissue. Therefore, a moisture content of each crop is important in assessing the level of essential minerals that people can obtain. For this reason, we calculated %RDA/AI of each mineral for adults after converting to fresh weight-based values using the moisture content of each crop from the USDA nutrient database (USDA, 2015). For komatsuna, where the information is not available on the USDA nutrient database, we calculated %RDA/AI assuming the moisture content was 95% (value was adapted from pak choi which is the same species).

Two minerals which are commonly of concern in vegetarian diets, partially due to relatively low bioavailability and thus potential inadequate nutritional status, are Fe and Zn (Hunt, 2003). Because of the low bioavailability of Fe in plant sources compared to meat, it is recommended to increase consumption of foods containing this mineral, especially for a vegetarian diet (Hunt, 2003). According to WHO, there are approximately one billion people worldwide that are anemic due to Fe deficiency (Abbaspour et al., 2014). Zn is an essential nutrient for basic cellular functions and the immune system, and Zn deficiency can occur with aging and diseases including diabetes mellitus or rheumatoid arthritis (Klouberta & Rink, 2015). Fresh *Brassica* vegetables (100 g) shown in Table 2 can provide 2.9-22.9 and 1.6-6.7% of RDA for Fe and Zn, respectively (Table 6). Among analyzed vegetables, mustard greens and Brussels sprouts were the best sources of Fe and Zn, respectively, based on %RDA value.

Table 6. The %RDA or %AI of each mineral for adults (men-women) provided by different *Brassica* vegetables

Crop	Fe	Zn	Na	K	Ca	P	Mg	Mn
Broccoli (n=7)	4.0-8.9	3.8-5.2	0.11-0.14	5.6	4.1-4.9	8.4	6.3-8.3	8.7-11.1
Brussels sprouts (n=2)	7.7-17.3	4.9-6.7	0.09-0.12	7.5	3.5-4.2	8.2	5.9-7.7	12.5-15.9
Cabbage (n=6)	2.9-6.4	2.1-2.9	0.05-0.07	4.8	4.3-5.1	4.0	4.0-5.3	7.1-9.0
Cauliflower (n=1)	3.8-8.5	3.2-4.3	0.10-0.12	4.7	2.4-2.8	5.3	4.9-6.5	6.8-8.7
Chinese broccoli (n=3)	3.8-8.5	2.5-3.5	0.05-0.06	4.0	6.3-7.6	5.4	4.8-6.3	12.8-16.3
Collard greens (n=1)	6.2-14.0	3.3-4.5	0.06-0.07	7.0	14.4-17.2	5.7	8.8-11.6	13.4-17.2
Kale (n=4)	8.0-18.1	4.5-6.1	0.16-0.21	9.6	20.7-24.9	6.7	14.7-19.3	21.6-27.6
Kohlrabi (n=4)	6.5-14.6	1.8-2.4	0.06-0.08	6.5	3.3-3.9	4.1	4.3-5.7	6.2-7.9
Komatsuna (n=1)	4.9-10.9	0.8-1.1	0.04-0.05	3.7	7.7-9.3	2.9	3.7-4.8	9.9-12.6
Mustard greens (n=2)	10.2-22.9	2.4-3.3	0.08-0.10	5.7	14.1-17.0	4.7	9.4-12.3	20.7-26.4
Pak choi (n=1)	4.9-11.0	3.3-4.6	0.02-0.03	4.0	6.6-7.9	4.0	3.6-4.8	11.9-15.2
Savoy cabbage (n=4)	4.1-9.2	2.5-3.5	0.05-0.06	6.1	5.7-6.9	6.1	5.5-7.2	9.0-11.5
Turnip greens (n=2)	7.6-17.1	2.6-3.5	0.05-0.06	6.2	18.4-22.1	3.4	9.6-12.6	18.6-23.7
Turnip (n=2)	6.0-13.5	1.8-2.5	0.10-0.12	5.0	6.2-7.5	2.4	5.1-6.7	5.7-7.3

Note. "n" indicates the number of variety of each crop. %RDA/AI was calculated as the relative ratio of mineral concentration in 100 g of fresh material to the minimum and maximum recommended intake level of each mineral for adults (> 19 y). Values for Na, K, and Mn were calculated based on AI, not RDA.

It is generally accepted that reduced consumption of Na and increased intake of K lowers the risk of hypertension (Lopez-Jaramillo et al., 2015; Sacks et al., 1998). In addition to its influence on blood pressure, K deficiency can result in impaired neuromuscular functions of skeletal, smooth, and cardiac muscle as well as muscular weakness, paralysis, and mental confusion (Soetan et al., 2010). In the US, the average intake of K is low for all ages and both genders (Ervin et al., 2004). Although Na is an essential mineral, worldwide Na intake is very often much higher than the recommended level (Brown et al., 2009). Fresh *Brassica* vegetables (100 g) investigated in this study provide less than 0.3% of Na and 4.0-9.6% of AI of K depending on the crop, and kale was found to provide the highest level of Na and K among the investigated crops (Table 6).

Minerals important for bone health include Ca, P, Mg, and Mn. Although increased intake is recommended, Ca intake in the US is low for almost all ages and both genders (Ervin et al., 2004). High levels of oxalate in some leafy vegetables, such as spinach, lowers bioavailability of Ca, but Santamaria et al. (1999) reported that oxalate was either not detected or present at very low levels in *Brassica* vegetables including broccoli, broccoli raab, cabbage, cauliflower, kohlrabi, radish, rocket, and savoy cabbage. In addition to its role as a constituent of bones and teeth, P is a component of adenosine triphosphate, phosphorylated metabolic intermediates, and nucleic acids, playing an important role in essential metabolisms (Soetan et al., 2010). Mg is an important component of a number of enzyme systems, and Mg deficiency may result in depression and related mental health problems (U. C. Gupta & S. C. Gupta, 2014). Mn also plays a role in a few enzyme systems and metabolisms in addition to its role in bone health (Soetan et al., 2010). The *Brassica* vegetables (100 g) analyzed in this study provide Ca, P, Mg, and Mn at 2.4-24.9, 2.4-8.4, 3.6-19.3, and 5.7-27.6% of RDA/AI, respectively, when consumed fresh (Table 6). Kale was the highest in %RDA/AI for Ca, Mg, and Mn while broccoli provided the highest level of P based on %RDA. In the present study, we focused on raw materials and their variation within crops. But there are other factors affecting the mineral concentration of these crops, such as cooking including the loss in cooking water (López-Berenguer et al., 2007). Therefore, these factors will also need to be considered to determine nutritional value based on mineral content.

4. Conclusions

Our results of mineral concentration showed that pak choi generally had the highest content of most minerals on a dry weight basis. However, %RDA/AI calculated using fresh weight-based concentration revealed that kale was the richest source of minerals, in particular, Ca, Mg, and Mn, providing up to 24.9, 19.3, and 27.6% of RDA or AI, respectively (based on 100 g fresh weight). To our knowledge, this is the first report comparing mineral composition and %RDA/AI of various *Brassica* crops grown under the same growing condition. The result of this study provides the understanding of the mineral composition of various *Brassica* vegetables and that the moisture content may greatly affect the mineral level in fresh vegetables. The results of this study will also help consumers' choice so that they can select vegetables that provide a higher level of dietary minerals needed in their diet. Additionally, our results suggest that replacing a crop with poor mineral concentration from a person's normal diet with a crop containing a higher level of minerals may be an effective strategy for elevating mineral intake and could be a part of a food-based solution for those with mineral deficiencies.

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