Original Research Article

Microgreens of Brassicaceae: Mineral Composition and Content of 30 Varieties

Zhenlei Xiao[1, 2], Eton E. Codling[3], Yaguang Luo[1*], Xiangwu Nou[4], Gene E. Lester[1], Qin Wang[2]

[1] Food Quality Laboratory, USDA Agricultural Research Service, Beltsville, MD 20705

[2] Department of Nutrition and Food Science, University of Maryland, College Park, MD 20740

[3] Crop Systems and Global Change Laboratory, USDA Agricultural Research Service, Beltsville, MD 20705

[4] Environmental Microbial and Food Safety Laboratory, U.S. Department of Agriculture, Agricultural Research Service, Beltsville, MD 20705, United States

* Corresponding author at: Food Quality Laboratory, USDA Agricultural Research Service, Beltsville, MD 20705. Tel: 301-504-6186, Fax: 301-504-5107. E-mail address: yaguang.luo@ars.usda.gov

Abstract:

The mineral element composition was analyzed for 30 varieties of microgreens, representing 10 species within 6 genera of the Brassicaceae family. Brassicaceae microgreens were assayed for concentrations of macroelements, including calcium (Ca), magnesium (Mg), phosphorous (P), sodium (Na), potassium (K), and of microelements, including copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn). Determinations of mineral elements in microgreen samples were performed using an inductively coupled plasma optical emission spectrophotometer (ICP OES). Potassium was the most abundant macroelement ranging from 176-387 mg/100 g fresh weight (FW), followed by P (52-86 mg/100g FW), Ca (28-66 mg/100g FW), Mg (28-66 mg/100g FW), and Na) 19-68 mg/100g FW. Among the microelements, Fe tended to be most abundant (0.47-0.84 mg/100g FW), followed by Zn (0.22-0.51 mg/100g FW), Mn (0.17-0.48 mg/100g FW), and Cu (0.041-0.13 mg/100g FW). Based upon the analysis of 30 varieties, the results demonstrate that microgreens are good sources of both macroelements (K and Ca) and microelements (Fe and Zn.). Consumption of microgreens could be a health-promoting strategy to meet dietary reference intake requirements for essential elements beneficial to human health.

Keywords: Microgreens, Brassicaceae, food composition, macroelements, microelements, ICP OES, hierarchical cluster analysis

1. Introduction

Essential mineral elements are a class of nutritionally important nutrients for human health, which are best obtained from dietary sources (Martinez-Ballesta et al., 2010). They are divided into two groups: the macroelements (such as Ca, Mg, P, K, and Na) and microelements (also known as trace elements, such as Fe, Zn, Cu, and Mn), both of which play crucial roles in various biological processes for both plants (Maathuis, 2009) and the human beings (Scherz and Kirchhoff, 2006). For humans, deficiencies in these elements can cause metabolic disorders and organ damage, leading to acute and chronic diseases and even death (dos Santos et al., 2013). For example, the importance of calcium and vitamin D on bone mass and bone metabolism is well known and studies have shown that adequate intake of magnesium and potassium from a healthy diet could contribute to optimize bone health, while deficiencies in these elements can cause dwarfism in children and osteoporosis in the elderly (Macdonald, et al., 2005; Nieves, 2005). Similarly, iron is vital to biological functions, including respiration, energy production, DNA synthesis, and cell proliferation (Hentze et al., 2010). Inadequate intake of iron is the leading cause of anemia, which remains a global health issue, affecting people of all ages (Camaschella, 2015). Adequate dietary intake of mineral elements is necessary for human health and wellness. Unfortunately, mineral malnutrition is still a common problem worldwide and considered one of the most important global challenges for human nutrition (Pinto et al., 2015).

Fruits and vegetables are rich sources of vitamins, minerals, dietary fibers and other phytochemicals, which play important roles in human nutrition. Epidemiological and clinical studies have indicated an inverse association between increased consumption of fruits and vegetable and the occurrence of certain chronic diseases, such as cardiovascular diseases, cancers

