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Original Research

Distribution and Accumulation of Selenium in Plants and Health Risk Assessment from a Selenium-Rich Area in China

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Abstract

In order to investigate the concentrations of selenium (Se) in plants of the Dashan Region, a typical Se-rich area of China, and to illuminate the daily dietary Se intake of residents in this region, 83 crop samples and 144 Chinese herb samples were collected. Total Se was analyzed in the edible portion of crops and the medical portion of Chinese herbs. The average concentrations of Se ranged from 100 to 3,100 μg kg^{-1} (dry weight/DW) in different crops and from 20 to 1,500 μg kg^{-1} in the Chinese herbs (DW). The crop that contained the highest concentrations of Se was radish, while maize contained the lowest levels. For the Chinese herbs, the highest concentrations of Se were found in *Rumex japonicas*, while *Cape jasmine* contained the lowest levels of Se. The average enrichment coefficients (ECs) were 6.1-300% in crops, and 1.6-117% in Chinese herbs. Among the crops, radish had the highest EC (300%), while pumpkin had the lowest (6.1%). Among the Chinese herbs, *Sapium sebiferum* had the highest EC (117%), while *Dicranopteris dichotoma* had the lowest (1.6%). Based on the composition of residents' daily diets, the estimated daily Se intake from crops was 282±20 μg day^{-1}, and was about 5 times higher than the RDA value suggested by WHO (55 μg day^{-1}). Although no selenosis incidents have occurred in the Dashan Region to date, the potential health risk caused by chronic exposure to high levels of Se cannot be ignored.

Keywords: Dashan Region, China, selenium, plant, daily dietary Se intake

Introduction

Selenium (Se) is a trace element that can function as an essential nutrient for humans and animals or as an environmental toxicant [1-2]. Se deficiency can lead to human diseases such as Keshan disease (an endemic cardiomyopathy) and Kashin-Beck disease (a type of osteoarthritis) [3-5]. By way of contrast, toxicity of Se will occur at high concentrations due to the replacement of sulphur with Se in amino acids, resulting in incorrect folding of the protein and consequently nonfunctional

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proteins and enzymes [6-8]. Generally, Se is important to humans and animals as an antioxidant. Many studies have shown that proper intake of Se could play a vital role in anti-aging, repairing cells, improving human immunity, and preventing cancer [3-4, 9-10].

Diet is the major source of Se intake for the general population. Se enters the food chain through plants, which take it up from the soil [11]. In Finland, for example, approximately 30% of the average daily Se intake came from plants directly, and the other 70% intake came from plants indirectly, by the consumption of animal origin products through the plant-animal-human food chain [12]. Se contents in plants are highly dependent on the levels of Se in soil and the plant's ability to take up and accumulate Se. Some native plants had the ability to accumulate Se when grown in seleniferous soils [13]. These plants are called Se accumulators and include some species of Astragalus, Stanleya, Morinda, and Neptunia, which can accumulate hundreds to several thousand mg of Se kg^{-1} (dry weight/DW) in their tissues. In contrast, most plants contain less than 25 mg of Se kg^{-1} (DW) and do not accumulate Se even they grow in seleniferous soils. These plants are called Se nonaccumulators [13].

The Dashan Region is located in southern Anhui Province, China. It is known as an Se-rich area, together with the other two Se-rich areas: Enshi of Hubei Province and Ziyang of Shanxi Province [14-15]. Previous investigations have indicated that the average concentration of Se in soil of the Dashan Region was about 5 times higher than that of the mean value of China [15]. Although no selenosis incidents have occurred in the Dashan Region, the potential health risk caused by chronic exposure of Se through the food chain cannot be ignored.

To date, there has no research focus on the distribution and accumulation ability of Se in the plants of the Dashan Region. Furthermore, the potential health risks caused by chronic exposure of Se through the consumption of plants are still unknown. The specific objectives of this study are: 1) to determine concentrations of Se in the plant samples of the Dashan Region, 2) to calculate the enrichment coefficients (EC) and identify the accumulation ability of these plants, and 3) to reveal the potential health risk of Se by consumption of these plants.

