Determination of Soil Cadmium Threshold for Potato

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In this study, pot experiments were conducted to investigate the characteristics of Cd transfer to potato tubers from two types of soil. The results showed that the Log-normal and Burr III functions can be used to determine the sensitivity of different potato varieties to Cd as well as the soil Cd threshold. With regard to the prediction accuracy, the root mean squared error (RMSE) values for the total Cd bioaccumulation factor (BAF_{total}) calculated with both functions were smaller than those for exogenous Cd bioaccumulation (BAF_{add}) in acidic and alkaline soils, indicating that BAF_{total} is more appropriate for the calculation of the soil Cd threshold. The average Cd threshold values in acidic soil calculated with the Log-normal and Burr III functions were 0.411 and 0.461 mg kg^{-1}, and the average values in alkaline soil were 0.716 and 0.888, respectively. The Log-normal function can also be applied to fit the sensitivity distributions of different species for the development of appropriate soil Cd threshold values for conservation purposes.

Keywords: cd, potato, bioaccumulation, food safety, soil threshold

INTRODUCTION

Cadmium (Cd) is a toxic heavy metal that is harmful to plants, microorganisms and humans (Zhong, et al., 2015). The evaluation of soil Cd levels and Cd transfer from the soil to plants is therefore a critical issue. Potato is the fourth most important crop in China, behind wheat, rice and corn. The ecology of Karst areas is fragile and human activities are more likely to cause soil Cd pollution in these areas. Therefore, it is necessary to pay more attention to Cd transfer from the soil to crops in Karst areas (Zhang, et al., 2020).

The Cd content in different organs generally increases in the order of leaves > stem/root > tuber (Chen, et al., 2014). The Cd content in the tuber is less than that in other organs and most of the Cd is retained by other organs (Ye, et al., 2020). Soil properties such as pH or organic matter (OM) markedly influence the distribution of metals between the phytoavailable and non-phytoavailable sections of a plant (Pinto, et al., 2015); (Hough, et al., 2004). Other metal ions can also affect plant absorption of Cd from the soil; for instance, correlation analysis of different potato varieties showed a strong positive relation between the bioaccumulation of Cd and the presence of zinc (Zn), copper (Cu) or manganese (Mn) (Ashrafzadeh, et al., 2017). The plant species also affect soil Cd uptake. For example, the tomato genotype affects the nutritional value, fruit quality, yield, etc, and Cd-tolerant cultivars were found to accumulate more Cd than sensitive cultivars (Carvalho, et al., 2018). The results of these studies confirmed that Cd uptake by plants is influenced by various factors including the soil properties and crop varieties. Bioaccumulation factor (BAF) is used to study the transfer of a pollutant from the soil to plants and to calculate the threshold value for the pollutant in the soil to ensure food safety. A prediction model for Pb transfer to wheat from 17 soil types with different Pb levels in China was fitted using the BAF and soil properties to determine the soil
Pb threshold (Liu, et al., 2016). Some scholars developed and compared regression models based on BAF for the uptake of Cd by potatoes through field investigations (Novotna, et al., 2015).

The cumulative probability distribution method have been used to evaluate the risk of pollutants in humans and are helpful to establish the soil threshold for heavy metals as well as for soil screening. The species sensitivity distribution (SSD) is a typical cumulative probability distribution that reflects the differences in the sensitivity of different species to the same pollutant (Liu, et al., 2015). Environmental toxicity data for pollutants such as the concentration necessary to achieve 50% of the maximal effect (EC50), no observed effect concentration (NOEC) and BAF for a limited number of species obtained through biological toxicity tests are sampled based on the SSD. Establishing a threshold that covers the fifth percentile of the SSD protects the majority of the species in an ecosystem (van der Hoeven, 2001). This strategy is applied more frequently to water environments; for example, the SSD for nine compounds indicates that crustaceans are the most sensitive species to anticancer drugs in aquatic ecosystems (Li D et al., 2021). Furthermore, it has been increasingly applied to soil environments in recent years. A soil-plant transfer model was applied to Cd data for 183 soil-plant pairs to fit the SSD and 5 grades of Cd sensitivity were obtained based on the Cd-BAF (Li, et al., 2019). Many function models are available for SSD fitting, including the Burr III, Log-normal, Log-logistic and Gamma functions. The Gaussian distribution function was used to determine the cumulative probability distribution for vegetables and the soil Cd threshold in the Hunan Province of southern China as well as to implement a reasonable soil Cd risk assessment strategy for the locality (Yang et al., 2016a). The potential health risk to humans from Cd exposure was evaluated using the target hazard quotient (THQ) and the probability distribution of THQ for 324 vegetable samples in Shandong, Jiangsu, Yunnan Province in China was identified with the Log-normal function (Hu, et al., 2018). The Cd toxicity threshold for paddy soil was determined based on the variation of BAF in various rice cultivars using SSD fitted with the Burr III function (Song, et al., 2015). The appropriate model depends on the specific situation in terms of the polluted species and the regulation of the environment.