56 and some degenerative diseases, such as osteoporosis and cataracts (Boeing et al., 2012; Hussain
57 et al., 2014).
58 Microgreens are an emerging class of specialty fresh produce, which have gained increasing
59 popularity with chefs and consumers in recent years. They are young seedlings of vegetables and
60 herbs, harvested when cotyledons are fully developed and the first pair of true leaves are
61 emerging or partially expanded. Previous studies have shown that microgreens are good sources
62 of vitamins and other phytonutrients, such as carotenoids and polyphenols (Sun et al., 2013; Xiao
63 et al., 2012) Owing to their nutrient-dense properties, microgreens have recently attracted
64 considerable attention from researchers of human nutrition, public health professionals and
65 educators, and health-conscious consumers. The mineral composition of microgreens has rarely
66 been reported. Kopsell and Sams (2013) investigated the changes in shoot tissue pigments,
67 glucosinolates and mineral elements of broccoli microgreens exposed to short-duration bluelight
68 from light-emitting diodes. Kou et al. (2014) found that pre-harvest application of calcium
69 improved post-harvest quality and shelflife of broccoli microgreens, and compared calcium
70 contents in treated and untreated samples. Pinto et al. (2015) and colleagues compared the
71 mineral profiles and nitrate contents of lettuce microgreen and mature lettuces. However, all of
72 these studies focused on an individual microgreen variety and there has not been a
73 comprehensive study on the mineral profiles of multiple varieties of microgreens.
74 Brassica vegetables (such as broccoli, cabbage, and radish) are well recognized and valued for
75 containing significant amounts of cancer-fighting glucosinoates as well as carotenoid
76 phytochemicals, vitamins and mineral elements (Kopsell and Sams, 2013).. The presence and
77 abundance of essential mineral elements is an important criterion for the assessment of

78 nutritional quality and influence on human health and have value for both consumers and public
79 health professionals.
80 This study reports mineral composition data including calcium (Ca), copper (Cu), iron (Fe),
81 potassium (K), sodium (Na), magnesium (Mg), manganese (Mn), phosphorous (P), and zinc (Zn),
82 as well as heavy metal toxins cadmium (Cd) and lead (Pb) for 30 of the most common
83 commercial varieties of Brassica microgreens using inductively coupled plasma optical emission
84 spectrometry (ICP OES). The data were evaluated using the multivariant analysis technique, as
85 well as by hierarchical cluster analysis (HCA).

86 **2. Materials and methods**

87 **2.1. Sample collection and preparation**

88 In total, 30 varieties of microgreens representing 6 Brassicaceae genera (**Table 1**) were
89 obtained from Fresh Origins Farm (San Marcos, CA, USA), between March to May 2014. All
90 the microgreens were grown in peat moss substrata in unheated greenhouses, under ambient light
91 and temperature. Microgreen samples were harvested without seed coats or roots. Samples were
92 immediately packed in clamshell containers and shipped overnight in a cardboard box filled with
93 insulating foam and ice packs to main a cold temperature. Upon receiving product at the USDA-
94 ARS Beltsville Agricultural Research Center (Beltsville, MD, USA), microgreen samples were
95 inspected and any individual microgreen with visible defect was discarded. Fifty grams of each
96 sample was collected and rinsed three times under tap water followed by a single deionized
97 water rinse to remove any surface residue. After washing, samples were flash frozen in liquid
98 nitrogen and lyophilized for 48-72 h. The commercial names, scientific names and growth period
99 (days) of the 30 varieties of Brassicaceae microgreens are listed in **Table 1.**

100 **2.2. Reagents and Standards**

101 All chemical reagents used in this study were of analytical grade and obtained from Thermo
102 Fisher Scientific Inc. (Frederick, MD, USA). Deionized water was used to prepare all solutions.
103 Standard stock solutions were prepared in 2% (v/v) nitric acid (HNO_3) with the concentration of
104 10,000 mg/L for elements Ca and K, and 1,000 mg/L for elements Mg, P, Na, Fe, Zn, Cu, and
105 Mn, respectively. SPEX CertiPrep (Metuchen, NJ, USA) certified reference materials were used
106 to prepare working standard solutions by diluting with 1 mol/L nitric acid. All laboratory
107 glassware used were decontaminated by submerging them in a sulfuric acid solution (10%, v/v)
108 for 24 h, and then rinsed with deionized water three times before use.

109 **2.3. Sample digestion**

110 The lyophilized microgreen tissue (1.5-2.0g) was ashed in a muffle furnace at 480 °C for 16 h.
111 The ash was further digested using 2 mL concentrated nitric acid (HNO_3, 65%, v/v) on a hot
112 plate. After drying, 10 mL of 3 mol/L hydrochloric acid (HCl) was added to each sample and
113 allowed to flux for 2 h. Subsequently, the digest was filtered using Whatman #40 filter paper and
114 the filtrate wasdiluted to a volume of 25 mL with 0.1 mol/L HCl (AOAC, 1984).