Experimental

Sample Collection and Preparation

Eighty-three crop samples and 144 Chinese herb samples were collected in a mountainous area of Anhui Province, China. All the soils from the roots of the plants were collected simultaneously. The sampling region is located at the intersection of Shitai and Qimen counties (Fig. 1). It contains Dashan, Shili, Shuangkeng,

Fig. 1. Study site in Chizhou, Anhui Province.

Table 1. Concentrations (μg kg^{-1}) and enrichment coefficient values of Se in different crops of the Dashan Region.

Crop (portion)	Concentrations of Se in crops	Concentrations of Se in soil samples	EC value
Pumpkin (pericarp)	120±39 (n=4)	2000±170	6.2%±2.0%
Fatmelon (pericarp)	120±42 (n=4)	860±110	14%±4.9%
Asparagus bean (fruit)	120±37 (n=4)	860±170	14%±4.3%
Luffa (fruit)	120±31 (n=4)	940±130	13%±3.3%
Shallot (stem and leaf)	170±33 (n=4)	990±150	17%±3.3%
Capsicum (fruit)	500±40 (n=4)	1400±190	37%±2.9%
Maize (grain)	100±53 (n=8)	740±200	14%±7.3%
Potato (tuber)	110±63 (n=10)	910±260	13%±7.5%
Rice (grain)	410±42 (n=5)	1100±190	39%±3.9%
Radish (root)	3100±2400 (n=11)	1200±730	300%±230%
Eggplant (fruit)	200±47 (n=4)	900±200	23%±5.5%
Fragrant-flowered garlic (stem and leaf)	270±36 (n=4)	890±190	31%±4.1%
Konjac (tuber)	230±29 (n=4)	930±110	25%±3.2%
Persimmon (fruit)	210±45 (n=4)	740±240	29%±6.3%
Tea (leaf)	340±58 (n=9)	780±190	45%±7.6%

and Xianyu villages of Shitai County, and Liuyuan village of Qimen County(E117°19′54″-117°24′53″, N30°00′00″-30°03′06″). A portable GPS device was used to locate the sampling sites. The sampling area is about 46.22 km^2. The annual average temperature of the sampling area is 16ºC. The annual average rainfall of this area is 1,626.4 mm, and total average annual evaporation capacity is 1,256.2 mm [15].

In the laboratory, an edible portion of crops and a medical portion of Chinese herbs (Tables 1-2) were washed with Milli-Q water, dried in an oven at 50ºC, and then ground into powders (0.15mm) in a grinder. Plant root soils were air-dried, homogeneously ground, and sieved through a 0.15 mm mesh. Finally, all the samples were stored at -20ºC before analysis.

Sample Digestion and Determination

The measurement of total Se was accomplished by the use of previously established methods [16]. Briefly, about 3 g of sample was digested overnight in a 50 mL conical flask by 10 mL of concentrated nitric acid and perchloric acid (4:1 v:v). The acid mixture was then heated at 100ºC for 1 h, 120ºC for 2 h, and then 180ºC for 1 h using an electric plate. The samples were then heated at 210ºC until no white fume appeared. The remaining solution was cooled to room temperature, and 5 mL of hydrochloric acid (HCl, 12 M) was added to convert Se^{6+} to Se^{4+}, for about 4 h. Finally, the solution was adjusted to 25 mL with Milli-Q water for Se analysis.

All of the prepared samples were analyzed with hydride generation atomic fluorescence spectrometry (HG-AFS 9230, Beijing Titan Instrument Co., China). HG-AFS, which uses sodium borohydride ($NaBH_4$) (or potassium borohydride, KBH_4) as a reducing agent, will reduce Se^{4+} to hydrogen selenide (H_2Se) in HCl solution. The irradiation of a hollow cathode lamp excites the electrons in atoms of Se and causes them to emit fluorescence. The strength of the fluorescence increases with the increasing content of Se. The detection limit of the HG-AFS method for samples was 0.1 μgL^{-1} solution.

