

Correlation between Selenium and Heavy Metal Content in *Camellia oleifera* in Hainan, China

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Abstract: Eighteen forests of *Camellia oleifera* in Hainan province, China were selected to measure the contents of selenium (Se), zinc (Zn), mercury (Hg), cadmium (Cd), chromium (Cr), lead (Pb) and arsenic (As) in soils, roots, leaves, and kernels, and analyze the correlation between the soil content and the corresponding content in the plant. It was found that the content of Se in soils ranged between 0.489 and 2.110 mg/kg, and was higher than 1.0 mg/kg in 10 out of 18 forests. The average content of six heavy metals was low and fulfilled the requirements of soil environment for green-food production, except that the contents of Cr, Pb, and Cd exceeded standards in few regions. The content of Se in *Camellia oleifera* was relatively low. Only five regions showed detectable levels of Se in kernels, with the highest in Fuwen Town of Dingan county of 0.085 mg/kg. The contents of Zn, Cr, Pb, Cd, As, and Hg in roots of *Camellia oleifera* were higher than in the leaves and kernels. The contents of Zn, Cr, and Pb were higher than that of Cd, As, and Hg. The As content in soil was in significant correlation with that in the roots of *Camellia oleifera*. The Pd content in the soil was positively correlated with that of the roots of *Camellia oleifera*. The Cr, Pd and Cd contents in roots were in positive correlation with that in the leaves significantly. However, the Hg content of the roots was positively correlated with that of the kernels. Furthermore, the Se content in roots of *Camellia oleifera* was negatively associated with that of the other six heavy metals, having a significantly negative correlation between Se and As.

Keywords: Correlation, Hainan province, Heavy metal, Oiltea, Selenium.

1. INTRODUCTION

Soil is an integral part of human ecological environment, and the foundation of agriculture and forestry production. Heavy metal pollution adversely affects the growth and development of plants and the quality of agricultural products [1]. Studies on rice [2] and persimmon [3] suggested that Se not only reduced the uptake of heavy metals such as cadmium (Cd) and lead (Pb), but also exerted anti-cancer effect on the human body [4, 5]. Studies focused on selenium (Se) and the other heavy metals in the soils cultivating rubber and pepper found abundant Se in soil in the Hainan province [6-8]. *Camellia oleifera* is an important and major source of edible oil in South China [9, 10]. It has a long history of planting and utilization in Hainan province. Also known as 'pomelo on the hill', *Camellia* oil from Hainan province is of high quality due to excellent production environment. Studies have been published on *Camellia oleifera* germplasm resources [11], varieties

selection [12], ecological adaptability [13], and high yield cultivation techniques [14]. However, the correlation between Se and heavy metal contents in soil and their corresponding contents in *Camellia oleifera* have yet to be reported. In the current study, 18 forests of *Camellia oleifera* from 11 major production counties in Hainan province were selected to measure the contents of selenium (Se), zinc (Zn), mercury (Hg), Cd, chromium (Cr), Pd and arsenic (As) in soils, roots, leaves, and kernels. The correlation between soil levels of Se and heavy metals and their corresponding contents in *Camellia oleifera* was analyzed in order to provide a scientific basis for pollution-free and Se-rich oil tea production in Hainan province, China.

2. MATERIAL AND METHODS

2.1. Materials

The forests of *Camellia oleifera* covering an area over one acre were selected from 11 counties including Chengmai, Dingan, Qionghai, Wenchang, Qiongzong, Danzhou, Tunchang, Wuzhishan, Baoting, Baisha, and Haikou. Detailed information was collected regarding the location, latitude, longitude, cultivation method and age of trees (Table 1).

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Table 1. General characteristics of sampling sites.