In the present study, we aimed to: 1) explore the transfer of Cd from two types of soil with different pH values to potato tubers of different cultivars; 2) compare the fit of SSD curves using the Log-normal and Burr III functions for different potato cultivars in the two soil types; and 3) obtain a soil threshold value for the safe production of potato using different calculation methods for BAF.

**MATERIALS AND METHODS**

**Pot Experiments**

Soil was collected from two Karst geological regions in China, specifically from Weineng and Guiyang cities in Guizhou Province. Soil samples were collected from the surface of a field (0–20 cm) in these regions, air dried and passed through a 2 mm sieve to remove large pieces of gravel prior to the pot experiments. The base Cd concentrations were 0.61 and 0.37 mg kg⁻¹ for the Weineng (yellow) and Guiyang (calcareous) soil, respectively. The two soils are the main soil types in Guizhou province. Soil properties were determined using standard methods. Soil pH was determined using a glass electrode with a soil:water ratio of 1:2.5 (g ml⁻¹). The pH values for the Weineng and Guiyang soil were 4.8 and 7.8. The measured OM values were 24.5 and 48.5 g kg⁻¹, respectively, using the potassium dichromate oxidation method. Ten commercial potato varieties commonly grown in the local area, namely Eeshu 5 (E5), Lishu 15 (L15), Qianyu 8 (Q8), Qingshu 9 (Q9), Weiyu 5 (W5), Lishu 13 (L13), Hongbaoashi (HBS), Heimeiren (HMR), ChuangyuA5e (CA5e) and Weiyu 7 (W7), were used in the experiments.

The potato varieties were planted in the two soil types in the way of pot experiment (greenhouse). Six kilograms of soil was placed in a plastic pot to ensure the normal growth of the potatoes. Exogenous Cd in solution (3CdSO₄ 8H₂O) was added to the soil and mixed uniformly. Two treatments were applied, with three replicates for each pot. The control treatment (CK) lacked additional Cd, and 0.9 mg kg⁻¹ Cd was mixed with the two soil types for the Cd treatment. The amount of Cd added was based on the risk value for Chinese Cd soil contamination in agricultural land (0.3 mg kg⁻¹ for soil pH ≤7.5, 0.6 mg kg⁻¹ for soil pH > 7.5). Additionally, 0.15 g kg⁻¹ N (CO(NH2)₂), 0.05 g kg⁻¹ P(Ca(H₂PO₄)₂) and 0.1 g kg⁻¹ K (K₂SO₄) were added to each pot as the base fertilizer. The treated soil was left to equilibrate for 40 days to allow the behavior of Cd ions in the soil to stabilize. Potatoes with similar sizes and weights were selected for planting in the pot experiments. The potatoes were watered with deionized water to ensure that the Cd absorbed by the plants came from the soil. The soil moisture content was maintained at about 70% of the water holding capacity.

**Detection of Cd in Soil and Plants**

After passing the soil through a 100 mesh sieve, 0.1 g was weighed (accurate to 0.0001) and transferred to a polystyrenefluoroethylene (PTFE) tank. Afterward, 3 ml nitric acid, 1 ml hydrochloric acid and 1 ml hydrofluoric acid were added and the capped tank was placed in a matched steel pipe before digesting for 20 h at 180°C on an electric heating plate. Perchloric acid (1 ml) was added as the acid driver. After digestion of the soil sample, the digestion solution was transferred to a 50 ml volumetric flask and a constant volume was maintained with ultrapure water. Finally, 10 ml of the supernatant from the digested sample solution was collected and the Cd concentration was measured using inductively coupled plasma mass spectrometry (ICP-MS; Thermo Fisher Scientific, Waltham, MA, United Sates, x2). The basic test conditions was injection speed: 0.8 ml min⁻¹; atomization gas flow rate: 0.92 ml min⁻¹; auxiliary gas flow rate: 0.7 ml min⁻¹; cooling gas: 13 L min⁻¹; the detection limit of the instrument is less than 1 ppb.