Quality Control

Confidence in the measurements was qualified by using blank controls, certified reference materials, and duplicates. National standard reference material GSS-1 (soil) and GSV-2 (shrub leaves) were used to check the recoveries of Se. The recoveries of the standard reference material ranged from 85 to 118%, with the relative standard deviation (RSD) being 10%. The detection limit (DL) of the instrument was 0.1 μg L^{-1} solution.

Results and Discussion

Distribution of Se in Crops of the Dashan Region

The concentrations and enrichment coefficients of Se in different crops of the Dashan Region can be found in Table 1. The crop with the highest levels of Se was radish, which had an average concentration of 3,100 μg kg^{-1}, and the lowest levels of Se were found in maize samples, with the average concentration of 100 μg kg^{-1}. The order of average concentration of Se from high to low was: radish, capsicum annuum, rice, tea, fragrant-flowered

Table 2. Average concentrations of Se in Chinese herbs (μg kg^{-1}) and enrichment coefficient values of Se in Chinese herbs of the Dashan Region.

Family name	Latin name	Alphabetic (Ping Yin)	Medical portion	Concentrations of Se in Chinese herbs	Concentrations of Se in soil samples	EC value
LABIATAE	*Mosla dianthera*	Xiao Yu Xian Cao	whole plant	540	1200	44%
	Perilla frutescens var. *acuta*	Bai Su	whole plant	410	890	46%
	Glechoma longituba	Huo Xu Dan	whole plant	110	1000	11%
	Perilla frutescens	Zi Su	whole plant	270	1900	14%
	Leonurus artemisia	Yi Mu Cao	aboveground part	320	920	35%
	Clinopodium polycephalum	Duan Xue Liu	aboveground part	490	1000	48%
ARACEAE	*Colocasia esculenta*	Yu	tuber	30	960	3.5%
	Pinellia cordata	Di Shui Zhu	tuber	720	1100	63%
	Acorus tatarinowii	Shi Chang Pu	rhizome	390	1100	35%
CRASSULACEAE	*Sedum sarmentosum*	Chui Pen Cao	whole plant	360	910	39%
	Sedum plumbizincicola	Ban Kuang Jing Tian	whole plant	90	1100	8.3%
	Sedum emarginatum	Ao Ye Jing Tian	whole plant	50	1400	3.7%
	Sedum shitaiense	Shi Tai Jing Tian	whole plant	390	1400	29%
CAPRIFOLIACEAE	*Sambucus chinensis*	Jie Gu Cao	whole plant	570	1300	43%
	Lonicera japonica	Jin Yin Hua	flower	550	2000	27%
ROSACEAE	*Eriobotrya japonica*	Pi Pa	fruit	600	730	83%
	Rubus hirsutus	Peng Lei	fruit	70	1300	5.3%
	Rosa laevigata	Jin Ying Zi	fruit	210	1900	11%
URTICACEAE	*Elatostema involucratum*	Lou Ti Cao	whole plant	820	1400	57%
	Pellionia radicans	Chi Che	whole plant	140	2700	5.3%
	Gonostegia hirta	Nuo Mi Tuan	whole plant	180	2400	7.7%
	Pilea sinofasciata	Cu Chi Leng Shui Hua	whole plant	310	680	46%
COMPOSITAE	*Dendranthema indicum*	Ye Ju Hua	aboveground part	50	510	9.8%
	Kalimeris indica	Ma Lan	whole plant	360	990	37%
	Gynura crepidioides	Ge Ming Cai	whole plant	120	1100	11%
GLEICHENIACEAE	*Hicriopteris glauca*	Li Bai	aboveground part	60	490	12%
	Dicranopteris dichotoma	Mang Qi	aboveground part	70	4400	1.6%
GRAMINEAE	*Coix lacrymajobi*	Yi Yi	Stem and leaf	120	2400	4.8%
	Triarrhena sacchariflora	Di	rhizome	90	1900	4.8%
UMBELLIFERAE	*Oenanthe javanica*	Shui Qin	whole plant	910	1600	56%
	Cryptotaenia japonica	Ya Er Qin	whole plant	190	1200	16%
POLYGONACEAE	*Reynoutria japonica*	Hu Zhang	aboveground part	290	1900	15%
	Rumex japonicus	Yang Ti	whole plant	1500	2600	56%

Table 2. Continued.