115 **2.4. Sample Analysis**

116 Concentrations of Ca, Mg K, P, Na Cu, Fe Mn, and Zn in the solutions of the digested samples
117 were determined using a Perkin-Elmer DV 4300 inductively coupled plasma optical emission
118 spectrophotometer (ICP OES, Norwalk, CT, USA) with axial viewing and a segmented-array
119 detector (SCD). A Cyclone spray chamber and a Mira-mist nebulizer were also utilized.
120 Scandium (15µg/L) was used as internal standard for all determinations. The instrumental
121 parameters are shown in **Table 2.**

122 The accuracy of the method was evaluated using a certified reference material: spinach leaves
123 (NIST 1570a), National Institute of Standards and Technology, Gaithersburg, MD, USA). The

124 certified material was digested using the same procedure employed for the microgreen samples.
125 For quality assurance, one blank and one spinach leaf standard were included for every 20
126 samples analyzed. The analytical results obtained in this study were in agreement with the
127 certified values (expressed as dry weight). The limit of detection (LOD) and limit of
128 quantification (LOQ) were both calculated by a background equivalent concentration (BEC) test
129 using the following formulas: LOD = 3 * BEC * relative standard deviation of 10 blanks (RSD_0);
130 LOQ = 10 * BEC * relative standard deviation of 10 blanks (RSD_0).

131 **2.6. Statistical analysis**

132 In this study, mineral composition analyses were performed on three replicate samples, which
133 were harvested from three different locations in the same greenhouse on the same day. Mineral
134 element concentrations were calculated on a fresh weight basis and data were expressed as mean
135 ± standard error. The differences among mineral contents of the samples were tested by one-way
136 analysis of variance (ANOVA) using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Mean
137 comparisons were evaluated using Tukey's honestly significant difference (HSD) test with P
138 value of 0.05 (n = 3).

139 In order to extrapolate the similarities and the dissimilarities among the 10 microgreen species
140 in mineral composition, hierarchical cluster analysis (Pontieri et al. 2015) was performed on the
141 normalized data sets (the total amounts of 9 mineral components in respective varieties of
142 microgreens) using PROC CLUSTER (SAS version 9.3, SAS Institute Inc, Cary, NC, USA).
143 Two clustering methods were used, namely, average-linkage method and Ward's minimum
144 variance method. Dendrograms were produced based on the HCA results using PROC TREE
145 (SAS version 9.3).

146 **3. Results and discussion**

147 **3.1. Determination of mineral element composition of microgreens**

148 The accuracy of the method was evaluated using spinach leaves NIST 1570a (Table 3A).
149 Instrumental LOD (-0.004-20.039 mg/kg dry weight (DW) and LOQ (-0.013-66.797 mg/kg (DW)
150 for each element analyses were shown in Table 3B.

151 Mineral macro- and microelements , including calcium (Ca), copper (Cu), iron (Fe),
152 potassium (K), sodium (Na), magnesium (Mg), manganese (Mn), phosphorous (P), and zinc (Zn)
153 were determined in 30 varieties of Brassicaceae microgreen samples (**Tables 4** and **5**). The
154 concentrations of macroelements in microgreens samples varied with species and varieties
155 (Table 4). The most abundant macroelement in all the microgreen samples was K, followed by P,
156 Ca, Mg and Na. Potassium was found in highest concentration in Wasabi microgreens (387
157 mg/100 g FW), while the lowest values of K was in Radish Daikon microgreens (176 mg/100 g
158 FW). The P concentration of samples analyzed in this study ranged from 52 mg/100 g FW
159 (Mustard Red microgreens) to 86 mg/100 g FW (Radish Daikon microgreens). Ca concentration
160 in the 30 microgreen samples varied, with the highest value in samples of Cabbage Savoy
161 microgreens (98 mg/100 g FW) and the lowest in Peppercress microgreens (39 mg/100 g FW).
162 The concentration of Mg ranged from 28-66 mg/100 g FW with the highest value in samples of
163 Cauliflower microgreens (66 mg/100 g FW) and the lowest in Mustard Red microgreens (28
164 mg/100 g FW). Sodium concentration was highest in Watercress microgreens (68 mg/100 g FW)
165 and lowest in Radish Ruby microgreens (19 mg/100 g FW). Overall, the macroelements (Ca, Mg,
166 P, K, and Na) represented 99.7 ± 0.0% of the mineral element content determined and potassium
167 was the principal element found in all samples (57.1 ± 1.4%). Phosphorus was the second most
168 abundant element in approximately 66% of the samples. Ca concentration exceeded that of P in
169 the remaining 33% of samples.

Microelements in the 30 microgreen varieties also showed significant variation among different varieties (Table 5) and the microelement concentrations of Fe, Zn, Cu and Mn ranged from 0.47-0.84 mg/100 g FW, 0.22-0.51 mg/100 g FW, 0.04-0.13 mg/100 g FW, and 0.17-0.48 mg/100 g FW, respectively. In most cases, Fe content was approximately 50% of the total microelement content determined (45.1 ± 0.7%) and was highest in Rapini microgreens, followed by Kohlrabi Purple and Komatsuna Red microgreens. The highest concentrations of Zn and Cu were also found in Rapini microgreens. Additionally, Upland Cress microgreens exhibited the highest concentration of Mn. At the other extreme, Kale Red, Mustard Red, Cabbage Chinese and Radish Ruby microgreens showed the lowest values of Fe, Zn, Cu and Mn, respectively. In addition, we assayed the microgreen samples for the toxic heavy metals (Cd and Pb). Neither Cd nor Pb were detected, (the limits of detection were 0.010 and 0.015 mg/kg, respectively), indicating the insignificance of concerns over heavy metals in microgreens grown and harvested under typical commercial production conditions.

