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Effect of Soil Selenium on Nutritional Quality of Vegetables in the Selenium-enriched Areas of Qinghai Plateau

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Abstract In order to improve the added value of the main vegetable products in Qinghai Province, we researched the effect of soil selenium content on vegetable quality in selenium-enriched area of Qinghai. Through the analysis of Qinghai selenium-enriched soil selenium content and 5 kinds of main vegetables corresponds to the total selenium, part of the mineral elements and soluble sugar and VC content, the effects of soil selenium levels on selenium absorption and nourishment quality of vegetables were researched. The results showed that he Qinghai selenium-enriched soil selenium content in the range of 100.00 - 563.00 μg/kg, among them, the soil samples with sufficient selenium and rich selenium accounted for 76.53% and 18.88%, respectively. Soil selenium content of garlic sampling area was relatively high, and soil selenium content of sugar beet sampling area was relatively low. Vegetable selenium content was in the range of 11.00 - 340.94 μg/kg, the average content of total selenium content of garlic was up to 170.40 μg/kg, and the average content of the total selenium content of radish is 73.00 μg/kg. 90.63% of the vegetables in the region reached the level of sufficient selenium, and 70.31% reached the level of selenium enrichment. The average content of Ca and Mg was higher than the national average. There was no significant correlation between selenium content of soil and vegetable and nutritional quality.

Key words Selenium-enriched areas of Qinghai, Vegetables, Selenium, Nutritional quality

1 Introduction

Selenium (Se), as a non-metallic element of the sixth main family in the periodic table of elements, is a necessary trace element for human and animal, and has various biological functions[1]. In 1817, Swedish chemist Jakob Berzelius first reported the discovery of natural forms of selenium[2]. In 1973, Rotruck confirmed that selenium was the constituent of glutathione peroxidase in organisms[3-5]. In addition, selenium also has anti-cancer, anti-tumor, anti-AIDS and anti-aging functions and other health functions[6]. The spatial distribution of selenium in the environment has a very significant inhomogeneity, and its abundance and deficiency level is related to geographical location, altitude, parent material of soil and other factors[7]. At present, selenium nutrition is generally deficient in the structure of food chain[8]. According to the survey, 72% of the counties (cities) in China are deficient in selenium to some extent, and one third of them are severely deficient in selenium, and two thirds of the world is deficient in selenium[9-11]. Selenium deficiency in the human body can cause dysfunction of some important organs, leading to the occurrence of many serious diseases[12]. Since selenium cannot be synthesized in the body, the body needs selenium that must be taken in through the diet. Before the 1950s, people studied the toxicity of selenium, began to study the nutritional function of selenium after the 1970s, and studied the relationship between selenium and life sciences after the 1990s. On the basis of continuous achievements in basic research, selenium-enriched agricultural products were successively developed at home and abroad, from adding inorganic selenium to extracting natural organic selenium, natural transformation of selenium to artificial transformation of selenium and artificial synthesis of organic selenium products and so on. Domestic researches mainly focus on selenium accumulation and selenium bioenrichment capacity in different vegetables, selenium-enriched vegetables and so on[13], but the relationship between soil selenium content and vegetable nutritional quality is less studied.

In recent years, the Department of Land and Resources of Qinghai Province has discovered 840 km^2 of selenium-enriched soil resources in Ping'an-Ledu region[14]. Soil selenium content in this area is 0.23 - 1.50 mg/kg, with an average of 0.44 mg/kg. Compared with other selenium-enriched areas in China, it is at selenium sufficiency level or moderate selenium enrichment level[15]. Currently, there is no research on the relationship between soil selenium content and vegetable nutritional quality in this area. Therefore, through the sampling analysis of the main vegetables and tillage soils in the selenium-enriched soil resources area of Qinghai, this paper studied the effects of different soil selenium levels on the selenium uptake and nutritional quality of vegetables, and provided the theoretical basis for comprehensive utilization of the selenium-enriched soil resources and raising the added value of the main vegetable products in Qinghai.

2 Materials and methods

2.1 Sampling types and areas Based on the multi-target regional geochemical survey results in the eastern areas of Qinghai Province, published by Qinghai Provincial Department of Land and Resources in 2010, the main vegetable species were randomly sampled in different selenium-enriched areas of Qinghai (Ping'an-Ledu). The types and sampling points of vegetables are shown in Table 1.