No.	County (City)	Town	Village	Longitude	Latitude	Altitude (m)	Type of Forest	Age of Forest (a)
1	Wenchang	Penglai	Hongqi farm	110°31'53.8"	19°31'43.5"	160	rubber mixed forest	45
2	Haikou	Dongshan	Dongshan forest farm	110°30'05.6"	19°37'48.4"	41	artificial pure forest	56
3	Chengmai	Jiale	Potang village	110°01'36"	19°35'02"	100	artificial pure forest	80
4	Chengmai	Heling farm	Qunchang village	109°47'05"	19°33'25"	157	artificial pure forest	50
5	Chengmai	Zhongxing	Liwan village	110°54'38"	19°37'57"	122	rubber mixed forest	82
6	Dingan	Fuwen	Baihe village	110°12'21.3"	19°26'47.7"	110	artificial pure forest	100
7	Dingan	Long-Hu	Gaolin village	110°29'0.2"	19°35'04.6"	60	artificial pure forest	10
8	Danzhou	Dacheng	Qiangtu village	109°24'38.1"	19°30'40.8"	155	artificial pure forest	210
9	Tunchang	Nankun	Shanyoupo village	109°58'39.4"	19°09'49.3"	217	artificial pure forest	45
10	Tunchang	Poxin	Xinpo village	110°30'5"	19°37'48.4"	40	artificial pure forest	46
11	Baisha	Xishui	Shihan village	109°32'19.2"	19°12'33.4"	210	artificial pure forest	32
12	Qiongzong	Changzheng	Xinzhai village	109°51'46"	18°58'33"	352	rubber mixed forest	43
13	Qiongzong	Wanling	Shiwan village	109°57'13.8"	19°10'26.7"	276	artificial pure forest	65
14	Qionghai	Huishan	Zhongjiu village	110°18' 20.2"	19°05' 17.6"	60	artificial pure forest	300
15	Qionghai	Jiaji	Hongxing committee	110°27'36"	19°15'02"	40	areca-nut mixed forest	54
16	Wuzhishan	Changhao	Shiha village	109°27'55.7"	18°40'47.6"	728	artificial pure forest	62
17	Wuzhishan	Tongshi	Nanding village	109°34'41.5"	18°49'50.3"	748	artificial pure forest	58
18	Baoting	Xiangshui	Maorui forest farm	109°31'40"	18°38'55.2"	738	artificial pure forest	46

Five mid-sized trees from each forest were selected as the samples. The samples of soil were collected by wooden spade one meter away from the sampling trees, at a depth of 0 to 20 cm. The soil samples were then mixed and stored up to 1 kg by quartation method. The slim roots of 5 g from each tree sample were taken after removing the surface soil. Forty mature leaves were collected from east, south, west, and north of each tree; four mid-sized fruits were collected as well.

Soil samples were naturally air-dried indoors and filtered through 0.147 mm nylon sieve. The plant samples were repeatedly cleaned by water and deionized water thrice to remove dirt and mud. The kernels were removed from the fruits. The leaves, roots and kernels were fixed at 105°C for 30 minutes and crushed after drying at 65°C to obtain a constant weight.

2.2. Determination of Se and Heavy Metals in Soil

The soil contents of Se, Hg, and As were measured according to the standard industrial methods in NYT1104-2006 (Chinese Standard, the same below), NY/T 1121.10-2006 and NY/T 1121.11-2006 using atomic fluorescence

spectrophotometry (AFS-9120, Beijing Jitian Instruments Co., Ltd, China). The soil contents of Zn, Cr, Pb and Cd were measured according to the processing methods described in the national standard (GB/T 17141-1997) by inductively coupled plasma mass spectrometry (ICP-MS) (ELAN, DRC-e, PerkinElmer, US).

2.3. Determination of Se and Heavy Metals in Plant

The content of Se in roots, leaves, and kernels of *Camellia oleifera* was measured according to the processing method described in the Chinese national standard GB/T 21729-2008. Zn, As, Cr, Hg, Pd and Cd were measured according to the processing method described in the national standards GB/T 5009.14-2003, GB/T 5009.11-2003, GB/T 5009.123-2003, GB/T 5009.17-2003, GB 5009.12-2010, and GB/T 5009.15-2003, respectively.

2.4. Statistical Analysis

All measurements were performed in triplicate. Excel 2010 and SPSS 17.0 software were utilized for statistical analysis. Certain data and analysis were absent due to undetectable low content of metal elements.

Table 2. Se and six heavy metals in the forest soil of *Camellia oleifera* in Hainan (mg·kg⁻¹).

