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ORIGINAL ARTICLE

Comparison of Trace Element, Metal, and Metalloid Contents in North and South Korean Plants

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Abstract

When relations improve between North and South Korea, there will be demand for North Korean edible plants because of the low labor cost and similar environmental conditions. However, there is no reliable information about trace elements, metals, and metalloids in edible plants from North Korea. Selenium (Se) and germanium (Ge) have positive effects on basic human health and are therapeutical in diverse illnesses. Metal and metalloid (Cd, Pb) poisoning, on the other hand, can cause many health problems. Plants collected from North Korea had higher selenium content than those from South Korea. Although none of the collected species exceeded the permissible levels of cadmium and lead, their content in plants was significantly higher in North Korea than in South Korea. The high metal contents in plants collected from North Korea may be associated with the soil physicochemical properties as well as the accumulated amounts of elements in the soil.

Key words : North Korea, Selenium, Germanium, Metals/metalloids, Plants

1. Introduction

Many heavy metals and metalloids are important constituents of pigments and enzymes for algae and plants, and hence, they are essential elements for ecosystem sustainability. However, most metals and metalloids, especially cadmium (Cd), lead (Pb), copper (Cu), and arsenic (As), can be toxic at high concentrations. They can inactivate enzyme functions and disturb many metabolic processes because of their similarity to essential heavy metals (Babula et al., 2008). Furthermore, highly concentrated heavy metals in soils and plants are a serious problem for human health because the food chain can be an important pathway for the entry of these toxic pollutants into human bodies (Khan et al., 2008).

The selenium (Se) and germanium (Ge) contents of edible plants, on other hand, have attracted worldwide attention because of their therapeutic effects on diverse illnesses (Goodman, 1988; Lee et al., 2003). Selenium is an essential trace nutrient important to human health as an antioxidant, and several epidemiological studies have found a relation between the amount of selenium intake and the incidence of some cancers (Carey et al., 2012). However, it can be toxic when the intake exceeds a suitable amount because of the incorporation of selenium in place of sulfur in amino acids (Germ et al., 2007). Organic germanium has also been well known for its therapeutic effects for almost two decades, such as for its immune system enhancement, oxygen enrichment, free radical scavenging, and heavy metal detoxification (Goodman, 1988).

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When relations improve between North and South Korea, there will be an interest in and demand for North Korean edible plants, for example, bracken, wild edible greens, and medical herbs, because of the low labor cost and similar environmental conditions to that of South Korea compared to that of China. However, no reliable data is available about the metal and metalloid contents of North Korean edible plants.

This study was conducted (1) to estimate the metal and metalloid contents in North and South Korean edible plants, (2) to compare the selenium (Se) and germanium (Ge) contents in North and South Korean edible plants, and (3) to assess the toxicity from metals and metalloids in North Korean edible plants and their potential as sources of essential trace nutrients.

2. Materials and method

Edible plants from North Korea were sampled from Pyongan and Hwanghae provinces in 2011 and 2012, and those from South Korea were sampled from Jeonla and Choongchung provinces in 2013 (Table 1). All of the samples were dried under shade immediately after sampling. To analyze the contents of metals and metalloids (cadmium (Cd), lead (Pb), copper (Cu), and arsenic (As)) and trace elements (selenium (Se) and germanium (Ge)), 0.5 g of ground plant samples were added to 10 mL of ultrapure grade 60% HNO_3 and digested on a hot plate at 100 ℃ for 1 hour, and 150 ℃ for 2 hours. Digested plant samples were cooled to room temperature and filtered using Whatman filter paper No. 40. The filtered sample solutions were diluted with deionized water to a total volume of 20 mL and subjected to analysis using an inductively coupled plasma emission spectrometer (ICPS-7510, Japan) for cadmium, lead, copper, and arsenic and an inductively coupled plasma mass spectrometer (Varian 820-MS, Australia) for selenium and germanium. Paired t-test was carried out to compare samples from North and South Korea. Statistical analyses were done in the R program (R version 3.0.1).

3. Results

For all 14 species, selenium contents were higher in South Korean than in North Korean samples (Fig.