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Table 1 Vegetable types and sampling areas

Sampling areas	Carrot	Potato	Radish	Sugar beet	Garlic
Ping'an County	Chuchugou Village	Baicaowan Village	Xiahongzhuang Village	Liming Village	Baicaowan Village
	Yima Village	Jiucaigou Village	Chuchugou Village	Chuchugou Village	Yima Village
	Hongshuiquan Village	Liming Village	Yima Village	Yima Village	Shangdian Village
	Hongtuzhuang Village	Shangdian Village	Xishangzhuang Village	Shangdian Village	Chuchugou Village
	Shangdian Village	Chuchugou Village	Hongshuiquan Village	Xishangzhuang Village	Hongshuiquan Village
	Xishangzhuang Village	Hongshuiquan Village	Hongtuzhuang Village	Hongshuiquan Village	Xiahongzhuang Village
	Xiahongzhuang Village	Yima Village	Shangdian Village	Xiahongzhuang Village	Xishangzhuang Village
	Jiucaigou Village	Hongtuzhuang Village	–	–	Hongtuzhuang Village
	Liming Village	–	–	–	–
Ledu County	Zhongxin Village	Shengjia Village	Xujiatai Village	Chaojia Village	Zhongxin Village
	Yangjia Village	Hongzhuang Village	Weijia Village	Kouzi Village	Chaojia Village
	Shengjia Village	Zhongxin Village	Shengjia Village	Duanjia Village	Yangjia Village
	Chaojia Village	Xujiatai Village	Yangjia Village	Hongzhuang Village	Hongzhuang Village
	Hongzhuang Village	Weijia Village	Zhongxin Village	Hexi Village	Kouzi Village
	Kouzi Village	Kouzi Village	Hongzhuang Village	Weijia Village	Duanjia Village
	Zhoujia Village	Duanjia Village	Chaojia Village	Shengjia Village	Xujiatai Village
	Xujiatai Village	Yangjia Village	Kouzi Village	Xujiatai Village	Hexi Village
	Hexi Village	Hexi Village	Zhoujia Village	Yaozhuang Village	–
	Yaozhuang Village	Yaozhuang Village	Duanjia Village	Zhoujia Village	–
	Weijia Village	–	Hexi Village	–	–

2.2 Methods

2.2.1 Sampling methods. Taking Ping'an and Ledu counties in the selenium-enriched areas as the areas, the soil was collected by the crossing method in each plot of the area, taking the main vegetable species in the areas as the object. Random sampling method was used to select 15 – 30 vegetable samples during vegetable maturity. Each plant was sampled by small, medium and large sizes, and each sample weighed 500 – 600 g. After sampling, it was placed into sample bag and marked with serial number, and stored in darkness and low temperature.

2.2.2 Sample pretreatment. Fibrous roots and yellow leaves were removed from the whole plant sample of rhizomatous vegetables. Old yellow leaves were stripped from leaf vegetables. They were firstly cleaned with flowing water, rinsed with distilled water, and finally cleaned with ultrapure water, and the filter paper was used to absorb the surface moisture. On the clean hard plastic cutting board, the fleshy roots or blades were cut with stainless steel cutter, respectively, and then the quartering method was used to take one fourth of samples and put them into the clean mouthpiece bottle and tray to mark the sample numbers. The former was stored in 1 – 4℃ refrigerator for analysis of total soluble sugar and VC in fresh samples. The latter was first deactivated with 105℃ oven for 1 h, then dried at 65 – 70℃ and ground with stainless steel mill, and collected in a clean mouthpiece bottle. The content of selenium, soluble sugar, VC and some nutrient elements in plants was to be analyzed.

2.2.3 Sample digestion. Wet digestion was adopted. 0.500 0 g of sample was weighed and placed in 300 mL digestion tube while setting a blank control. 20 mL mixed acid (HNO_3: $HClO_4$ = 4∶1) was added, shaken and placed overnight. DK-20Velp automatic digestion furnace was used for digestion, the mixed acid was added in time in during the heating process, to avoid evaporation explosion, and when the solution was clear and colorless, digestion was complete. Then it was heated to the remaining volume of 2 – 3 mL, and 10 mL of 6 mol/L HCl was added. The solution was then heated until the solution became clear and accompanied by the appearance of white smoke. The solution was cooled down and transferred to a 25 mL volumetric flask. The volume was fixed to the scale with ultrapure water, and the mixture was to be determined.