Location	pH	Zn	Cr	Pb	Cd	As	Hg	Se
Wenchang-Penglai	4.5±0.2	110±0.6	267±0.4	5.51±0.2	0.1500±0.030	1.34±0.05	0.050±0.012	1.540±0.135
Haikou-Dongshan	4.4±0.2	98.8±0.5	145±0.3	10.2±0.3	0.1130±0.016	2.92±0.20	0.062±0.003	0.944±0.032
Chengmai-Jiale	4.8±0.3	36.0±0.3	10.4±0.2	25.7±0.1	0.0569±0.003	1.81±0.06	0.030±0.001	1.100±0.062
Chengmai-Heling farm	5.1±0.2	24.3±0.5	24.0±0.2	14.5±0.2	0.0508±0.001	1.64±0.05	0.075±0.003	1.200±0.017
Chengmai-Zhongxing	4.5±0.2	8.26±0.2	5.64±0.3	7.93±0.2	0.0195±0.002	1.48±0.07	0.017±0.001	0.489±0.032
Dingan-Fuwen	4.6±0.3	42.7±0.3	39.9±0.3	27.9±0.4	0.0491±0.004	6.40±0.36	0.059±0.004	0.996±0.099
Dingan-Longhu	4.2±0.1	98.5±0.4	174±0.4	37.4±0.4	0.1420±0.007	1.88±0.05	0.072±0.003	1.610±0.035
Danzhou-Dancheng	4.7±0.2	65.0±0.5	81.0±0.5	25.8±0.4	0.0521±0.007	2.61±0.15	0.118±0.007	0.999±0.095
Tunchang-Nankun	4.6±0.1	68.4±0.4	43.1±0.7	62.0±0.3	0.0726±0.001	0.61±0.01	0.048±0.003	0.857±0.006
Tunchang-Poxing	5.0±0.3	78.0±0.3	7.54±0.4	40.2±0.4	0.0494±0.010	1.24±0.18	0.042±0.009	1.230±0.192
Baisha-Xishui	5.6±0.2	30.3±0.6	16.4±0.6	19.4±0.6	0.0569±0.003	2.46±0.07	0.031±0.002	0.665±0.055
Qiongzong-Changzheng	5.3±0.2	65.2±0.4	42.9±0.5	38.3±0.4	0.0569±0.003	1.72±0.19	0.053±0.003	1.150±0.178
Qiongzong-Wanling	5.0±0.3	26.0±0.4	54.2±0.3	28.2±0.3	0.0504±0.002	1.18±0.17	0.065±0.004	1.700±0.142
Qionghai-Huishan	4.0±0.2	20.3±0.7	17.1±0.4	10.1±0.9	0.0570±0.008	1.21±0.10	0.040±0.014	0.520±0.087
Qionghai-Jiaji	4.6±0.3	96.4±0.4	43.6±0.4	37.6±0.4	0.3070±0.022	4.28±0.30	0.110±0.021	2.110±0.173
Wuzhishan-Changhao	5.4±0.1	55.0±0.5	9.32±0.4	30.8±0.4	0.1260±0.024	2.87±0.33	0.060±0.003	0.804±0.031
Wuzhishan- Tongshi	4.9±0.1	68.4±0.4	21.5±0.4	32.9±0.3	0.0397±0.005	0.73±0.14	0.097±0.016	1.070±0.253
Baoting-Xiangshui	4.5±0.2	39.5±0.4	6.56±0.2	41.1±0.6	0.0813±0.002	2.18±0.15	0.080±0.003	1.590±0.030

3. RESULTS AND ANALYSIS

3.1. Soil Contents of Se and Heavy Metals

It was found from 18 forests that Se content ranged between 0.480 and 2.110 mg/kg, which was high according to the classification method [3]. The Se content exceeded 1.0 mg/kg in 10 forests such as in Penglai of Wenchang county. All the soil samples were acidic, and the heavy metal content was relatively low; the 'Soil Environmental Quality Standard' (GB, 15618 - 1995) was used as a reference. The As and Hg contents of all the tested regions were lower than first-grade standard level. The Zn content was lower than first-grade standard level except of Penglai in Wenchang. The Cr content of all the tested regions was lower than the first-grade standard level except for Penglai in Wenchang county, Dongshan in Haikou county, and Longhu in Dingan county. Though Pb content of six counties such as Longhu in Dingan county exceeded first-grade standard level, all tested samples were lower than second-grade standard. The Cd content in all tested regions was lower than natural background, except in Jiaji of Qionghai county, which was higher than second-grade. All tested soil samples fulfilled the requirements of soil environmental quality for

green food production using 'green food producing area environment quality' (NY/T 319 - 2013) as reference, except soil Cr in Penglai of Wenchang county, Dongshan of Haikou county, and Longhu of Dingan county, soil Pb in Nankun of Tunchang county, and soil Cd in Jiaji of Qionghai county (Table 2).