Potato tubers were collected at maturity and washed three times successively with tap water and purified water to remove soil particles from the surface. The potato tubers were placed in a
105°C electric oven for 15 min to remove green sections and then dried to a constant weight at 75°C. The plant samples were ground and stored for determination of the Cd content. We weighed 0.2 g (accurate to 0.0001) of edible plant samples into a PTFE tank, then added 5 ml nitric acid and two to three drops of hydrofluoric acid for 12 h for pre-digestion. The initial digestion solution was heated to 160 °C and digested for 8 h to remove OM. After cooling, a constant volume of 50 ml was maintained. The determination method for the Cd content in the plants was the same as that for the soil. For quality control, all the acid reagents used were of high grade purity. The glassware and PTFE tube used for digestion were soaked in 25% nitric acid solution for 12 h before use. The soil reference material GSS-5 and plant reference material GBW10021 were adopted for quality control.

**Calculation Method for BAF**

BAF represents the ratio of the heavy metal concentration in plants to the heavy metal concentration in the soil environment. The BAF for the CK treatment (BAF<sub>ck</sub>) was calculated using the equation:

\[
BAF_{ck} = \frac{C_{plant} - C_{CK:plant}}{C_{soil} - C_{CK:soil}}
\]  

Where, \(C_{plant}\) and \(C_{soil}\) are the concentrations of heavy metals in the plants and soil for the Cd treatments.

Some scholars (Ding, et al., 2013) proposed a BAF calculation method for exogenous pollutants that only considers the effects of exogenous pollutants on plants. The BAF for exogenous Cd (BAF<sub>add</sub>) was calculated with the equation:

\[
BAF_{add} = \frac{(C_{plant} - C_{CK:plant})}{(C_{soil} - C_{CK:soil})}
\]  

Where, \(C_{plant}\) and \(C_{soil}\) are the concentrations of heavy metals in the plants and soil for the Cd treatments, respectively.

**RESULTS AND DISCUSSION**

**BAF for Cd in Two Soil Types**

The variability of BAF is important for the assessment of Cd exposure for plants in contaminated soil and represents the current contamination situation (Augustsson, et al., 2015). As seen in Figure 1, the total Cd-BAF for tubers grown in Weining soil varied between 0.09 (HMR) - 0.33 (QS9) for BAF<sub>ck</sub> and 0.07 (HMR) - 0.25 (CA5e) for BAF<sub>total</sub>. The average BAF<sub>ck</sub> and BAF<sub>total</sub> values for the 10 potato varieties evaluated in this study were 0.23 and 0.17, respectively. Twenty-one potato samples were collected from a field in the Czech Republic and the average BAF was 0.34, which was greater than the values obtained in the current study because of differences in the soil properties (Novotna, et al., 2015). The BAF<sub>ck</sub> for each potato variety was slightly higher than the corresponding BAF values for the Cd treatments. In contrast, the BAF<sub>add</sub> for carrot in 21 soil types from China was less than the BAF<sub>total</sub> for the Cd treatment (soil spiked with 0.6 mg kg<sup>-1</sup> Cd) (Ding, et al., 2013). The difference in the results may be attributed to the use of different crops and the crop growth conditions. For both the CK and Cd treatments, the HMR potato variety accumulated the least Cd while the CA5e variety accumulated the most. In a previous study, three potato cultivars that easily uptake Cd from the soil, known as Cd accumulators, were identified from 10 cultivars based on the BAF and plant Cd concentration (Ashrafzadeh, et al., 2017). These studies demonstrate that identifying crop genotypes with low or high Cd accumulation based on the enrichment factor is an effective method to avoid Cd pollution in food.

The BAF<sub>add</sub> of Cd for the 10 potato varieties evaluated in this study ranged from 0.04 (HMR) to 0.19 (CA5e), and the average BAF<sub>add</sub> was 0.13, which was slightly less than the average BAF<sub>total</sub> and BAF<sub>ck</sub>. The BAF<sub>total</sub> and BAF<sub>ck</sub> indicated that the CA5e potato variety could easily uptake soil Cd, while the HMR and HBS varieties absorbed less Cd from the soil. A prediction model was established based on soil Cd content, plant Cd content and soil properties (pH and organic carbon) and the results showed that the BAF<sub>total</sub> and BAF<sub>add</sub> can be used to develop a prediction model.
model for Cd transfer from the soil to vegetables as well as for identifying soil thresholds for food safety (Liang, et al., 2013). Empirical soil-carrot transfer models were developed for 21 soil types in China and the prediction model for added Cd was found to be better than the model for total Cd (\( R^2: 0.77 > 0.73 \)) (Ding, et al., 2013). These results indicated that BAF\(_{\text{total}}\) and BAF\(_{\text{add}}\) are both valuable parameters for studying soil Cd uptake in crops and calculating the soil threshold.