2.2.4 Methodology for measuring items. Selenium content was determined by hydride atomic fluorescence spectrometry[16]; mineral elements (P, K, Ca, Mg) were determined by inductively coupled plasma mass spectrometry; soluble sugar was determined by anthrone colorimetry; VC was determined by 2.6 dichlorophenol indophenol method.

2.2.5 Data analysis. Microsoft Excel 2003 was used for data processing and drawing. The selenium-enriched samples were evaluated in Table 2, and the selenium-enriched samples were evaluated by dividing the ecological landscape selenium threshold value[17]. The nutritional quality of vegetables was determined by the nutritional content of vegetables. Based on the nutritional contents of some vegetables listed in[18], the nutritional quality of some vegetables involved in this study was measured in Table 3. The selenium uptake rate was calculated as follows:

Selenium uptake rate (%) = Total selenium in vegetables/Total selenium in soil × 100.

3 Results and analysis

3.1 Analysis of selenium content and nutritional quality of soil and garlic in selenium-enriched areas of Qinghai Table 4 showed that the soil selenium in the sampling area was 180.00 – 570.00 μg/kg; 33.33% of soil samples reached the selenium enrichment level. The content of selenium in garlic was 26.90 – 340.94 μg/kg, and the average absorption rate was 52.23%. The

lowest absorption rate of garlic was 14.94% in Weijia Village of Ledu County and the highest absorption rate of garlic was 85.45% in Zhongxin Village of Ledu County.

Table 2 The boundary value of ecological landscape selenium

Content classification	Total selenium content of topsoil//mg/kg	Selenium content of grain//μg/kg	Effect of selenium
Lack	≤0.125	≤25.00	Selenium deficiency
Boundary	0.125 – 0.175	25.00 – 40.00	Potential selenium deficiency
Medium	0.175 – 0.400	40.00 – 70.00	Selenium sufficiency
High	0.400 – 3.000	70.00 – 100.00	Selenium enrichment
Excess	≥3.000	≥100.00	Selenium poisoning

Table 3 Nutrient content of edible vegetables

Types	Soluble sugar//%	Nutritive component content//mg/100 g				
		VC	P	K	Ca	Mg
Garlic	27.6	7	117	302	39	21
Carrot	8.8	13	27	190	32	16
Radish	5.0	21	26	173	36	14
Potato	17.2	27	40	342	8	23
Sugar beet roots	23.3	8	18	254	56	38
Sugar beet leaves	4.0	30	40	547	117	72

The content of selenium in garlic was lower than 70 μg/kg in Weijia Village in Ledu County and Yima Village in Ping'an County, but the content of selenium in garlic was above 70 μg/kg in other villages. According to the evaluation standard of selenium enrichment, 80.65% of garlic in the sampling area reached the level of selenium enrichment. The average content of total selenium in soil and garlic was 570.00 and 340.94 μg/kg respectively in Hongzhuang Village of Ledu County. The content of K and P was also the highest, the content of soluble sugar and VC was relatively low, and the content of other nutrients was at the average level. The content of total selenium in soil and garlic was the lowest in Weijia Village, Ledu County, which was 180.00 and 26.90 μg/kg, respectively. The content of Ca in garlic was also the lowest, the content of soluble sugar reached the highest level, and the content of other nutrients was at about the average level.

The correlation analysis showed that the total selenium content in soil was significantly correlated with the selenium content in garlic ($R = 0.785 > R_{0.01,9} = 0.735$). At the same time, the content of selenium in garlic was significantly correlated with its P level ($R = 0.763 > R_{0.01,9} = 0.735$), but it was not correlated with other qualities.

Table 4 Selenium content and nutritional quality of soil and garlic in selenium-enriched areas of Qinghai

