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Effect of Pb on growth, accumulation and quality component of tea plant

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Abstract

The present study evaluates growth, lead (Pb) uptake and quality component of tea plant grown for 3 years on a Pb contaminated soil. Results showed that phytotoxic symptoms appeared more obviously and biomass decreased significantly as application of Pb increased. The ability of Pb accumulation of tea plant, having a positive correlation with Pb treatment concentrations, was in the sequence of root > stem > shoot. Root was the main part of tea plant to fix Pb. At the minimum concentration of Pb treatment (800mg.kg\textsuperscript{-1}), Pb content in shoot had exceeded the maximum amount limit (5mg.kg\textsuperscript{-1} DM) in tea for safe drinking. Pb increased catechin content while caffeine and free amino acid contents were reduced slightly.

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Keywords: Pb treatment; biomass; Pb accumulation; quality component; tea plant

1. Introduction

Rapid economic growth and human activities have caused serious heavy metal contamination of soils in many parts of the world, including China. Soil heavy metal contamination mainly comes from long-term irrigation with polluted water, air precipitation due to human activities, inappropriate development of mineral resources, and the application of large amount of fertilizers and pesticides\cite{1}. Tea, made of fresh tender leaves of tea plant, is a very popular beverage. Nowadays, Pb residues in tea have aroused wide concern\cite{2}. And tea garden soils contaminated by Pb were found in China. Previous studies have

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mainly been focusing on Pb accumulating patterns of different tissues under Pb stress in a short time by hydroponic or pot experiment, etc[3-10]. This research lasted 3 years when tea plants are formally put into production. It was done with typical type of tea garden soils in Sichuan Province, and after treating each soil sample with Pb, the growth, Pb distribution, and quality component changes were investigated to learn effects of Pb treatments on tea plant, which can provide a scientific foundation for tea plants cultivation, tea processing and safe consumption.

2. Materials and Methods

2.1 Soil preparation

The soils used were representative of the average characteristics of tea garden soils in Sichuan Province. Table 1 shows details of the soil properties.

Table 1. Physical-chemical characteristics of soil

| Soil nature | pH  | Organic matter (g.kg⁻¹) | N (g.kg⁻¹) | Polsen (mg.kg⁻¹) | K (mg.kg⁻¹) | Pb (mg.kg⁻¹) |
|-------------|-----|-------------------------|------------|------------------|-------------|--------------|
| Purple soil | 5.18| 10.38                   | 54.36      | 6.73             | 41.37       | 28.36        |

2.2 Plant growth

Mingshan-Baihao (camellia sinensis L.), 30cm in height and 3mm in diameter, were cutting seedlings taken from the same tree. For heavy metal application, stock solutions of Pb(CH₃COO)₂.3H₂O were mixed with potting soil at the following six levels per 1000 g of soil: (1) 0 (control); (2) 800 mg of Pb as Pb(CH₃COO)₂.3H₂O; (3) 1100 mg of Pb; (4) 1400 mg of Pb; (5) 1700 mg of Pb; (6) 2100 mg of Pb. Then, 8000g of each treated soil sample was charged into a separate PVC pot (30/35 cm, diameter/height). Six tea plants were transplanted into each pot on April 24th 2007. Every two pots was one single treatment and each treatment was replicated three times. The growth period lasted for 3 years.

2.3 Plant analysis

Plants were then harvested by cutting the root, stem and shoot (one bud with two leaves) on December 22th 2010. Organs were washed with tap water and rinsed several times with deionised water, dried at 80°C for 24h, and the dry matter (DM) was measured. Pb concentrations in the digests were determined by ICP-AES[3, 6, 11-14]. Catechin, caffeine and free amino acid were measured by HPLC.

2.4 Data analysis

Data was submitted to one-way ANOVA with SPSS (version 13.0). LSD was performed for comparisons of means derived from control and Pb treatments at a significant level of 0.05.

3. Results and discussion

3.1 Plant growth and biomass

After grown for 3 years, tea plant showed variable phytotoxic symptoms. Some slightly yellow leaves and weak sprouting ability were observed between 800 and 1400 mg.kg⁻¹ of Pb, whereas some yellower and wilting leaves and smaller buds appeared between 1700 and 2100 mg.kg⁻¹ of Pb. As application of Pb increased, all these symptoms turned even more obvious. But there was no plant dead during the study.
It indicated that tea plant had a good tolerance of Pb and Pb treatments in this experiment did not cause any serious harm to them..

One of the most common effects of Pb stress on crops is loss of photosynthetic pigments and is well documented by several earlier workers[3, 6, 12-14]. And then biomass production decreased for inhibited photosynthesis that was induced by chlorophyll loss. In this study, biomass of root, stem and shoot decreased along with, respectively, 17.54-65.38%, 3.32-50.37% and 20.10-73.45% reduction compared to the control (Figure 1). Significant decline in DM of shoot suggested that tea plant would yield poorly under Pb stress.