It is worth noting that Rapini microgreens contained the highest amounts of Fe, Zn and Cu, as well as very high concentrations of Ca, Mg, P, K, Na, and Mn. In addition, the samples of Kohlrabi Purple microgreens also showed very high values of all microelements and macroelements. In contrast, the Mustard Red microgreen samples were observed to have the lowest contents of Mg, P and Zn, as well as relatively low amounts of Ca, K, Fe and Cu. Radish Ruby microgreens contained considerable amounts of P and Zn, but low amounts of Na, Mn, Ca, K, Fe and Cu. Among the 30 varieties of microgreen samples, Rapini and Radish Ruby microgreens represented the varieties with the highest and lowest overall mineral element contents (649 ± 6 mg/100 g FW and 398 ± 13 mg/100 g FW), respectively.

192 Little published data is available on mineral composition of microgreens, thus limiting data
193 comparison. In general, the mineral element contents of the tested microgreen samples showed
194 very similar profiles described for more mature plants in most of the Brassicaceae family,
195 including broccoli, cauliflower, watercress, kale, cabbage and radish assayed in previous studies
196 (Kawashima and Valente Soares, 2003; Sanchez-Castillo et al., 1998; Santos et al., 2014; Souzan
197 and El-Aal, 2007). Santos et al. (2014) quantified nine elements (P, K, Ca, Mg, Na, Fe, Mn, Zn
198 and Cu) in ready-to-eat "baby leaf" vegetables. The results obtained in our study forwatercress
199 microgreens are in good agreement with the values for "baby leaf" watercress reported by those
200 authors. A recently published study by Pinto et al. (2015) compared the mineral element
201 compositions of lettuce microgreens and mature lettuce grown under the same conditions and
202 showed that lettuce microgreens possessed higher contents of most elements (Ca, Mg, Fe, Mn,
203 Zn, Se and Mo) than the mature lettuces.
204 Previous studies (Khader and Rama, 2003; Santos et al., 2014) demonstrated that in addition to
205 the intrinsic factors of microgreen species and varieties, the major sources of variability in
206 nutrient composition and mineral content were extrinsic factors, such as soil composition, water
207 availability, application of fertilizers, climatic conditions, seasonal variations, and maturity
208 stages. In our study, plant maturity stage (i.e. growth period in days) would be the main extrinsic
209 factor which affected the mineral content since all other extrinsic factors aforementioned were
210 held constant by the grower.
211 Plant cells tend to accumulate K for essential functions such as cellular metabolism and
212 stomatal opening and exclude Na, resulting in a high K/Na ratio in plant tissues (Flyman and
213 Afolayan, 2008; Khader and Rama, 2003). Phosphorous and Zn assimilation are correlated with
214 the initial stages of plant development (e.g., the synthesis of new protoplasm), whereas Ca and

215 Fe are usually accumulated at more mature stages of growth or in more mature parts of plants.
216 The results obtained from the 30 microgreen varieties tested in this study demonstrated that K is
217 the principle mineral accumulated in all samples with a variable K/Na ratio ranging from 3.1 to
218 11.6. Phosphorous concentrations were higher than Ca concentrations in most of samples (66%)
219 and Fe was always higher than Zn levels. These trends were also found in a previous study on
220 baby greens (Santos et al., 2014).

221 **3.2. Hierarchical cluster analysis in 10 genera**

222 This study profiled mineral element components of microgreen samples in 30 varieties
223 representing 10 species in 6 genera of the Brassicaceae family. Our data demonstrate that
224 variation was present not only in overall mineral element contents among the 30 microgreen
225 varieties, but also in the concentrations of the different mineral elements. We utilized two
226 hierarchical cluster analysis methods (average-linkage distance between two clusters and Ward's
227 minimum variance in semi-partial R-square) to evaluate whether these trends were consistent
228 across the 10 species examined (Fig. 1a and Fig. 1b, respectively). Both hierarchical cluster
229 analyses provided the same prediction, showing that the 10 microgreen genera were classified
230 into two groups. One group containing three species (*Raphanus sativus, Brassica oleracea*, and
231 *Brassica napus)* was distinct from the other group represented by seven species (*Barbarea verna,*
232 *Nastritum officinale, Brassica rapa, Lepidium bornariense, Brassica juncea, Eruca sativa,* and
233 *Brassica narinosa*). The latter group was represented by one cluster with *Barbarea verna* and
234 *Nastritum officinale* and a second cluster comprised of *Brassica rapa, Lepidium bornariense,*
235 *Brassica juncea, Eruca sativa,* and *Brassica narinosa*. Cluster analysis groupings based on
236 mineral element content were not an informative indicator of genus relatedness.