LILIACEAE	*Smilax glabra*	Tu Fu Ling	rhizome	270	1200	23%
	Tricyrtis macropoda	You Dian Cao	root	130	1200	11%
MORACEAE	*Ficus pumila*	Pi Li	stem and leaf	470	1300	36%
VALERIANACE-AE	*Patrinia villosa*	Bai Hua Bai Jiang	whole plant	230	980	24%
ARALIACEAE	*Aralia chinensis*	Cong Mu	stem	250	2700	9.3%
ACTINIDIACEAE	*Actinidia chinensis*	Zhong Hua Mi Hou Tao Ye	leaf	600	2500	25%
SAURURACEAE	*Houttuynia cordata*	Yu Xing Cao	whole plant	280	2100	13%
OSMUNDACEAE	*Osmunda japonica*	Zi Qi	aboveground part	1000	2300	44%
THEACEAE	*Camellia oleifera*	You Cha	leaf	780	2400	32%
EUPHORBIACE-AE	*Sapium sebiferum*	Wu Jiu	branch and leaf	800	680	117%
ERICACEAE	*Lyonia ovalifolia*	Mi Fan Hua	branch and leaf	160	830	19%
LAURACEAE	*Lindera aggregata*	Wu Yao	branch and leaf	110	1020	10%
PLANTAGI-NACEAE	*Plantago asiatica*	Che Qian	whole plant	520	1140	46%
JUNCACEAE	*Juncus effusus*	Deng Xing Cao	whole plant	510	960	53%
ACANTHACEAE	*Rostellularia procumbens*	Jue Chuang	whole plant	300	1400	21%
CHLORAN-THACEAE	*Chloranthus spicatus*	Jin Li Lan	whole plant	170	1300	14%
MYRSINACEAE	*Ardisia crenata*	Zhu Sha Gen	whole plant	220	1100	20%
GESNERIACEAE	*Lysionotus pauci-florus*	Diao Shi Ju Tai	branch	470	980	48%
AMARYLLI-DACEAE	*Lycoris radiata*	Shi Suan	bulb	190	1000	19%
AQUIFOLIACE-AE	*Ilex latifolia*	Ku Ding Cha	Leaf	100	850	12%
VERBENACEAE	*Premna microphylla*	Dou Fu Chai	branch and leaf	110	2100	4.9%
DIOSCOREACE-AE	*Dioscorea bulbifer*	Huang Du	tuber	660	1800	38%
MYRSINACEAE	*Ardisia crispa*	Bai Liang Jin	whole plant	40	470	8.5%
HUPERZIACEAE	*Huperzia serrata*	She Zu Shi Shan	whole plant	360	1500	24%
DRYNARIACEAE	*Drynaria roosii*	Hu Jue	whole plant	100	1400	7.2%
SAXIFRAGACE-AE	*Saxifraga stolonifera*	Hu Er Cao	whole plant	370	1400	26%
CUCURBITA-CEAE	*Gynostemma penta-phyllum*	Jiao Gu Lan	stem and leaf	670	1000	66%
LYCOPODIACE-AE	*Lycopodium japoni-cum*	Shi Song	stem and leaf	820	2300	36%
CRUCIFERAE	*Cardamine hirsuta*	Sui Mi Ji	whole plant	800	1400	56%
BERBERIDACE-AE	*Epimedium sagit-tatum*	San Zhi Jiu Ye Cao	whole plant	60	850	7.1%
SYMPLOCACE-AE	*Symplocos stellaris*	Lao Shu Shi	branch	410	960	43%
PRIMULACEAE	*Lysimachia fortunei*	Xing Xiu Cai	whole plant	390	2100	18%

Table 2. Continued.