3.2. Se and Heavy Metals Contents in Plant

As shown in Table 3, there was difference in all root samples obtained from 18 forests in terms of Se and heavy metals contents. The Se content in roots was relatively low, with the maximum of only 0.104 mg/kg being the highest in Heling farm and Jiale in Chengmai county, followed by Wuzhishan county. The Zn, Cr and Cd, Pb, As and Hg contents in roots were the highest in Nankun of Tunchang county, Jiale in Chengmai county, Changhao of Wuzhishan county, Dacheng of Danzhou county and Heling farm of Chengmai county, respectively.

As shown in Table 4, Se content in leaves of *Camellia oleifera* was the highest in Heling farm of Chengmai county, followed by Jiale of Chengmai county; and it was the lowest

Table 3. Se and six heavy metals in the roots of *Camellia oleifera* in Hainan (mg·kg⁻¹).

Location	Zn	Cr	Pb	Cd	As	Hg	Se
Wenchang-Penglai	47.1±0.2	26.10±0.27	2.90±0.19	0.52±0.10	0.13±0.01	<0.01	<0.02
Haikou-Dongshan	38.6±0.8	13.26±1.24	6.18±0.16	0.33±0.02	0.31±0.01	0.042±0.001	<0.02
Chengmai-Jiale	58.7±0.2	53.16±0.13	15.4±0.32	1.60±0.15	0.29±0.02	0.110±0.024	0.092±0.004
Chengmai-Heling farm	17.9±0.4	12.79±0.26	6.30±0.28	0.54±0.17	0.16±0.02	0.220±0.012	0.104±0.004
Chengmai-Zhongxing	31.1±1.9	29.08±0.25	9.10±0.31	1.30±0.14	0.22±0.02	0.036±0.002	<0.02
Dingan-Fuwen	13.2±0.5	31.78±0.25	25.1±0.30	0.83±0.08	0.35±0.01	0.045±0.003	0.030±0.001
Dingan-Longhu	15.4±0.3	30.71±0.14	6.30±0.17	0.43±0.06	0.17±0.01	0.032±0.002	<0.02
Danzhou-Dancheng	12.4±0.2	48.18±0.15	23.9±0.20	1.30±0.14	0.72±0.02	0.041±0.002	0.034±0.002
Tunchang-Nankun	61.2±0.2	31.54±0.29	23.2±0.41	0.95±0.14	0.20±0.02	0.072±0.002	<0.02
Tunchang-Poxing	31.1±0.2	16.86±0.24	13.8±0.19	0.58±0.07	0.12±0.01	<0.01	<0.02
Baisha-Xishui	21.2±0.3	7.42±0.16	22.3±0.26	1.40±0.13	0.50±0.04	0.048±0.002	0.032±0.001
Qiongzong-Changzheng	9.5±0.1	11.68±0.15	23.3±0.10	0.88±0.06	0.10±0.03	0.048±0.001	0.042±0.006
Qiongzong-Wanling	8.7±0.2	14.60±0.28	17.6±0.10	0.47±0.07	<0.1	0.030±0.006	0.016±0.002
Qionghai-Huishan	6.4±0.1	14.63±0.46	3.50±0.06	0.41±0.01	<0.1	0.022±0.001	0.035±0.007
Qionghai-Jiaji	6.0±0.1	7.85±0.16	3.10±0.17	0.05±0.01	<0.1	0.046±0.001	0.041±0.007
Wuzhishan-Changhao	25.2±0.2	26.57±0.37	49.1±0.44	0.61±0.13	0.65±0.01	0.095±0.001	0.074±0.004
Wuzhishan-Tongshi	18.7±0.5	12.16±0.17	8.55±0.43	0.40±0.13	0.10±0.02	0.088±0.001	0.080±0.006
Baoting-Xiangshui	14.4±0.1	10.26±0.19	6.57±0.08	0.26±0.03	0.09±0.01	0.040±0.002	0.088±0.005

Table 4. Slenium and six heavy metals in the leaves of *Camellia oleifera* in Hainan (mg·kg⁻¹).