237 **4. Conclusions**

238 The determination of mineral elements by ICP OES provided a satisfactory quantification of
239 Ca, Mg, P, K, Na, Fe, Zn, Mn, and Cu in 30 different varieties of microgreens in the
240 Brassicaceae family. Samples were analyzed for the toxic heavy metals Cd and Pb, as well and
241 neither of them was detected. The results of this study revealed that Brassicaceae microgreens
242 are a good source of both macroelements (e.g., K and Ca) and microelements (e.g., Fe and Zn) in
243 a balanced human diet and the consumption of microgreens could be a health-promoting strategy
244 to meet the requirement of element dietary reference intakes, particularly for children.

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321

Figure captions

Fig. 1. The average-linkage on the normalized data sets of mineral components by means of the Hierarchical method (a) and Ward's minimum variance using Euclidean distance as measure of similarity among species (b). A = *Brassica narinosa*; E = *Eruca sativa*; J = *Brassica juncea*; L = *Lepidium bonariense*; N = *Brassica napus*; O = *Brassica oleracea*; P = *Nasturtium officinale*; R = *Brassica rapa*; S = *Raphanus sativus*; V = *Barbarea verna*.

Fig. 1.

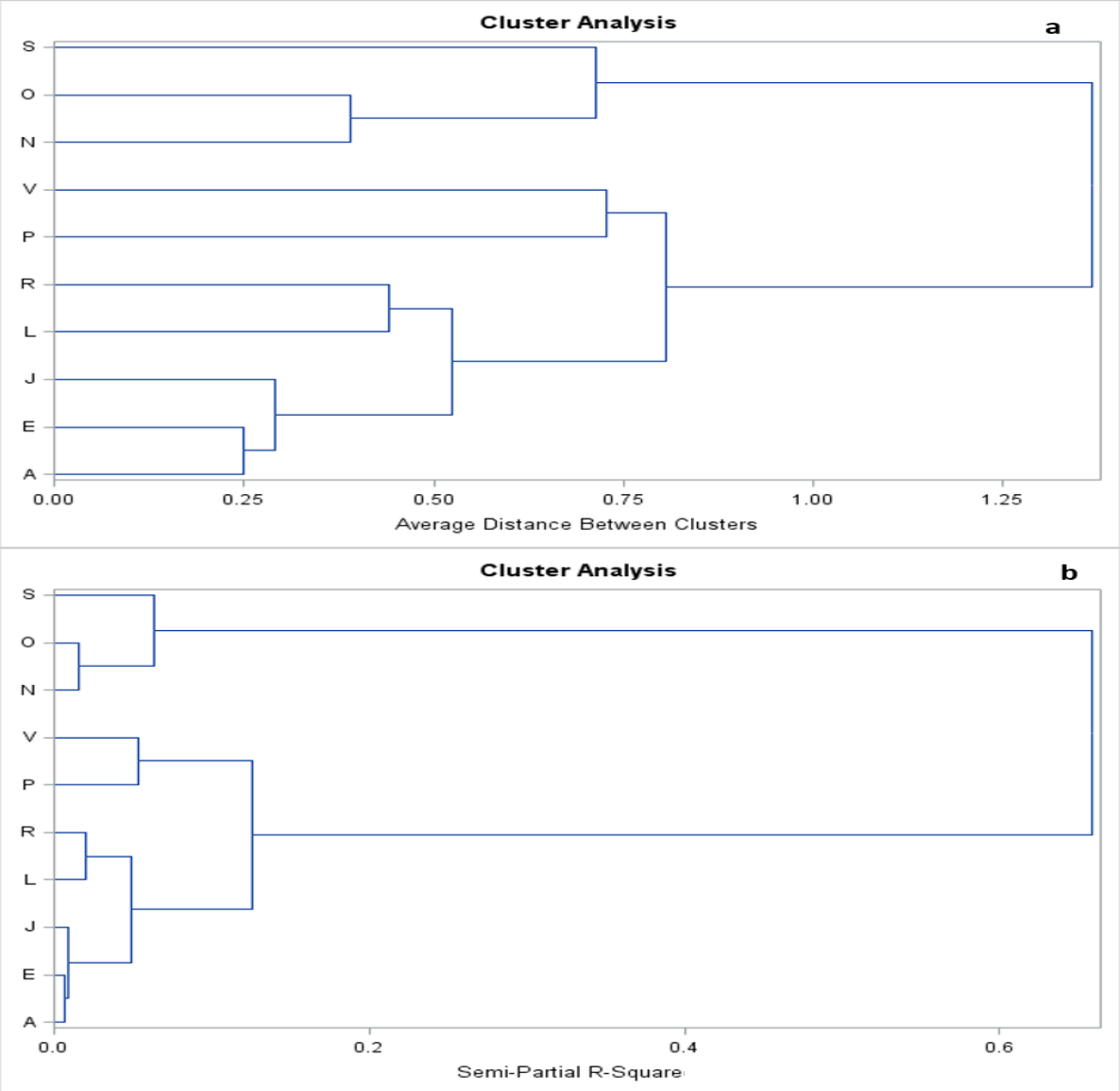

Table 1. Product information of 30 commercially grown microgreens in Brassicaceae family assayed in this study.

Commercial name	Scientific name (genus and species)	Growth length (day)	Dry weight percentage (%)
Arugula	*Eruca sativa Mill.*	7	6.4 ± 0.1
Broccoli	*Brassica oleracea L. var. italica*	9	7.9 ± 0.1
Brussel sprouts	*Brassica oleracea L. var. Gemmifera*	9	6.5 ± 0.1
Cabbage Chinese	*Brassica rapa L. var. pekinensis*	6	5.2 ± 0.0
Cabbage green	*Brassica oleracea L. var. capitata f. alba*	9	6.1 ± 0.0
Cabbage red	*Brassica oleracea L. var. capitata f. rubra*	7	5.9 ± 0.0
Cabbage savoy	*Brassica oleracea L. var. capitata f. sabauda*	9	7.0 ± 0.0