Family name	Latin name	Alphabetic (Ping Yin)	Medical portion	Concentrations of Se in Chinese herbs	Concentrations of Se in soil samples	EC value
SELAGINELLACEAE	*Selaginella moellendorffii*	Jiang Nan Chun Bai	whole plant	130	450	29%
POLYPODIACEAE	*Polypodium nipponicum*	Shui Long Gu	whole plant	160	880	18%
SOLANACEAE	*Nicotiana tabacum*	Yan Ye	whole plant	770	1000	75%
RUBIACEAE	*Gardenia jasminoides*	Zhi Zi	branch	20	840	2.2%
THUIDIACEAE	*Thuidium cymbifolium*	Da Yu Xian	whole plant	1100	1500	71%
CYPERACEAE	*Cyperus rotundus*	Suo Cao	whole plant	720	790	91%
PTERIDACEAE	*Pteridium aquilinum* var.*latiusculum*	Jue	whole plant	260	2400	11%

garlic, konjac, persimmon, shallot, pumpkin, fatmelon, asparagus bean, luffa, potato, and maize.

In the Dashan Region, paddy rice is the primary cereal, and it accounts for a significant proportion of daily dose of protein and micronutrients. Distribution of Se in rice from China and all over the world can be found in Fig. 2 [2]. In China, the mean value of Se in rice is about 88 μg kg^{-1}. However, the concentrations found in the rice samples of the Dashan Region (410±42μg kg^{-1}) were much higher than this value, and was also higher than the mean global value (95 μg kg^{-1}). Compared with previous measurements of Se in rice samples of other regions of China, the levels of Se in rice samples of the Dashan Region were relatively higher than those found in Kaiyang of Guizhou Province (mean = 230 μg kg^{-1}) [17], the Three Gorges Reservoir Region of Chongqing (mean = 55 μg kg^{-1}) [18], Hanyin of Shanxi Province (mean = 172 μg kg^{-1}) [19], and Suzhou of Jiangsu Province (mean = 23.6 μg kg^{-1}) [16], but was about 2 times lower than that found in rice samples of Enshi of Hubei Province (mean = 960 μg kg^{-1}), which was recognized as the "world capital of Se" [20]. Furthermore, Se in other crops of the Dashan region, such as maize, potato, pumpkin, eggplant, capsicum, and radish, were also obviously higher than those found in crops of other regions of China, but were lower than those detected in crops of Enshi. The details can be found in Table 3 [7, 16-21]. Generally, levels of Se in crops of the Dashan region were at the high end of China. According to the classification of Tan [22], crops in China could be classified into 5 different groups by the levels of Se: deficient (<25 μg kg^{-1}), marginal (25-40 μg kg^{-1}), moderately high (40-70 μg kg^{-1}), high (70-1,000 μg kg^{-1}), and excessive (1,000+ μg kg^{-1}). According to the classification, about 92% of crops in the Dashan Region presented high levels of Se, such as rice, tea, eggplant, and capsicum, etc., and the other 7.7% of crops had excessive levels of Se, such as radish (Fig. 3).

Distribution of Se in Chinese Herbs of the Dashan Region

Chinese herbs have been used for centuries in China, and more than 300 herbs are commonly used today. Dashan is one of the most important Chinese herb production areas of Anhui Province. In order to reveal the levels of Se in Chinese herbs of Dashan, 144 Chinese herb samples were collected (72 species with duplication).

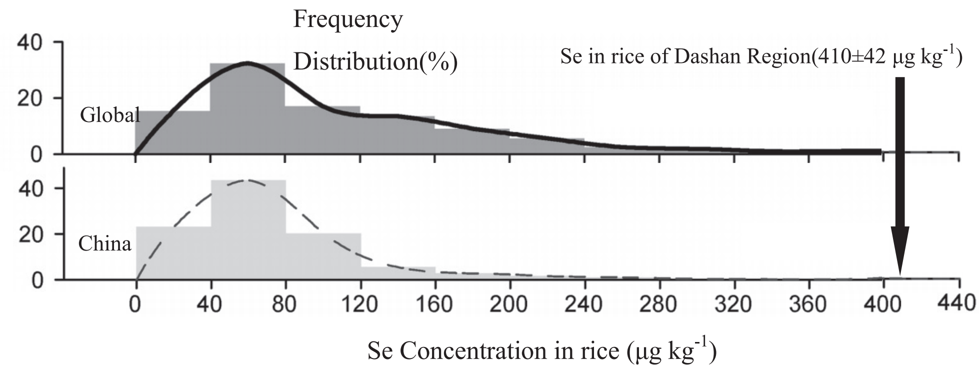

Fig. 2. Se Distribution in rice from China and globally [2].