Location	Zn	Cr	Pb	Cd	As	Hg	Se
Wenchang-Penglai	<0.4	0.82±0.05	0.42±0.05	0.045±0.006	<0.1	<0.01	0.025±0.004
Haikou-Dongshan	<0.4	1.35±0.12	0.60±0.04	0.028±0.004	<0.1	0.022±0.003	0.057±0.002
Chengmai-Jiale	<0.4	2.28±0.05	0.54±0.05	<0.01	<0.1	0.032±0.004	0.077±0.005
Chengmai-Heling farm	<0.4	0.59±0.04	1.50±0.07	<0.01	<0.1	<0.01	0.120±0.003
Chengmai-Zhongxing	<0.4	1.56±0.05	1.00±0.04	<0.01	<0.1	0.095±0.005	0.056±0.010
Dingan-Fuwen	<0.4	2.45±0.05	1.30±0.07	0.012±0.002	<0.1	0.014±0.005	0.046±0.005
Dingan-Longhu	<0.4	3.03±0.07	0.66±0.05	0.031±0.006	<0.1	0.035±0.005	0.045±0.005
Danzhou-Dancheng	<0.4	0.89±0.04	0.51±0.05	0.024±0.005	<0.1	0.086±0.005	<0.02
Tunchang-Nankun	<0.4	1.38±0.07	0.30±0.03	0.022±0.005	<0.1	<0.01	0.020±0.002
Tunchang-Poxing	<0.4	1.99±0.11	0.30±0.02	0.018±0.004	<0.1	0.046±0.005	0.064±0.005

Table 4. contd...

Location	Zn	Cr	Pb	Cd	As	Hg	Se
Baisha-Xishui	<0.4	1.44±0.11	0.50±0.08	0.089±0.007	<0.1	0.030±0.002	0.039±0.006
Qiongzong-Changzheng	<0.4	1.25±0.06	0.20±0.04	<0.01	<0.1	0.032±0.006	0.051±0.006
Qiongzong-Wanling	<0.4	0.06±0.01	0.15±0.01	0.013±0.003	<0.1	0.045±0.003	0.059±0.007
Qionghai-Huishan	<0.4	0.35±0.06	0.89±0.05	0.038±0.003	<0.1	0.033±0.004	<0.02
Qionghai-Jiaji	<0.4	0.48±0.01	0.09±0.02	0.034±0.006	<0.1	0.021±0.005	0.025±0.005
Wuzhishan-Changhao	<0.4	1.52±0.05	0.34±0.05	0.015±0.005	<0.1	0.062±0.007	0.047±0.006
Wuzhishan- Tongshi	<0.4	1.55±0.08	0.09±0.01	0.012±0.006	<0.1	0.073±0.003	0.025±0.002
Baoting-Xiangshui	<0.4	0.28±0.02	0.25±0.01	0.014±0.001	<0.1	0.038±0.006	0.035±0.004

Table 5. Se and six heavy metals in *Camellia oleifera* Kernels in Hainan (mg·kg⁻¹).

Location	Zn	Cr	Pb	Cd	As	Hg	Se
Wenchang-Penglai	<0.4	0.59±0.03	0.04±0.01	0.024±0.002	<0.1	<0.01	0.038±0.004
Haikou-Dongshan	<0.4	1.35±0.04	0.59±0.02	0.020±0.002	<0.1	0.011±0.001	<0.02
Chengmai-Jiale	<0.4	4.54±0.06	0.06±0.01	0.031±0.004	<0.1	0.010±0.004	<0.02
Chengmai-Heling farm	<0.4	4.25±0.05	0.21±0.04	0.025±0.005	<0.1	<0.01	<0.02
Chengmai-Zhongxing	<0.4	0.63±0.05	0.94±0.01	0.039±0.004	<0.1	0.012±0.001	<0.02
Dingan-Fuwen	<0.4	0.16±0.01	<0.05	0.019±0.004	<0.1	0.039±0.004	0.085±0.006
Dingan-Longhu	4.80±0.1	0.18±0.01	0.20±0.01	0.016±0.004	<0.1	0.037±0.005	0.060±0.006
Danzhou-Dancheng	3.80±0.1	0.22±0.02	0.14±0.02	0.030±0.002	<0.1	0.032±0.004	0.041±0.001
Tunchang-Nankun	11.1±0.1	0.22±0.03	0.08±0.01	0.023±0.004	<0.1	0.015±0.004	<0.02
Tunchang-Poxing	11.7±0.2	3.92±0.06	0.08±0.01	0.024±0.004	<0.1	<0.01	<0.02
Baisha-Xishui	11.9±0.1	0.60±0.01	0.15±0.03	0.025±0.004	<0.1	0.010±0.002	<0.02
Qiongzong-Changzheng	9.50±0.1	0.29±0.04	0.20±0.02	0.048±0.003	<0.1	0.026±0.003	<0.02
Qiongzong-Wanling	1.40±0.1	0.40±0.05	<0.05	0.018±0.003	<0.1	0.018±0.006	<0.02
Qionghai-Huishan	10.8±0.1	4.13±0.04	0.14±0.02	0.016±0.005	<0.1	0.011±0.005	<0.02
Qionghai-Jiaji	6.00±0.1	2.74±0.05	0.31±0.01	0.037±0.022	<0.1	0.013±0.004	<0.02
Wuzhishan-Changhao	16.8±0.1	1.55±0.04	0.19±0.02	0.013±0.004	<0.1	<0.01	<0.02
Wuzhishan- Tongshi	24.3±0.1	0.65±0.04	0.33±0.03	0.036±0.006	<0.1	0.0135±0.004	<0.02
Baoting-Xiangshui	17.7±0.1	0.12±0.02	0.13±0.01	0.014±0.002	<0.1	0.0120±0.001	0.022±0.005