Sampling areas	Sampling point	Selenium content//μg/kg		Soluble sugar//%	Nutritive component content//mg/100 g				
		Soil	Garlic		VC	K	Ca	Mg	P
Ping'an	Yima Village	210.00	66.44	17.47	17.13	77.55	42.88	60.30	33.56
County	Shangdian Village	500.00	167.19	25.73	9.01	111.00	60.75	81.41	40.85
	Xishangzhuang Village	340.00	260.94	30.28	10.01	143.18	58.96	85.93	47.87
	Xiahongzhuang Village	407.50	205.69	20.93	11.03	117.64	59.86	76.13	44.28
	Mean	364.38 ± 122.04	175.06 ± 82.00	23.60 ± 5.59	11.80 ± 3.65	112.34 ± 27.03	55.61 ± 8.52	75.94 ± 11.17	41.64 ± 6.10
Ledu	Zhongxin Village	226.67	193.68	20.05	22.73	125.62	58.37	69.35	42.74
County	Hexi Village	220.00	74.42	25.44	12.64	138.18	44.67	75.38	45.40
	Weijia Village	180.00	26.90	70.91	10.38	114.95	28.59	75.38	40.21
	Hongzhuang Village	570.00	340.94	11.96	4.83	151.28	46.46	66.33	51.36
	Chaojia Village	375.00	277.44	41.44	7.61	133.12	37.52	70.85	45.79
	Duanjia Village	207.50	90.31	37.75	18.36	121.38	58.07	70.10	41.84
	Mean	296.53 ± 150.46	167.28 ± 124.29	34.59 ± 20.9	12.76 ± 6.27	130.75 ± 13.01	45.61 ± 11.62	71.23 ± 3.56	44.56 ± 3.95
	Total sample size	30	30	30	30	30	30	30	30

3.2 Analysis of selenium content and nutritional quality of soil and sugar beet in selenium-enriched areas of Qinghai

Table 5 showed that the soil selenium in the sampling area was 185.00 – 490.00 μg/kg; 22.22% of soil samples reached the selenium enrichment level. The content of selenium in sugar beet was 49.89 – 136.00 μg/kg, and the average absorption rate was 27.28%. The lowest absorption rate of sugar beet was 13.21% in Hongzhuang Village of Ledu County and the highest absorption rate of garlic was 56.18% in Weijia Village of Ledu County.

The content of selenium in sugar beet was lower than 70 μg/kg in Chuchugou Village, Goutan Village of Ping'an County, Hexi Village, Hongzhuang Village, Chaojia Village, Kouzi Vil-

lage of Ledu County, but the content of selenium in sugar beet was above 70 μg/kg in other villages. According to the evaluation standard of selenium enrichment, the sugar beet reached the level of selenium sufficiency, and 77.78% of sugar beet reached the level of selenium enrichment. The highest soil selenium content was 490.00 μg/kg in Shangdian Village of Ping'an County and the lowest soil selenium content was 185.00 μg/kg in Weijia Village of Ledu County. The content of total selenium in sugar beet was the highest in Zhongzhong Village of Ledu County, which was 136.00 μg/kg, but the content of soluble sugar was the lowest, and the content of VC, K and Mg was also low. The content of the other nutrients was at the average level. The content of total selenium in sugar beet was the lowest in Goutan Village and Chuchugou Village of Ping'an County, which was only 49.89 μg/kg, and the content of P was the highest and the content of Mg was the lowest in sugar beet in Goutan Village. The content of other nutrients was at the average level. In Chuchugou Village, the content of K in sugar beet was the lowest, the content of VC, P and soluble sugar in sugar beet was relatively low, and the content of other nutrients was at the average level.

Through the analysis, it was found that the relationship between total selenium content in soil and selenium content in sugar beet was not regular. At the same time, the relationship between selenium content of sugar beet and other qualities was not regular.

Table 5 Selenium content and nutritional quality of soil and sugar beet in selenium-enriched areas of Qinghai

Sampling areas	Sampling point	Selenium content//μg/kg		Soluble sugar//%	Nutritive component content//mg/100 g				
		Soil	Sugar beet		VC	K	Ca	Mg	P
Ping'an	Chuchugou Village	230.00	49.89	20.03	1.78	104.95	107.21	159.80	13.61
County	Yima Village	216.70	70.77	27.79	1.74	146.50	98.87	165.83	13.46
	Goutan Village	200.00	49.89	21.32	4.45	120.35	153.66	120.60	31.46
	Hongtuzhuang Village	376.00	78.10	24.79	4.00	121.05	131.03	193.97	15.09
	Shangdian Village	490.00	85.44	22.56	5.43	130.10	139.37	183.92	15.14
	Xishangzhuang Village	346.60	103.94	22.22	9.34	257.35	203.69	316.58	20.60
	Xiahongzhuang Village	380.00	96.18	20.95	5.70	292.43	166.17	189.95	20.17
	Mean	319.90±107.64	76.31±21.10	22.81±2.66	4.63±2.61	167.54±75.07	142.85±35.87	190.09±61.08	18.50±6.42
Ledu	Xujiatai Village	230.00	77.94	24.59	2.39	134.90	85.76	241.20	12.13
County	Zhongxin Village	250.00	136.00	6.30	7.29	113.70	146.51	186.93	19.33
	Hexi Village	220.00	53.87	24.26	29.67	118.70	121.50	195.98	19.29
	Weijia Village	185.00	103.94	26.58	13.57	206.14	496.72	239.19	21.62
	Hongzhuang Village	415.00	54.83	20.43	13.23	143.36	212.62	215.82	18.09
	Chaojia Village	387.50	68.77	23.51	13.40	174.75	354.67	227.51	19.86
	Kouzi Village	230.00	68.94	23.70	17.47	160.74	296.38	219.62	19.72
	Duanjia Village	205.00	87.19	24.00	17.63	159.18	94.70	233.66	20.55
	Mean	265.31±86.36	81.44±27.55	21.67±6.44	14.33±8.02	151.43±30.51	226.11±145.96	219.99±19.82	18.82±2.89
	Total sample size	35	36	36	36	36	36	36	36