The Cd-BAF of tuber grown in Guiyang soil ranged from 0.03 (W5) to 0.08 (L15) for BAF\(_{\text{ck}}\) and from 0.05 (L15) to 0.13 (QY8) for BAF\(_{\text{total}}\). The average BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\) of the tubers were 0.06 and 0.09 for different potato varieties, respectively. Some researchers studied the accumulation of Cd in potato with different soil Cd levels (soil Cd < 25 mg kg\(^{-1}\)) and found that the BAF\(_{\text{total}}\) and BAF\(_{\text{add}}\) ranged from 0.20 to 0.81. The BAF\(_{\text{total}}\) values in these studies were larger than our results, probably due to higher Cd pollution (<25 mg kg\(^{-1}\)) and low OM content (14.6 g kg\(^{-1}\)) in the soil compared to our soil conditions (soil Cd: 0.9 mg kg\(^{-1}\), OM: 48 g kg\(^{-1}\)) (Chen, et al., 2014). Most of the BAF\(_{\text{total}}\) values were higher than the BAF\(_{\text{ck}}\) values for specific varieties in the alkaline Guiyang soil and the opposite results were obtained in the acidic Weining soil. The biggest difference between the BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\) was found in the W5 variety, which had a BAF\(_{\text{total}}\) value that was 2.74 times greater than the BAF\(_{\text{ck}}\). The BAF\(_{\text{add}}\) ranged from 0.02 (L15) to 0.17 (QY8), with an average BAF\(_{\text{add}}\) of 0.11, which was close to the BAF\(_{\text{total}}\) for the Cd treatments.

The transfer of Cd from the soil to the potato tubers was limited with the HMR and HBS varieties in both the Weining soil and Guiyang soil for the CK and Cd treatments. The QY8 and CA5e varieties were sensitive to Cd uptake from the Guiyang soil, while QY8, QS9 and CA5e were sensitive to Cd uptake from the Weining soil. QY8 and CA5e were sensitive to Cd uptake with the CK and Cd treatments in the Weining and Guiyang soils, as indicated by the high BAF\(_{\text{total}}\) and BAF\(_{\text{add}}\). The BAF\(_{\text{add}}\) and BAF\(_{\text{total}}\) values demonstrated that Cd-sensitive and insensitive potato varieties were similar in the two soil types with different pH values and the genotype affected food safety in the polluted soils.

The BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\) values in the alkaline Guiyang soil differed from those in the acidic Weining soil. Figures 1, 2 show that the ability of the potato varieties to absorb Cd in acidic soil was stronger than that in alkaline soil for both the CK and Cd treatments based on the average BAF\(_{\text{total}}\) and BAF\(_{\text{ck}}\). pH is an important factor that affects the adsorption, desorption, precipitation, dissolution and complexation of heavy metals in the soil and can directly or indirectly affect the retention of heavy metals in the soil. In a previous study in which the soil pH was increased by 0.50 units through lime addition, the uptake of Cd by rice grain decreased by 35.3% and the Cd transfer ratio increased as the soil pH decreased in acidic and alkaline soils (Zhu, et al., 2016). The results of the current study demonstrated that the soil type and genotype significantly affect Cd uptake by potato and so
does the interaction between these two factors. Luyin No. One was identified from four potato cultivars as a suitable cultivar for planting in slightly Cd-contaminated soils (<0.6 mg kg\(^{-1}\)). The average reported BAF\(_{\text{add}}\) for different cultivars is 2.3, which is less than the reported BAF\(_{\text{total}}\) value (2.76) in soil with pH 6.9 and is similar to the results for our acidic Weining soil (BAF\(_{\text{add}}\) 0.13 < BAF\(_{\text{total}}\) 0.17) (Ding, et al., 2014). In general, there was significant difference between the Weining soil and Guiyang soil in both the BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\), however, BAF\(_{\text{add}}\) was different from BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\) (Table 1 in the Supplementary Data S1). The BAF\(_{\text{ck}}\), BAF\(_{\text{total}}\) and BAF\(_{\text{add}}\) of some varieties have significant differences, while other varieties have no significant differences among each other in the two soils, moreover, the significant difference of the BAF\(_{\text{total}}\) was similar to that of BAF\(_{\text{add}}\) (Table 2 in the Supplementary Data S1).