Table 3. Comparison with a previous study of concentrations (μg kg^{-1}) and enrichment coefficient (EC value, %) values of Se in the crops and Chinese herbs of the Dashan Region.

Research area	Types	Concentrations of Se	EC value	Sampling date	Reference
Crops and Vegetables					
Dashan, Anhui, China	Rice (n=5)	410 (365-480)	39(34-45)	2013	This study
Suzhou,Jiangsu, China	Rice(n=21)	23.6(15~35)	—	2011	[16]
Kaiyang, Guizhou, China	Rice(n=5)	230(74~710)	—	2013	[17]
Three Gorges Reservoir Region, Chongqing, China	Rice(n=225)	55(2~170)	—	2006	[18]
Hanyin, Shanxi, China	Rice(n=4)	172(137~202)	(0.4~30)	2013	[19]
Enshi, Hubei, China	Rice(n=66)	960(—)	—	2013	[20]
Dashan, Anhui, China	Maize (n=8)	100 (35-200)	14(7.1-20)	2013	This study
Ping'an,Qinghai, China	Maize (n=4)	70(24~87)	—	2012	[7]
Kaiyang, Guizhou, China	Maize(n=5)	190(53~360)	—	2013	[17]
Three Gorges Reservoir Region, Chongqing, China	Maize(n=225)	42(2~103)	—	2006	[18]
Hanyin, Shanxi, China	Maize(n=4)	14(6~31)	—	2013	[19]
Enshi, Hubei, China	Maize(n=124)	430(—)	—	2013	[20]
Dashan, Anhui, China	Potato (n=10)	110 (50-212)	13(6.5-28)	2013	This study
Ping'an,Qinghai, China	Potato(n=31)	8.4(3~22)	—	2012	[7]
Suzhou,Jiangsu, China	Potato(n=21)	6(4~11)	—	2011	[16]
Enshi, Hubei, China	Potato(n=7)	280 (40~1070)	—	2013	[20]
Dashan, Anhui, China	Pumpkin (n=4)	120(69-165)	6.2(3.8-8.6)	2013	This study
Ping'an,Qinghai, China	Pumpkin(n=5)	17(6~21)	—	2012	[7]
Hanyin, Shanxi, China	Pumpkin(n=2)	113(72~155)	—	2013	[19]
Enshi, Hubei, China	Pumpkin(n=9)	760(310~3200)	—	2013	[20]
Dashan, Anhui, China	Eggplant (n=4)	200 (140-257)	23(16-29)	2013	This study
Suzhou,Jiangsu, China	Eggplan(n=21)	1.7(0.8~3.9)	—	2011	[16]
Kaiyang, Guizhou, China	Eggplant(n=3)	46(23~78)	—	2013	[17]
Enshi, Hubei, China	Eggplant(n=9)	1040(430~3200)	—	2013	[20]
Leping, Jiangxi, China	Eggplant(n=3)	17.5(9~27)	0.029	2012	[21]
Dashan, Anhui, China	Capsicum (n=4)	500 (443-540)	37(33-40)	2013	This study
Kaiyang, Guizhou, China	Capsicum(n=6)	150(67~330)	—	2013	[17]
Leping, Jiangxi, China	Capsicum(n=3)	17(9~25)	0.037	2012	[21]
Dashan, Anhui, China	Radish (root) (n=11)	3100 (680-8262)	300(133-901)	2013	This study
Kaiyang, Guizhou, China	Radish(n=3)	180(78~260)	—	2013	[17]
Chinese herbs					
Dashan, Anhui, China	—(n=144)	370 (20~1500)	29 (1.6-117)		This study
Minjiang Estuary Wetland, Fujian, China	—(—)	— (17~85)	27(16~35)	—	[23]
Xishuangbanna, Yunnan, China	—(—)	85 (—)	—	—	[24]
Salek valley, Slovenia	—(—)	140 (10~320)	—	—	[25]
Baoding, Hebei, China	—(n=7)	90 (43~210)	—	—	[26]
Liaoning, China	—(—)	140 (90~210)	—	—	[27]