Cauliflower	*Brassica oleracea L. var. botrytis*	9	6.8 ± 0.0
Collard	*Brassica oleracea L. var. viridis*	10	7.0 ± 0.2
Kale Chinese	*Brassica oleracea L. var. alboglabra*	8	7.5 ± 0.0
Kale red	*Brassica oleracea L. var. acephala*	9	5.6 ± 0.1
Kale Tucsan	*Brassica oleracea L. var. acephala*	9	7.5 ± 0.1
Kohlrabi purple	*Brassica oleracea L. var. gongylodes*	8	8.0 ± 0.4
Komatsuna red	*Brassica rapa L. var. perviridis*	8	6.7 ± 0.2
Mizuna	*Brassica rapa L. var. nipposinica*	8	5.5 ± 0.0
Mustard Dijon	*Brassica juncea (L.) Czern.*	9	6.1 ± 0.1
Mustard red	*Brassica juncea (L.) Czern.*	9	4.9 ± 0.1
Pak choy	*Brassica rapa L. var. chinensis*	8	5.0 ± 0.0
Peppercress	*Lepidium bonariense L.*	6	5.7 ± 0.4
Radish China rose	*Raphanus sativus L.*	9	6.8 ± 0.1
Radish daikon	*Raphanus sativus L. var. longipinnatus*	8	6.7 ± 0.4
Radish red	*Raphanus sativus L.*	7	6.9 ± 0.1
Radish ruby	*Raphanus sativus L.*	5	10.3 ± 0.1
Rapini	*Brassica rapa L. var. ruvo*	8	8.4 ± 0.3
Rutabaga	*Brassica napus L. var. napobrassica*	9	5.9 ± 0.1
Tatsoi	*Brassica narinosa L. var. rosularis*	7	5.8 ± 0.0
Turnip	*Brassica rapa L. var. rapa*	9	5.3 ± 0.1
Upland cress	*Barbarea verna (P. Mill.) Aschers*	20	7.2 ± 0.2
Wasabi	*Brassica juncea (L.) Czern.*	7	6.8 ± 0.1
Watercress	*Nasturtium officinale L.*	17	6.2 ± 0.2

Table 2. Instrumental parameters used in the inductively coupled plasma optical emission spectrometry (ICP OES) in this study.

Parameters	Conditions	
Radio frequency generator (MHz)	40	
Radio frequency power (kW)	1.5	
Plasma gas rate (L min^{-1})	15.0	
Auxiliary gas rate (L min^{-1})	0.2	
Nebulizer gas rate (L min^{-1})	0.6	
Mist chamber	Cyclone	
Nebulizer	Mira-mist	
Injector tube diameter (mm)	2.0	
Spray chamber	Cyclonic	
Nebulizer	Gem Cone	
Emission lines (nm)	Ca (II) 315.887	Fe (II) 238.204
	Mg (II) 279.077	Zn (II) 206.200
	P (I) 214.914	Cu (I) 324.752
	K (II) 404.721	Mn (II) 257.610
	Na (I) 589.592	

Table 3A. Results observed for the certified reference materials spinach leaves NIST 1570a.