Table 1. List of edible plants species sampled in North and South Korea

Scientific name	English common name	Part	No. of samples from North Korea	No. of samples from South Korea
Astragalus mongholicus	–	Root	1	2
Aster scaber	Aster	Leaf	3	2
Codonopsis lanceolata	Todok	Root	4	2
Ganoderma lucidum	Ling Chin	Fruit body	1	1
Glycine max	Black soybean	Fruit	1	1
Ipomoea batatas	sweet potato	Stem	2	1
Oryza sativa	Black rice	Fruit	1	2
Pteridium aquilinum	Bracken	Shoot	4	2
Pimpinella brachycarpa	–	Leaf	5	1
Perilla frutescens	Beefsteak-mint	Fruit	2	1
Platycodon grandiflorus	Balloon-flower	Root	4	1
Panicum miliaceum	Broomcorn millet	Fruit	2	2
Sesamum indicum	Sesame	Fruit	2	2
Vigna angularis	Azuki Bean	Fruit	3	2

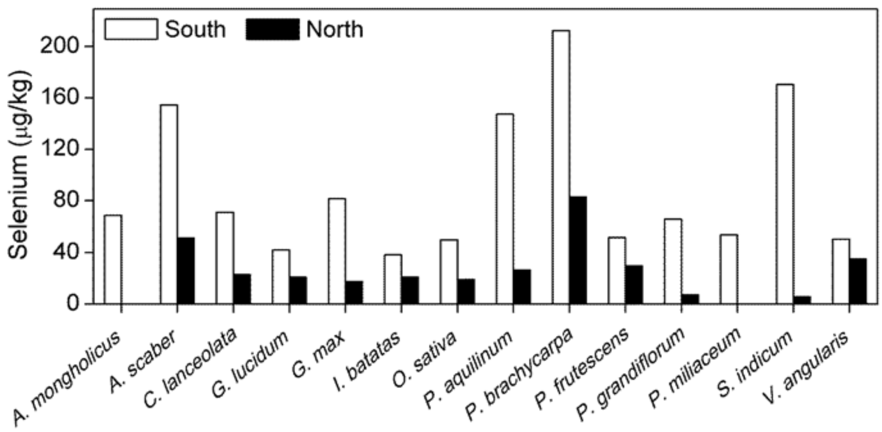

Fig. 1. Comparison of the selenium contents in 14 plant species between North and South Korea.

Table 2. Paired *t*-test results of the contents of five elements extracted from North and South Korean edible plants. The mean of the differences between South and North Korean samples is shown by using an associated degree of freedom (df = 13)

Statistics	Selenium	Germanium	Cadmium	Copper	Lead
Mean of the differences	65.5	-5.16	-0.11	0.47	-0.34
95% confidence interval	(38.3, 92.7)	(-12.1, 1.7)	(-0.2, -0.04)	(-1.8, 2.8)	(-0.7, -0.02)
t value	5.21	-1.61	-3.81	0.44	-2.29
p value	<0.001	0.131	0.002	0.665	0.039

1). The mean difference in selenium contents was 65.5 μg/kg, and the difference was significant based on the results of paired *t*-test (Table 2). *Pimpinella brachycarpa* had the highest selenium content (212.2 μg/kg) among 14 plant species that were assessed, and *Astragalus mongholicus* and *Panicum miliaceum* from North Korea had no detectable selenium.

Germanium contents in edible plants showed different trends compared to selenium contents (Fig. 2). Plants had higher germanium contents in North than in South Korea except for that in *Codonopsis lanceolata*, *Panicum miliaceum*, and *Sesamum indicum.* However, the difference was not statistically significant at the 5% probability level based on the results of paired *t*-test (Table 2).

Fig. 3 shows the difference in cadmium contents between North and South Korean edible plants. All plants of North Korea had higher cadmium contents than those of South Korea. The mean of the differences in cadmium levels between South and North Korea was 0.11 mg/kg, which was statistically significant ($p < 0.01$) (Table 2). *Ganoderma lucidum* had the highest cadmium content (South: 0.32 mg/kg; North: 0.48 mg/kg) among the 14 assessed species. Only four species of South Korea had cadmium levels detectable by using the inductively coupled plasma emission spectrometer.

All the assessed plant species of North Korea had significantly higher lead contents than those of South Korea ($p < 0.05$) (Table 2), except for *Astragalus mongholicus* and *Codonopsis lanceolata* (Fig. 4).

No significant differences were observed when

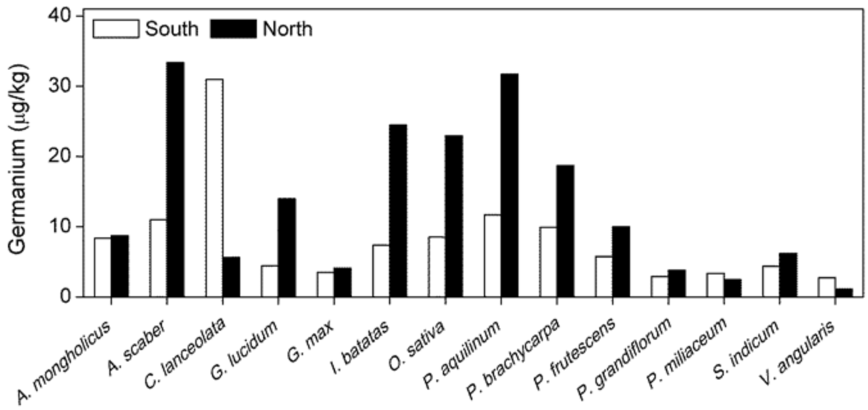

Fig. 2. Comparison of the germanium contents in 14 plant species between North and South Korea