![Figure 1. Biomass production of different parts of tea plant by Pb treatments in DM (dry matter). Different letters indicate significant differences at P≤0.05.](image)

3.2 Pb accumulation within the plant tissues

As can be seen from the Table 2, Pb treatments had appreciable effects on Pb accumulation in plant tissues. Root had a significantly stronger ability of Pb accumulating than stem and shoot with the following order: root>stem>shoot. In contrast with the control, Pb accumulation increased, respectively, by 30.61-97.62, 30.21-185.16, 10.15-40.04 times in root, stem and shoot. Root was the main part of tea plant that fixed Pb. Pb accumulation in tea plant was much more higher than its normal plant concentrations 1-5 mg.kg-1 DM[1, 15]. And results presented in this study confirmed that tea plant was hyper-accumulator of Pb. Similar results were showed in hydroponic and pot experiment[3-10].

Moreover, in this study, Pb concentration in shoot had exceeded the maximum amount limit in tea(5mg.kg-1). It suggested that tea made of shoot in this experiment was unsafe to drink. According to the linear regression equation, adding 483.19mg.kg-1 of Pb into soil can cause Pb content in tea exceed the maximum amount limit.
Table 2. Pb accumulation in root, stem and shoot (mean value±SD)

| Treatments | Root      | Stem       | Shoot       |
|------------|-----------|------------|-------------|
| Pb0        | 51.29±0.55| 7.71±0.08  | 0.84±0.02   |
| Pb800      | 1570.21±73.89 | 232.95±11.08 | 8.53±0.11   |
| Pb1100     | 2268.19±238.80 | 443.41±11.48 | 12.30±0.11  |
| Pb1400     | 3095.02±114.06 | 559.72±10.19 | 18.44±0.24  |
| Pb1700     | 3768.35±187.93 | 1241.67±2.53 | 29.78±0.12  |
| Pb2100     | 5006.72±402.47 | 1427.57±9.28 | 33.63±0.02  |

Transfer factor (TF) is a ratio of metal content in soil and plants, establishing the pattern of metal translocation from soil to plant parts, i.e. root (TFr), stem (TFst) and shoot (TFsh). TF is calculated by dividing the metal concentrations in plant tissue with the amount of bio-available metals in contaminated soil[16]. Pb is considered as the least mobile among the studied metals[17]. Non-essential toxic element-Pb showed lower translocation (TFsh<1) for shoot and tended to accumulate mostly in root and stem(Table 3). The higher values of TFr and TFst can be attributed to their shorter distance from the soil to tissues and Pb’s weak mobile ability.

Table 3. Translocations factors(TF) between soil extractable Pb with Pb content in plant parts(DM), TFr, TFst and TFsh respectively

| Treatments | Root | Stem | Shoot |
|------------|------|------|-------|
| Pb0        | 5.51 | 0.83 | 0.090 |
| Pb800      | 2.73 | 0.41 | 0.015 |
| Pb1100     | 3.18 | 0.62 | 0.017 |
| Pb1400     | 3.26 | 0.59 | 0.019 |
| Pb1700     | 3.11 | 1.02 | 0.025 |
| Pb2100     | 3.25 | 0.93 | 0.022 |

Linear regressions (R²) were performed between soil exchangeable metals (mg.kg⁻¹) with metal concentrations in different plant parts—root, stem and shoot (mg.kg⁻¹ of DM) to evaluate the metal translocation from soil to plant parts. TFr, the highest TF value, was statistically supported by the highest R² (0.9943) value, expressing the highest Pb translocation in soil-plant system.

3.3 Effect of Pb treatment on total contents of catechin, caffeine and free amino acid

Investigation of quality components response against various metal stresses on different crop plant species is important for the identification of potential excellent-quality variety. Results for quality parameters were represented in Table 4. Under Pb stress, tea plant showed varied reduction in total caffeine and free amino acid contents but increase in catechin. And this can be attributed to enhanced carbon metabolism which induced weak nitrogen metabolism at the same time. Catechin content was positively correlated with Pb treatment concentrations (R²=0.587) while the other two contents were negatively correlated along with R², respectively, -0.6571 and -0.8529. Moreover, the taste became terrible because increases in ratios of catechins and free amino acids aggravated bitter and astringent of tea [18].
Table 4. Catechin, caffeine and free amino acid content