3.3 Analysis of selenium content and nutritional quality of soil and potato in selenium-enriched areas of Qinghai Table 6 showed that the range of soil selenium in this region was 100.00 – 500.00 μg/kg; 13.04% of soil samples reached the selenium-enrichment level. The content of selenium in potato was 50.00 – 150.00 μg/kg, and the average absorption rate was 32.44%. The lowest absorption rate of potato was 23.71% in Hexi Village of Ledu County while the highest absorption rate of potato was 64.00% in Hongshuiquan Village of Ping'an County.

The content of selenium in potato was lower than 70 μg/kg in Weijia Village, Xujiatai Village of Ledu County, Hongshuiquan Village of Ping'an County, while the content of selenium in potato was above 70 μg/kg, and 68.63% of potato reached the level of selenium enrichment. In Hongshuiquan village, Ping'an county, the average content of soil selenium was 100 μg/kg, the content of Ca was also the lowest, the content of VC was the highest, the content of P was relatively low, and the content of other nutrients was at the average level. The average content of selenium in soil of Chuchugou Village of Ping'an County was 150 μg/kg, which was the highest, the content of Mg and P was the lowest, and the content of other nutrients was at the average level. The average content of total selenium in soil and potato in Shangdian Village of Ping'an County was the highest, reaching 500.00 and 150.00 μg/kg, respectively. The content of soluble sugar and K was the lowest, the content of P was relatively high, and the content of other nutrients was at about the average level. The average content of total selenium in potato was the lowest in Weijia Village, Ledu County, which was 50.00 μg/kg. The content of VC was the lowest, the content of P was relatively low, and the content of other nutrients was at about the average level.

The total selenium content in soil was significantly correlated with the selenium content in potato ($R = 0.836 > R_{0.01,11} = 0.684$). At the same time, the content of selenium in potato was significantly correlated with its P level ($R = 0.587 > R_{0.05,11} = 0.553$), but not correlated with other qualities.

Table 6 Selenium content and nutritional quality of soil and potato in selenium-enriched areas of Qinghai

Sampling areas	Sampling point	Selenium content//μg/kg		Soluble sugar//%	Nutritive component content//mg/100 g				
		Soil	Potato		VC	K	Ca	Mg	P
Ping'an County	Chuchugou Village	360.00	150.00	7.08	16.59	126.35	32.16	84.42	12.56
	Yima Village	225.00	78.00	10.58	13.01	205.19	34.54	121.61	17.66
	Hongshuiquan Village	100.00	64.00	7.58	54.46	190.10	16.68	107.54	13.22
	Shangdian Village	500.00	150.00	5.35	9.78	106.65	57.18	126.63	28.46
	Xishangzhuang Village	325.00	130.00	7.35	20.83	145.12	35.74	120.60	25.32
	Xiahongzhuang Village	415.00	130.00	16.89	11.61	194.24	182.25	121.10	32.91
	Mean	320.83 ± 141.75	120.00 ± 37.00	9.14 ± 4.16	21.05 ± 16.83	161.28 ± 40.77	59.76 ± 61.39	113.65 ± 15.67	21.69 ± 8.44
Ledu County	Xujiatai Village	215.00	67.35	12.84	22.89	208.15	48.24	123.62	19.28
	Zhongxin Village	300.00	87.00	12.05	6.49	228.70	50.03	141.71	26.25
	Hexi Village	350.00	83.00	10.36	10.52	214.15	28.59	105.53	18.98
	Weijia Village	180.00	50.00	16.54	3.20	206.70	42.88	105.53	16.81
	Hongzhuang Village	410.00	110.00	17.04	23.17	201.70	42.88	102.51	18.64
	Chaojia Village	260.00	74.00	16.02	4.75	286.00	64.32	111.56	22.29
	Mean	285.83 ± 85.58	78.56 ± 20.21	14.14 ± 2.76	11.84 ± 9.01	224.24 ± 31.66	46.16 ± 11.66	115.07 ± 15.06	20.38 ± 3.38
	Total sample size	46	51	51	51	51	51	51	51