	Certified Value	Measured Value
Macro-Element	(%)	
Ca	1.527 ± 0.041	1.310 ± 0.100
K	2.903 ± 0.052	2.896 ± 0.320
Mg	0.890 NC*	0.746 ± 0.050
P	0.518 ± 0.011	0.509 ± 0.050
Na	1.818 ± 0.430	1.685 ± 0.230
Micro-Element	(mg/kg DW)	
Fe	NV**	218.2 ± 15.0
Cu	12.2 ± 0.6	11.3 ± 1.1
Mn	75.9 ± 1.9	58.5 ± 3.6
Zn	82.0 ± 3.0	66.0 ± 5.0

*NV = No values; **NC = Not certified.

Table 3B. Limit of detection (LOD) and limit of quantification (LOQ) based on background equivalent concentration (BEC).

	LOD	LOQ
Macro-Element	(mg/kg DW)	(mg/kg DW)
Ca	0.009	0.029
K	20.039	66.797
Mg	0.002	0.005
P	-0.004	-0.013
Na	0.043	0.142
Micro-Element	(mg/kg DW)	(mg/kg DW)
Fe	-0.002	-0.006
Cu	0.002	0.005
Mn	0.000	0.000
Zn	0.001	0.003
Cd	0.000	0.000
Pb	0.001	0.005

Table 4. Mean macroelement concentrations of Ca, Ma, P, K and Na in 30 commercially grown microgreens in Brassiceceae family.

Commercial name	(mg/100g FW)				
	Ca	**Mg**	**P**	**K**	**Na**
Arugula	67 ± 2[a]	41 ± 1	63 ± 1	343 ± 13	35 ± 1
Broccoli	88 ± 2	51 ± 1	69 ± 0	326 ± 9	52 ± 2
Brussel sprouts	81 ±4	49 ± 1	57 ± 1	293 ± 5	54 ± 3
Cabbage Chinese	68 ± 1	31 ± 0	69 ± 1	240 ± 35	25 ± 1
Cabbage green	92 ± 1	55 ± 1	57 ± 1	192 ± 2	57 ± 1
Cabbage red	75 ± 1	39 ± 0	65 ± 0	240 ± 2	32 ± 1
Cabbage savoy	98 ± 3	62 ± 2	59 ± 2	238 ± 9	65 ± 3
Cauliflower	94 ± 2	66 ± 1	62 ± 0	224 ± 13	61 ± 1
Collard	71 ± 3	53 ± 1	75 ± 2	266 ± 5	44 ± 1
Kale Chinese	66 ±1	45 ± 1	68 ± 0	246 ± 23	38 ± 3
Kale red	59 ± 3	36 ± 1	60 ± 1	332 ± 18	43 ± 3
Kale Tucsan	80 ± 1	52 ± 2	69 ± 2	283 ± 8	51 ± 2
Kohlrabi purple	92 ± 5	55 ± 2	77 ± 3	342 ± 7	50 ± 3
Komatsuna red	55 ± 1	40 ± 2	70 ± 4	357 ± 3	32 ± 2
Mizuna	48 ± 5	29 ± 0	57 ± 1	354 ± 7	35 ± 4
Mustard Dijon	51 ± 4	35 ± 2	62 ± 2	365 ± 32	35 ± 1
Mustard red	47 ± 2	28 ± 1	52 ± 2	289 ± 5	27 ± 1
Pak choy	58 ± 1	31 ± 2	59 ± 4	284 ± 12	42 ± 5
Peppercress	39 ± 1	33 ± 2	58 ± 4	320 ± 26	29 ± 1
Radish China rose	54 ± 2	48 ± 2	71 ± 3	270 ± 7	38 ± 2
Radish daikon	66 ± 2	60 ± 3	86 ± 4	176 ± 10	57 ± 4
Radish red	56 ± 3	49 ± 2	81 ± 2	283 ± 10	42 ± 1
Radish ruby	41 ± 3	39 ± 2	82 ± 3	215 ± 6	19 ± 0
Rapini	92 ± 2	55 ± 1	85 ± 2	359 ± 1	56 ± 2
Rutabaga	59 ± 2	44 ± 1	64 ± 1	270 ± 14	39 ± 4
Tatsoi	62 ± 2	33 ± 1	66 ± 1	329 ± 13	36 ± 1
Turnip	57 ± 3	32 ± 1	61 ± 1	341 ± 12	26 ± 1
Upland cress	79 ± 5	47 ± 2	56 ± 0	376 ± 9	35 ± 1
Wasabi	56 ± 3	41 ± 1	69 ± 3	387 ± 9	33 ± 5
Watercress	51 ± 2	32 ± 2	62 ± 2	360 ± 3	68 ± 4

[a]Values are expressed as mean ± standard error (n=3).