† average (range)

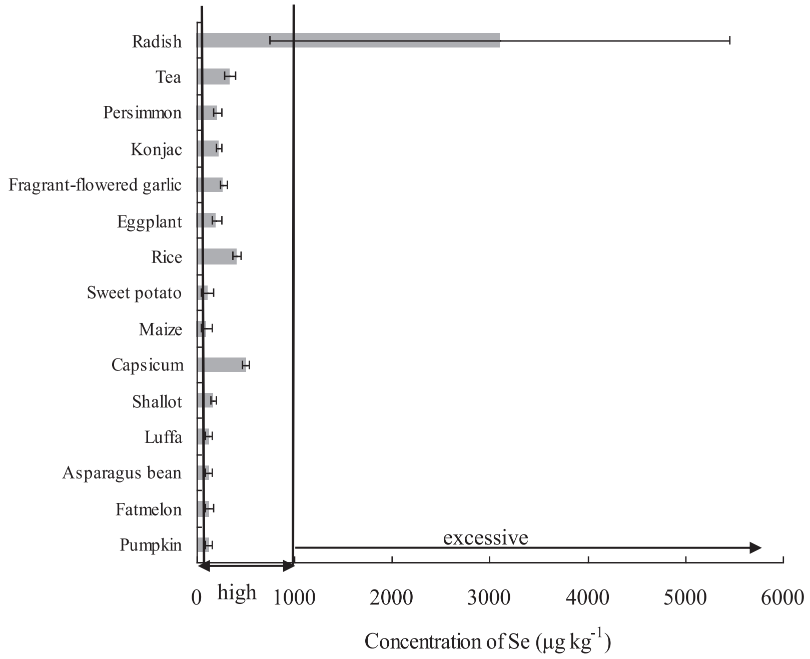

Fig. 3. Levels of Se in different crops of the Dashan Region.

The highest levels of Se were found in *rumex japonicus*, with an average concentration of 1,500 μg kg^{-1}, while the lowest concentrations of Se were detected in *cape jasmine*, with an average concentration of 20 μg kg^{-1}. The average concentration of Se in all Dashan herbs of was 370 μg kg^{-1}.

Compared with previous studies carried out in China, the levels of Se in Dashan herbs were higher than those found in Xishuangbanna of Yunnan Province (average concentration of 85 μg kg^{-1}), Liaoning Province (average concentration of 143 μg kg^{-1}), Baoding of Hebei Province (average concentration of 90 μg kg^{-1}), and the forest region of Heilongjiang and Jilin (average concentration of 196 μg kg^{-1}). Furthermore, Se in Dashan herbs were also higher than those found in Slovenia (average concentration of 140 μg kg^{-1}) [23-27]. In general, Dashan herbs were found to be much more enriched with Se than those in other regions of China.

Accumulation of Se in Dashan Plants

In order to reveal the ability to accumulate Se of diverse plants, enrichment coefficients (ECs) of Se were calculated with the equation $EC = C_{Se\text{-}plant}/C_{Se\text{-}soil}$ [28], where $C_{Se\text{-}plant}$ is the concentration of total Se in the plant (μg kg^{-1}, DW), and $C_{Se\text{-}soil}$ is the concentration of total Se in the soil (μg kg^{-1}, DW).

The details of ECs of Se in crops and Dashan herbs can be found in Tables 1-2. The mean values of ECs of Se in diverse crops were in the range 6.1-300% with an arithmetic mean of 41%, while the mean values in Chinese herbs were in the range 1.6-117% with an arithmetic mean of 29%. Generally, the ECs of Se in crops were relatively higher than those found in Chinese herbs. For different kinds of crops, relatively high ECs of Se were found in radish, tea, and rice, with mean values of 300%, 45%, and 38%, respectively. For Chinese herbs, highest ECs of Se were found in *Sapium sebiferum* (117%).