3.4 Analysis of selenium content and nutritional quality of soil and carrot in selenium-enriched areas of Qinghai Table 7 showed that the range of soil selenium in this area was 100.00 – 563.00 μg/kg; 23.53% of the soil samples reached the selenium-enrichment level. The content of selenium in carrot was 9.35 – 170.44 μg/kg, and the average absorption rate was 33.50%. The lowest absorption rate of carrot was 4.68% in Xujiatai Village of Ledu County, and the highest absorption rate of carrot was 63.94% in Hongshuiquan Village of Ping'an County.

Table 7 Selenium content and nutritional quality of soil and carrot in selenium-enriched areas of Qinghai

Sampling areas	Sampling point	Selenium content//μg/kg		Soluble sugar//%	Nutritive component content//mg/100 g				
		Soil	Carrot		VC	K	Ca	Mg	P
Ping'an County	Chuchugou Village	360.00	98.44	11.96	2.94	212.50	203.69	60.30	20.19
	Yima Village	210.00	116.44	9.00	4.79	201.70	260.87	99.50	27.61
	Hongshuiquan Village	100.00	63.94	28.42	0.89	141.50	221.56	84.42	16.11
	Hongtuzhuang Village	400.00	129.69	10.46	7.29	225.08	328.55	125.12	34.66
	Shangdian Village	563.00	117.27	11.92	6.03	218.88	266.82	100.50	28.44
	Xishangzhuang Village	330.00	170.44	16.29	8.54	222.68	312.68	131.15	36.18
	Xiahongzhuang Village	390.00	113.19	112.70	7.38	228.80	298.39	105.53	30.80
	Mean	336.14 ± 147.61	115.63 ± 32.09	28.68 ± 37.62	5.41 ± 2.72	207.31 ± 30.38	270.36 ± 46.35	100.93 ± 23.96	27.71 ± 7.32
Ledu County	Xujiatai Village	200.00	9.35	5.60	17.49	326.98	131.14	27.16	13.13
	Zhongxin Village	240.00	65.15	16.26	7.24	262.95	280.52	96.48	24.85
	Hexi Village	220.00	113.10	8.86	19.80	220.80	351.99	131.15	29.98
	Weijia Village	200.00	80.83	19.02	5.21	200.05	364.50	120.60	28.07
	Hongzhuang Village	458.00	159.44	12.10	9.83	292.63	389.51	111.56	37.82
	Chaojia Village	313.33	100.60	13.67	13.04	337.20	384.75	103.52	35.65
	Kouzi Village	296.67	99.94	17.76	8.35	295.95	331.14	117.59	31.28
	Mean	275.43 ± 92.13	89.77 ± 46.14	13.32 ± 4.86	11.56 ± 6.17	276.65 ± 51.64	319.08 ± 90.71	101.15 ± 34.54	28.68 ± 8.14
	Total sample size	47	49	49	49	49	49	49	49

The content of selenium in carrot was lower than 70 μg/kg in Xujiatai Village, Zhongxin Village of Ledu County, but the content of selenium in carrot was above 70 μg/kg in other villages, and 89.80% of carrots in the area were enriched with selenium. The average content of selenium in soil of Shangdian Village, Ping'an County was the highest, reaching 563.00 μg/kg, the content of soluble sugar in carrot was relatively low, and the content of other nutrients was at the average level. In Hongshuiquan village, Ping'an County, the average content of selenium in soil was the lowest, only 100.00 μg/kg, the content of VC in carrot was the lowest, and the content of other nutrients was lower than the average level. In Xishangzhuang Village, Ping'an County, the average content of total selenium in carrot was the highest, reaching 170.44 μg/kg, the content of Mg was also the highest, the content of VC, Ca, P was relatively high, and the content of other nutrients was at the average level. The average content of total selenium in carrot in Xujiatai Village of Ledu County was the lowest, which was only 9.35 μg/kg. The content of soluble sugar,

Ca and Mg in carrot were also the lowest, and the content of other nutrients was at about the average level.