in Dacheng of Danzhou county and Huishan of Qionghai county. Cr content in leaves was the highest in Longhu of Dingan county, followed by Fuwen of Dingan county. Pb, Cd, and Hg contents in the leaves were the highest in Heling farm of Chengmai county, Xishui of Baisha county, and Zhongxing of Chengmai county, respectively. The Cd content was undetectable in leaves in four counties including

the Heling farm of Chengmai county; the content of Hg was undetectable in leaves in three counties which include Penglai of Wenchang county. The Zn and As contents in leaves from all 18 counties were undetectable.

As shown in Table 5, Se content in kernels of *Camellia oleifera* was very low, only detectable in five regions and

Table 6. Coefficients of Se and heavy metal elements in soils and different parts of *Camellia oleifera* in Hainan.

	Zn	Cr	Pb	Cd	As	Hg	Se
Root	0.191	0.134	0.308*	-0.497**	0.436**	0.075	-0.214
Leaf	-	0.088	-0.176	-0.127	-	0.004	-0.139
Kernel	-0.107	-0.218	0.015	0.809**	-	0.164	-

Note: **indicates correlated at P<0.01 level; *indicates correlated at P<0.05 level. Certain data are absent due to undetectable content of Zn and Se in leaves and As and Se in kernels in some areas. Similar conditions apply in the following tables.

Table 7. Coefficients of Se and heavy metal levels in roots, leaves, and seeds of *Camellia oleifera* in Hainan.

	Zn	Cr	Pb	Cd	As	Hg	Se
Leaf	-	0.469**	0.151	0.576**	-	-0.157	-0.076
Kernel	0.244	-0.038	0.075	-0.305*	-	0.605**	-

Table 8. Coefficients of Se and heavy metal concentrations in roots and leaves of *Camellia oleifera* in Hainan.

	Zn	Cr	Pb	Cd	As	Hg
Root	-0.141	-0.079	-0.147	-0.095	-0.368*	-0.119
Leaf	-	0.239	-0.057	-0.025	-	0.159

was highest in Fuwen of Dingan county. Zinc content in kernels was highest in Tongshi of Wuzhishan county, and undetectable in six regions including Penglai of Wenchang county. Cr content in kernels exceeded 1.0 mg/kg in seven regions such as Dongshan of Haikou county. Pd content in kernels was over 0.5 mg/kg in Dongshan of Haikou county and Zhongxin of Chengmai county. The contents of Cd, As and Hg were very low, undetectable in kernels of all the 18 forests.

3.3. Correlation of Se and Heavy Metals Between Soil and Roots, Leaves, and Kernels of *Camellia oleifera*

Significant positive correlation in As and Pb contents was observed between soil and roots of *Camellia oleifera*. However, significant negative correlation of Cd content between soil and roots of *Camellia oleifera* was observed. Significant positive correlation between soil and kernels was only found for Cd content; suggesting that only soil As and Pb content showed high biological availability for *Camellia oleifera* (Table 6).