Compared with previous studies of China, the ECs of Se in Dashan rice (ranging from 34% to 45%) were much higher than those found in Hanying of Shanxi Province, which ranged from 0.4% to 30% [19]. The ECs of Se in Dashan eggplant (16% to 29%) and capsicum (33% to 40%) were higher than those found in Leping of Jiangxi Province, in which the mean EC values of Se in eggplant and capsicum were 0.029 and 0.037, respectively (Table 3) [21]. For Chinese herbs, the ECs of Se found in the Dashan Region were also higher than those found in Minjiang Estuary Wetland of Fujian Province [23]. Overall, the crops and Chinese herbs not only had the relatively high levels of Se but also had the better ability to accumulate Se from soil.

Daily Intake of Se from Plants of the Dashan Region

Food is the major resource of Se intake for humans. Dietary intake varies with the geographical source of the foods and the eating habits of the residents. In contrast to many other micronutrients, the intake of Se varies hugely worldwide, ranging from deficient (associated with selenium-deficiency diseases) to toxic concentrations that cause garlic breath, hair and nail loss, disorders of the nervous system and skin, poor dental health, and paralysis [4]. The recommended dietary allowance (RDA) of Se for humans varies by country, region, age, and sex. The RDA value for Se is 55 μg day^{-1} in the United States, Canada, and Europe. In China, the RDA value is 60 μg day^{-1}. In Australia and New Zealand, the RDA values for adult men and women are 60 and 55 μg day^{-1}, respectively.

Table 4. Comparison with a previous study of estimated selenium intake of adults in the Dashan Region.

Country	Se intake (μg /person per d)	Reference
China		
Dashan Region	280±20	This study
Belgium	60	[30]
Switzerland	66	[31]
Japan	82.7 (mountain community 118 (coastal community)	[32]
Slovenia	87	[33]
Korea	58	[34]
Greece	39.3	[35]
Saudi Arabia	75~122	[36]

In the UK, the reference nutrient intake is set at 75 and 60 μg day^{-1} for adult men and women, respectively. The RDA values suggested by WHO for adult men and women are 34 and 26 μg day^{-1} [4]. The tolerable upper Se intake level for adults is 400 μg day^{-1} [4].

Concentrations of Se in the crops were used to conduct human health risk assessments. The estimated daily intake (EDI, μg day^{-1}) of Se for the general population was calculated using the following equation: $EDI = C \times C_R$, where C is the mean concentration of Se in each species (μg kg^{-1}) and C_R represents the consumption of crops per capita per day (kg day^{-1}). The daily diet of residents in the Dashan Region from plants mainly contains 0.5 kg of cereals and 0.378 kg of vegetables [29]. According to the composition of residents' daily diet and the Se concentrations of different crops in the Dashan Region, the estimated daily Se intake from plants per capita was 280±20 μg day^{-1}. In this case, the content of Se in crops could satisfy daily Se intake sufficiently, while the daily Se dietary intake also is lower than the tolerable upper Se intake level [4]. Compared with other regions of China, the EDI of Se for Dashan residents was higher than those found in the Keshan disease area and the moderate Se area, but were lower than those in the selenosis area. Compared with other countries, the EDI of Se in the Dashan was higher than those in Belgium, Switzerland, Japan, Korea, Slovenia, Greece, and Saudi Arabia [30-36]. In summary, the EDI of Se in Dashan was at the highest level of the world (Table 4). Based on this research, Se-rich agricultural products could be developed in the Dashan Region and the crops that had strong enrichment ability of Se could be utilized in low-Se areas to produce Se-rich foodstuffs and thereby increase health benefits in the Se deficiency areas.

Conclusions

The levels of selenium ranged from 100 to 3,100 μg kg^{-1} (DW) in crops, and 20 to 1,500 μg kg^{-1} in Chinese herbs. The Enrichment coefficient values were 6.1-300% in crops and 1.6-117% in Chinese herbs of the Dashan Region. The crops and Chinese herbs not only had relatively high levels of Se but also had the better ability to accumulate Se from soil. The estimated daily Se intake per capita from crops was 282±20 μg day^{-1}. The content of Se in crops could satisfy daily Se intake sufficiently, while the daily Se dietary intake also was lower than the tolerable upper Se intake level.

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