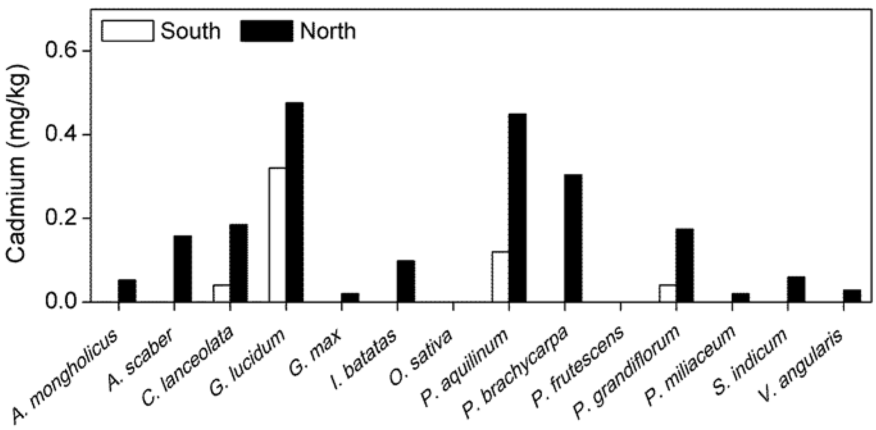

Fig. 3. Comparison of the cadmium contents in 14 plant species between North and South Korea

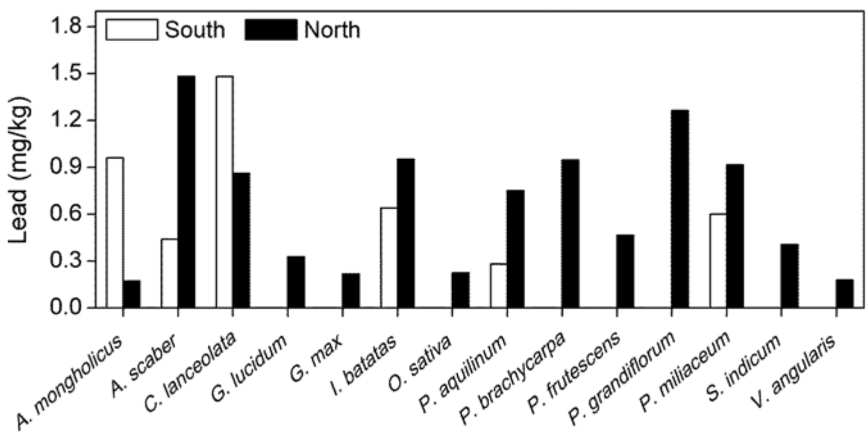

Fig. 4. Comparison of the lead contents in 14 plant species between North and South Korea

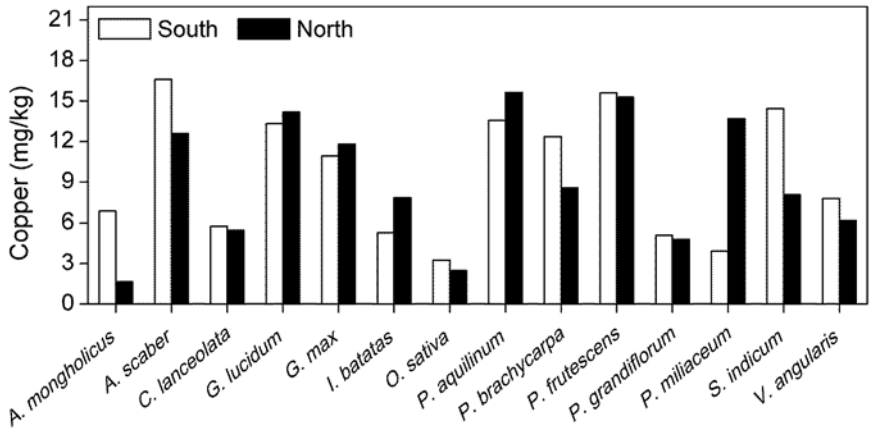

Fig. 5. Comparison of the copper contents in 14 plant species between North and South Korea.

comparing the copper contents between North and South Korean edible plants (p = 0.665) (Fig. 5, Table 2). The copper contents were dramatically different depending on the species. *Oryza sativa* had the lowest copper content among the 14 assessed species.