There was a significant correlation between total selenium content and carrot selenium content ($R = 0.585 > R_{0.05,13} = 0.514$), and there was a significant correlation between total selenium content and carrot P content ($R = 0.537 > R_{0.05,13} = 0.514$). At the same time, the content of selenium in carrot was significantly correlated with Ca level ($R = 0.632 > R_{0.05,13} = 0.514$), extremely significantly correlated with Mg level ($R = 0.734 > R_{0.01,13} = 0.641$), extremely significantly correlated with P level ($R = 0.846 > R_{0.01,13} = 0.641$), but not correlated with other qualities.

3.5 Analysis of selenium content and nutritional quality of soil and radish in selenium-enriched areas of Qinghai From Table 8, it was found that the variation range of soil selenium in the sampling area was 190.00 – 505.00 μg/kg; 16% of soil samples reached the level of selenium enrichment. The selenium content of radish was 11.00 – 149.44 μg/kg, and the average absorption rate was 26.65%. The lowest absorption rate of radish was 2.77% in Hongzhuang Village of Ledu County and the highest absorption rate of radish was 48.21% in Liming Village of Ping'an County.

The content of selenium in radish was lower than 70 μg/kg in Weijia Village, Hexi Village, Chaojia Village, Hongzhuang Village and Xujiatai Village, but the content of selenium in radish was above 70 μg/kg, and 88.89% of radishes in this region reached the selenium-enrichment level. The average content of selenium in soil of Hongzhuang Village of Ledu County was the highest, reaching 505.00 μg/kg, the content of K in the corresponding radish was relatively high, and the content of other nutrients was at about the average level. The average content of soil selenium in Weijia Village of Ledu County was the lowest, reaching 190.00 μg/kg, the content of K, Ca, Mg and P in radish in the sampling area was higher than the content of K, Ca, Mg and P in radish in other areas, and the content of other nutrients was at about the average level. In Liming Village of Ping'an County, the content of total selenium in radish was the highest, reaching 149.44 μg/kg, while the content of soluble sugar and P in radish was lower than that in other sampling areas, and the content of other nutrients was close to the average level. The total selenium content of radish in Hexi Village of Ledu County was the lowest, which was only 11.00 μg/kg, and the content of nutrients in radish in this area was at about average level.

The relationship between the total selenium content of soil and the selenium content of radish or the content of other nutrients was not regular. At the same time, the relationship between selenium content of radish and other qualities was also not regular.

Table 8 Selenium content and nutritional quality of soil and radish in selenium-enriched areas of Qinghai

Sampling areas	Sampling point	Selenium content // μg/kg		Soluble sugar // %	Nutritive component content // mg/100 g				
		Soil	Radish		VC	K	Ca	Mg	P
Ping'an	Chuchugou Village	230.00	97.94	8.74	26.45	275.60	886.23	208.04	32.11
County	Yima Village	220.00	90.77	5.70	25.30	173.75	567.00	28.76	28.76
	Shangdian Village	500.00	105.44	11.41	18.36	226.52	486.00	177.89	39.16
	Xishangzhuang Village	330.00	134.44	7.34	3.82	262.35	464.56	192.96	38.47
	Liming Village	310.00	149.44	5.56	22.73	183.00	532.45	256.28	23.66
	Mean	318.00 ± 112.56	115.60 ± 25.16	7.75 ± 2.43	19.33 ± 9.21	224.25 ± 45.68	587.25 ± 171.83	172.78 ± 85.72	32.43 ± 6.56
Ledu	Xujiatai Village	193.33	45.00	13.54	19.30	218.17	540.79	224.12	39.29
County	Zhongxin Village	240.00	93.00	13.36	29.16	284.35	634.30	248.74	45.33
	Hexi Village	250.00	11.00	12.50	25.16	251.74	628.04	261.55	39.75
	Weijia Village	190.00	12.00	9.02	10.38	317.82	683.12	372.86	51.43
	Hongzhuang Village	505.00	14.00	7.49	10.65	311.94	719.17	231.40	50.67
	Chaojia Village	360.00	14.00	7.49	10.65	311.94	719.17	231.40	50.67
	Kouzi Village	250.00	100.00	13.99	17.88	299.35	567.47	206.23	41.88
	Duanjia Village	203.33	82.00	15.43	10.02	259.44	551.51	189.95	32.45
	Mean	273.71 ± 107.98	46.38 ± 39.37	11.60 ± 3.13	16.65 ± 7.49	281.84 ± 35.62	755.45 ± 81.19	245.78 ± 56.02	43.93 ± 6.8
	Total sample size	40	45	45	45	45	45	45	45