To investigate the transferability of metal elements from roots to leaves and kernels, the correlation study was used to compare the contents of each element in different parts of *Camellia oleifera* (Table 7). It was found that there was significant positive correlation between roots and leaves in terms of Cr and Cd content; and there was positive correlation between roots and leaves in terms of Pd content. However, significant negative correlation was found between roots and leaves in terms of Hg and Se contents. In addition, there was significant positive correlation between roots and kernels with regard to Hg content; whereas, significant negative correlation was found between roots and

kernels in terms of Cd content, implying that Cr and Cd are easily translocated from roots to leaves, and Hg from roots to kernels.

3.4. Correlation Between Se and Six Metal Elements in Roots and Leaves

The relationship between the roots and leaves regarding the Se content and 6 metal elements is shown in Table 8. There was negative correlation of content between Se and the other six metal elements in the roots of *Camellia oleifera*, and significant negative correlation was found between Se and As in roots. A positive correlation between Se and Cr content as well as Hg in leaves, and negative correlation between Se and Pd as well as Cd, suggested that Se reduced the absorption of heavy metals by roots, especially the absorption of As.

4. DISCUSSION

Se-enriched soil is widely distributed in Hainan Island of China. Se content was high in the soils of Haikou and Chengmai counties [15]. It has been confirmed in the current study that Se content ranged between 0.489 and 2.110 mg/kg in 18 forests of *Camellia oleifera*, which is higher than that in the soil of rice paddy fields [15]. The soil Se content was higher than 1.0 mg/kg in 10 forests out of 18. However, there was no significant correlation between the soil and roots of *Camellia oleifera* with respect to Se content. The Se content in leaves and kernels was also low, probably due to acidic soil conditions and impaired biological availability of Se [16]. Our findings suggest that blindly supplementing Se fertilizer in the nutrient management of

Camellia oleifera should be avoided. Instead, alkaline fertilizer to promote the activation of Se and improve its bioavailability in soil [17], or screen for suitable *Camellia oleifera* varieties should be recommended to produce effective and economical Se-enriched camellia oil [2, 18]. The average content of heavy metals in soil was low in *Camellia oleifera* forests of Hainan province and fulfilled the requirements for green-food production. However, the heavy metal content in soil and *Camellia* trees greatly varied geographically with different cultivation methods, which might be attributed to diverse soil characteristics and use of chemical fertilizers [19]. Therefore, instead of chemical fertilizers containing heavy metals, ecofriendly cultivation using manures [20] and forest intercropping [21] should be adopted.

The content of heavy metals in roots was higher than that in leaves and kernels, suggesting that *Camellia* restricts the translocation of heavy metals from roots to leaves and kernels [22], which is the key to successful utilization of seeds of *Camellia oleifera*. The mechanism of heavy metal distribution in the plant following absorption from soils should be further elucidated. Also, production processes that limit heavy metal transfer from roots to kernels should be adopted. Variations in heavy metal accumulations by different organs of plants are a consequence of species and climate diversity [23], which is also known as heavy metal enrichment coefficient.

CONCLUSION

In the current study, the enrichment coefficient was relatively higher for Zn, Cr and Pb by the roots of *Camellia oleifera*, which was consistent with the study based on tropical trees such as *Casuarina equisetifolia* [24]. Significant positive and negative correlations were found between soil and roots with regard to As and Pb contents, respectively, implying that As and Pb are easily activated and absorbed by *Camellia oleifera*, since they are associated with high utilization efficiency of phosphate [25]. Therefore, it is necessary to further analyze the relationship between essential elements and heavy metal activation in *Camellia* [26]. A significant positive correlation between the roots and leaves in terms of Cr and Cd contents was observed. A significant positive correlation between roots and kernels in terms of Hg content suggested that the transportation of Hg into fruits was relatively easier. It is thus essential to control the Hg content in soil to reduce the risk of Hg absorption. Se and six heavy metals were in negative correlation in roots, especially Se and As, implying that strengthening of Se enrichment effectively reduced the accumulation of heavy metals [27]. Therefore, in addition to increasing Se bioactivity in soil, Se supplementation through leaves is recommended to regulate heavy metal distribution in fruits [28], after carrying out additional testing and analysis.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGEMENTS

This work is supported by Special Fund for Forestry Scientific Research in the Public Interest (201504705).

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Received: August 27, 2014

Revised: November 21, 2014

Accepted: December 19, 2014

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