Paired *t*-test was conducted to find statistical differences in the contents of five elements between North and South Korean plants (Table 2). Selenium, cadmium, and lead contents showed significant differences at the 5% probability level.

4. Discussion

Selenium is a trace nutrient required for basic human health and is important in metabolism and antioxidative processes (Lee et al., 2003). Although it is widely distributed on the earth's surface, the uptake of selenium by plants depends on soil physicochemical factors such as redox-behavior, pH, or microbiological activity. For example, selenite can be oxidized to soluble selenate ions in soils with high pH (pH 7.5-8.5), which increases the availability of selenium to plants (Stadlober et al., 2001); further, the presence of organic matter and acids can inhibit the absorption of selenate (Babula et al., 2008). The high selenium content in South Korean plants may reflect the different plant growing conditions as well as the concentration of selenium in soils. Specifically, some fertilizers in South Korea contain selenate to increase the selenium in plant products. However, enhancing selenate levels using fertilizers should be done carefully so as not to induce environmental problems from its toxic effects (Lee et al., 2003).

While germanium is not listed as an essential trace nutritional element, the health-enhancing properties of organic germanium compounds have been reported in several papers, e.g., for the treatment of cancer and AIDS, immune system enhancement, and free radical scavenging (Goodman, 1988; Lee et al., 2005). Germanium is classified into inorganic and organic germanium. Inorganic germanium is commonly found in soils, and it is transformed into organic germanium compounds after being absorbed by plants or microorganisms (Kang et al., 2011). Higher germanium contents were found in the North Korean samples of 11 of the 14 species collected, which suggests that germanium may be distributed differently between North and South Korean soils. Lee et al. (2005) reported that the average inorganic germanium content is 0.24 mg/kg in paddy field soils in Gyeongnam Province, South Korea, and measured germanium contents in crops and medicinal plants collected from Gyeongnam Province (range: 11-126 μg/kg). However, there are no reports about germanium contents in North Korean soils.

Although heavy metals and metalloids are ubiquitous in the environment, metal pollution has become one of the most serious environmental problems today because of human activities such as mining, gas exhaust, energy and fuel production, and fertilizer and pesticide applications (Alkorta et al., 2004). Edible plants collected in North Korea had more levels of heavy metals (Cd, Pb) than in those from South Korea. Heavy metal accumulation in plants differs depending on the species and plant parts. Furthermore, the important factor affecting the bioavailability of metals is their concentration in soil and the physicochemical properties of soil. Cadmium is one of the most mobile heavy metals from the soil to plants, and it can accumulate in plants without toxicity symptoms (Alkorta et al., 2004), which suggests that plants with high cadmium accumulation can be more easily consumed by humans. It has been reported that food is the most important source of cadmium exposure in most countries (WHO, 1992). Diverse data are available indicating that cadmium poisoning can adversely affect the functioning of kidneys, bones, and the cardiovascular system. The permissible level of cadmium in foodstuffs is 0.5 mg/kg according to the Korean Food and Drugs Administration (Song et al., 2011). While none of the plants species exceeded the permissible level of cadmium, some North Korean plants, such as *Ganoderma lucidum* and *Pteridium aquilinum*, should be consumed with care. Especially, edible plants collected near mining or industrial areas should not be eaten.

Lead absorption into plants increases with increasing soil pH, cation exchange capacity, organic carbon content, and phosphate levels (United States Environmental Protection Agency, 1992). Lead content was also significantly higher in North than in South Korean plants. Lead poisoning can cause many health problems related to the nervous system. Especially, children are more susceptible to lead exposure than that by adults, and they may further be affected by behavior disturbances and learning and concentration difficulties (Järup, 2003). Foodstuffs are also the main source of lead exposure in the general population. The permissible level of cadmium in foodstuffs is 2.0 mg/kg according to the Korean Food and Drugs Administration (Song et al., 2011). None of the assessed plant species exceeded the permissible level of lead.

In summary, some trace element (Se) and metal (Cd, Pb) contents in plant species were significantly different between North and South Korea. These differences may be correlated with soil physicochemical properties in the sampled regions as well as the amount of each element in the soil. In further studies, soil analyses should be done to determine the association between plants and soils. Nevertheless, when the trade of food stuffs between North and South Korea increases, further specific metal and metalloid content analyses will be necessary to ensure food safety.

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