4 Discussions and conclusions

4.1 Discussions The spatial distribution of selenium in the environment has a very significant inhomogeneity, and its abundance and deficiency level is related to geographical location, elevation, soil parent material and other factors. The content of nutrient elements in vegetables varies according to different regions and species. For the same types of vegetables, the selenium content in the vegetables in the selenium-enriched areas is higher than that in the areas with the average or sufficient selenium; the content of selenium in different vegetables is also different in the same area.

The selenium content of garlic and carrot was relatively high in selenium-enriched areas of Qinghai. The selenium uptake by vegetables varied according to the types, for example, from the level of soil selenium, Shangdian Village, Hongtuzhuang Village of Ping'an County, Chaojia Village and Hexi Village of Ledu County are all selenium-enriched areas, but the selenium content in vegetables from the sampling area was not high, which might be related to local soil structure, soil texture and physical and chemical properties in addition to absorptive capacity.

Among the vegetables in the selenium-enriched areas, garlic,

radish and beet were ranked in the top three in terms of the average content of total selenium (170.40 μg/kg, 73.00 μg/kg and 79.05 μg/kg, respectively), and in the three kinds of vegetables, the samples reaching selenium-enrichment level accounted for 80.65%, 88.89% and 77.78%, respectively. Selenium can be used as nutrient to maintain ion balance in plants, which is beneficial to metabolism, growth and development of plants[19].

In the nutritional qualities, the soluble sugar content of garlic was 30.20%, and the soluble sugar content of other vegetables was about the national average. The content of P and K in garlic did not reach the national average, and the content of Mg in garlic was 2 – 4 times of the national average. However, the average content of Ca and Mg in each vegetable was higher than that in the whole country, which might be due to the alkaline soil in the selenium-enriched areas.

Dong Guanghui *et al.*[20] suggested that selenium could promote the absorption of macroelements in plants and improve the nutritional quality of crops. In the selenium-enriched areas of Qinghai, the content of selenium in garlic, potato and carrot was extremely significantly correlated with the content of selenium in soil of the sampling areas, and the content of selenium in the above vegetables was also significantly correlated with some mineral elements, possibly because selenium promoted the absorption of other mineral ions in vegetables, which increased the content of relative nutrients while the vegetables were enriched with selenium.

4.2 Conclusions The range of soil selenium content in the selenium-enriched areas of Qinghai was 100.00 – 563.00 μg/kg; the soil samples with sufficient selenium and rich selenium accounted for 76.53% and 18.88%, respectively. Soil selenium content (323.67 μg/kg) in garlic sampling area was relatively high, while soil selenium content (290.79 μg/kg) in sugar beet sampling area was relatively low.

The range of selenium content in vegetables was 11.00 – 340.94 μg/kg; the content of total selenium in garlic was the highest, the average content was 170.40 μg/kg, and the average content of total selenium in radish was 73.00 μg/kg. In this area, 90.63% of vegetables reached the level of sufficient selenium and 70.31% reached the level of enriched selenium. The average content of total selenium in vegetables was in the order of garlic > carrot > potato > sugar beet > radish.

The total selenium level of soil affected the uptake of selenium by vegetables to some extent, and the average selenium content of garlic, potato and carrot was significantly or extremely significantly correlated with the total selenium content of corresponding soil samples. In the main nutritional qualities of vegetables in selenium-enriched areas of Qinghai, the average content of soluble sugar, VC, K, Ca, Mg and P was 7.75% – 34.59%, 4.63 – 21.05 mg/100 g, 112.34 – 281.84 mg/100 g, 45.61 – 755.45 mg/100 g, 71.23 – 245.78 mg/100 g, 18.50 – 44.56 mg/100 g, respectively. The vegetable types corresponding to the highest nutrient content were garlic, potato, radish, radish, radish and garlic. The average content of Ca and Mg in each vegetable was higher than that in the whole country.

In a word, the content of main nutritional components of five kinds of vegetables in selenium-enriched areas of Qinghai was mostly higher than the national average while they were enriched with selenium.

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