| Treatment | EGC   | EC    | EGCG  | ECG   | Caffeine | Amid acid |
|-----------|-------|-------|-------|-------|----------|-----------|
| Pb0       | 15.30±0.4 <sup>9</sup> | 9.90±0.4 | 100.75±6.21 | 22.52<sup>bc</sup>±0.8 | 45.82<sup>a</sup>±3.58 | 33.41<sup>a</sup>±1.97 |
| Pb800     | 26.19±0.58 | 13.79±0.70 | 113.65<sup>abc</sup>±11.6 | 22.55<sup>bc</sup>±0.6 | 41.80<sup>b</sup>±1.8 | 21.66<sup>b</sup>±1.8 |
| Pb1100    | 18.29±0.23 | 9.67±0.39 | 103.65<sup>b</sup>±11.33 | 20.96±1.67 | 40.43<sup>b</sup>±2.2 | 17.17±1.02 |
| Pb1400    | 21.39±0.9 <sup>6</sup> | 11.79±0.29 | 113.09<sup>abc</sup>±7.53 | 25.41±0.98 | 39.65<sup>b</sup>±1.9 | 16.98±1.99 |
| Pb1700    | 21.54±1.4 <sup>9</sup> | 11.05±0.17 | 116.06<sup>b</sup>±8.54 | 24.37<sup>ab</sup>±1.1 | 40.67<sup>b</sup>±1.4 | 16.51<sup>c</sup>±1.18 |
| Pb2100    | 19.23±0.71 | 11.67±0.41 <sup>b</sup> | 125.81±6.13 | 26.59<sup>a</sup>±2.72 | 40.81<sup>b</sup>±1.8 | 14.81<sup>c</sup>±1.25 |

4. Conclusion

This investigation reveals that Pb can inhibit tea plant growth by reducing biomass and debase tea quality by changing quality component contents. Pb treatment may lead to some sort of health risk to people due to consumption of tea growing on Pb polluted soil. Tea plant, having a strong ability of transferring Pb from the soil to tissues, is a hyper-accumulator of Pb in comparison to normal plants. So it has the potential to be used for the phytoextraction of Pb from a polluted soil. Therefore deep going study on Pb contaminated soil amendment by tea plant is strong recommended.

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References

[1]. Chaney, R., Toxic element accumulation in soils and crops: protecting soil fertility and agricultural food chains. Inorganic contaminants in the vadose zone. Springer-Verlag, Berlin, 1989: p. 140–158.

[2]. Ren-zhou, D. and Z. Jiu-qian, Research Progress of Major Influencing Factors to Tea Safety. Journal of Hebei Agricultural Sciences, 2008. 7.p.60-62.

[3]. Hai-xia, L. and X. Jian-guo, Absorption and Accumulation of Lead and Cadmium in Mengshan Tea Plant [J]. Journal of Agro-Environment Science, 2008. 3.p.1077-1083.

[4]. Hongyan, J. and G. Shuying, A review on research of lead pollution in tea. Journal of Tea, 2004.p.210-212.

[5]. Mengli, K., et al., A Study on Properties of uptake and accumulation of lead by tea plant [J]. Journal of Tea, 2004. 2.p.88-90.

[6]. Qian, T., et al., Effects of plumbum and chromium stress on the growth of tea plants. Southwest China Journal of Agricultural Sciences, 2008.p.156-162.
[7]. Xia, J., Lead Stress on Growth of Tea Trees and Physiological Index in Leaves of Tea. Journal of Agro-Environment Science. 29(1): p. 43-48.

[8]. Shi, Y., et al., Influence Factors on Lead Contents in Longjing Tea. Journal of Agro-Environment Science, 2004. 23(5): p. 899-903.

[9]. WenYan, H., et al., Pb absorption and accumulation in tea plants. Journal of Tea Science, 2009. 29(3): p. 200-206.

[10]. Yang, R., et al., Effects of metal lead on growth and mycorrhizae of an invasive plant species (Solidago canadensis L.). Journal of Environmental Sciences, 2008. 20(6): p. 739-744.

[11]. Zhao, F., S. McGrath, and A. Crosland, Comparison of three wet digestion methods for the determination of plant sulphur by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Communications in soil science and plant analysis, 1994. 25(3): p. 407-418.

[12]. Gupta, S., et al., Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. Environmental Monitoring and Assessment. 165(1): p. 169-177.

[13]. John, R., et al., Effect of cadmium and lead on growth, biochemical parameters and uptake in Lemna polyrrhiza L. Plant Soil and Environment, 2008. 54(6): p. 262.

[14]. Singh, A., P. Misra, and P. Tandon, Cadmium induced metabolic disorders in pea (Pisum sativum L.). Journal of Ecophysiology and Occupational Health, 2005. 5(3/4): p. 185.

[15]. Markert, B., Presence and significance of naturally occurring chemical elements of the periodic system in the plant organism and consequences for future investigations on inorganic environmental chemistry in ecosystems. Plant Ecology, 1992. 103(1): p. 1-30.

[16]. Smolders, E., Cadmium uptake by plants. International Journal of Occupational Medicine and Environmental Health, 2001. 14(2): p. 177-183.

[17]. Nayek, S., S. Gupta, and R. Saha, Metal accumulation and its effects in relation to biochemical response of vegetables irrigated with metal contaminated water and wastewater. Journal of Hazardous Materials. 178(1-3): p. 588-595.

[18]. Yibo, H., Analysis of Influencing Factors on Quality of Xinyang Maojian Tea. Journal of Anhui Agricultural Sciences, 2007. 35(22): p. 6842.