Table 5. Mean concentrations of microelementary minerals in 30 commercially grown microgreens in Brassicaceae family.

	(mg/100g FW)					
Commercial name	**Fe**	**Zn**	**Cu**	**Mn**	**Cd**	**Pb**
Arugula	0.71 ± 0.01[a]	0.35 ± 0.01	0.07 ± 0.00	0.29 ± 0.01	ND[b]	ND
Broccoli	0.67 ± 0.01	0.37 ± 0.00	0.09 ± 0.00	0.37 ± 0.00	ND	ND
Brussel sprouts	0.57 ± 0.01	0.29 ± 0.01	0.08 ± 0.00	0.37 ± 0.01	ND	ND
Cabbage Chinese	0.66 ± 0.01	0.36 ± 0.01	0.04 ± 0.00	0.30 ± 0.01	ND	ND
Cabbage green	0.59 ± 0.01	0.29 ± 0.01	0.05 ± 0.00	0.33 ± 0.00	ND	ND
Cabbage red	0.62 ± 0.01	0.36 ± 0.01	0.08 ± 0.00	0.31 ± 0.00	ND	ND
Cabbage savoy	0.57 ± 0.02	0.27 ± 0.01	0.05 ± 0.00	0.38 ± 0.01	ND	ND
Cauliflower	0.62 ± 0.01	0.29 ± 0.01	0.06 ± 0.00	0.31 ± 0.00	ND	ND
Collard	0.65 ± 0.01	0.40 ± 0.01	0.09 ± 0.00	0.36 ± 0.01	ND	ND
Kale Chinese	0.64 ± 0.04	0.37 ± 0.01	0.06 ± 0.00	0.28 ± 0.01	ND	ND
Kale red	0.47 ± 0.01	0.29 ± 0.01	0.06 ± 0.00	0.32 ± 0.01	ND	ND
Kale Tucsan	0.72 ± 0.02	0.37 ± 0.00	0.09 ± 0.00	0.44 ± 0.01	ND	ND
Kohlrabi purple	0.75 ± 0.03	0.43 ± 0.02	0.11 ± 0.01	0.39 ± 0.01	ND	ND
Komatsuna red	0.74 ± 0.05	0.38 ± 0.02	0.08 ± 0.01	0.34 ± 0.01	ND	ND
Mizuna	0.57 ± 0.02	0.28 ± 0.01	0.06 ± 0.00	0.36 ± 0.01	ND	ND
Mustard Dijon	0.56 ± 0.01	0.29 ± 0.01	0.06 ± 0.00	0.39 ± 0.01	ND	ND
Mustard red	0.62 ± 0.07	0.22 ± 0.01	0.06 ± 0.00	0.24 ± 0.00	ND	ND
Pak choy	0.49 ± 0.02	0.30 ± 0.01	0.05 ± 0.01	0.29 ± 0.02	ND	ND
Peppercress	0.48 ± 0.03	0.41 ± 0.03	0.06 ± 0.01	0.24 ± 0.02	ND	ND
Radish China rose	0.62 ± 0.03	0.35 ± 0.01	0.08 ± 0.00	0.27 ± 0.01	ND	ND
Radish daikon	0.57 ± 0.02	0.28 ± 0.01	0.05 ± 0.00	0.19 ± 0.00	ND	ND
Radish red	0.67 ± 0.02	0.43 ± 0.00	0.11 ± 0.01	0.30 ± 0.00	ND	ND
Radish ruby	0.55 ± 0.01	0.40 ± 0.01	0.06 ± 0.00	0.17 ± 0.00	ND	ND
Rapini	0.84 ± 0.05	0.51 ± 0.02	0.13 ± 0.01	0.40 ± 0.00	ND	ND
Rutabaga	0.52 ± 0.02	0.26 ± 0.01	0.07 ± 0.00	0.39 ± 0.00	ND	ND
Tatsoi	0.57 ± 0.01	0.35 ± 0.01	0.05 ± 0.00	0.29 ± 0.01	ND	ND
Turnip	0.58 ± 0.01	0.34 ± 0.01	0.07 ± 0.00	0.41 ± 0.00	ND	ND
Upland cress	0.63 ± 0.01	0.41 ± 0.01	0.12 ± 0.00	0.48 ± 0.01	ND	ND
Wasabi	0.65 ± 0.05	0.42 ± 0.01	0.08 ± 0.00	0.26 ± 0.01	ND	ND
Watercress	0.52 ± 0.01	0.41 ± 0.02	0.09 ± 0.01	0.39 ± 0.01	ND	ND

[a]Values are expressed as mean ± standard error (n=3).

[b]ND means the heavy metals (Cd and Pb) were not detected (namely, under the limit of detection, which were 0.000 and 0.001 mg/kg dry weight for Cd and Pb, respectively) in this assay.