### Comparison of Log-Normal and Burr III Functions

SSD is used to create a cumulative probability distribution curve with toxicity data that follow certain probability distributions such as the Log-normal distribution. A cumulative probability of “p” indicates that (100-p)% of organisms in the ecosystem are relatively safe in an environment containing the pollutant at the given concentration (Maltby, et al., 2009). It is worth noting that the “p” value is determined by the local environment safety management department rather than science, and 5% is often used as the threshold value for ecological safety. The soil Cd threshold for each potato variety was obtained based on the BAF (C\(_{\text{soil threshold}}\) = 0.1/BAF, 0.1 mg kg\(^{-1}\) is the limit for the Chinese food safety standard (GB 2762–2017); BAF can refer to BAF\(_{\text{ck}}\), BAF\(_{\text{total}}\) or BAF\(_{\text{add}}\)). The C\(_{\text{soil threshold}}\) of 10 potato varieties was applied to calculated the final soil Cd threshold in order to protect 95% potato and the value of soil Cd threshold was equaled to the 5% cumulative probability. The Burr III or Log-normal function was used to generate an SSD curve and a 5% cumulative probability to protect 95% of species was set as the final soil threshold to protect most potato varieties from Cd damage. A similar method was applied to determine the Cd soil threshold for wheat in different soils using the SSD fitted with the Log-normal function (Liu, et al., 2015). The soil Cd threshold increased with the increase of the cumulative probability. When the cumulative probability was less than 30%, the soil threshold calculated with the Log-normal function was less than that calculated with the Burr III function. In contrast, when the cumulative probability was greater than 30%, the opposite results were obtained for the soil threshold calculated with the two functions. The BAF\(_{\text{ck}}\) indicated that the sensitivity levels of the QS9 and HMR varieties to soil Cd were significantly different. QY8 and QS9 easily absorbed Cd from the soil and other potato varieties were relatively insensitive to Cd compared to these two varieties (Figure 3A). The BAF\(_{\text{total}}\) values for the potato varieties were evenly distributed on the two SSD curves. The soil Cd threshold fitted with the Log-normal function was less than that obtained with the Burr III function at a low cumulative probability (<30%) and was similar to the BAF\(_{\text{ck}}\). The HMR variety was the most insensitive to Cd, evidenced by both the BAF\(_{\text{ck}}\) and BAF\(_{\text{total}}\). The soil Cd threshold was obtained based on the BAF\(_{\text{total}}\) and the SSD curves fitted with the Burr III and Log-normal functions were “S-shaped” (Figure 3B). When we focused on the effect of Cd addition on the bioavailability of potato tubers (BAF\(_{\text{add}}\)), we found that the CA5e potato variety was relatively sensitive to soil Cd while the HMR variety had a strong resistance to soil Cd uptake. The curves calculated with the Burr III and Log-normal functions were almost the same when the cumulative probability
was less than 5%; therefore, the soil Cd thresholds calculated with the two functions were relatively similar when the protection of more than 95% of potato varieties was taken into consideration (Figure 3C). Based on a combination of the BAFtotal and BAFadd values, the CA5e and HMR potato varieties were the most sensitive and insensitive to soil Cd in Weining soil in Karst areas, respectively. The identification of Cd-resistant potato varieties is helpful for local food safety. In a study using SSD, Xiangzao 17 was identified as the most sensitive rice cultivar to soil Cd among 20 rice cultivars based on the cumulative probability distribution curve calculated with 1/BAF. The results demonstrated that the SSD method was helpful to screen sensitive and insensitive varieties for pollutants (Song, et al., 2015).

The soil threshold for Cd established with the Burr III function was higher than that calculated with the Log-normal function at a low cumulative probability, and the opposite was true for a high cumulative probability (Figures 4A,B). This result was similar to the results for the SSD curves of BAFck and BAFtotal for the Cd treatments in Weining soil. However, the SSD curve fitting for BAFadd with the Burr III function was quite different from that with the Log-normal function, and unlike the SSD curve in acidic Weining soil (Figure 4C). QY8 was sensitive and L15 was insensitive to Cd uptake, as indicated by their respective curves for BAFtotal and BAFadd. The Burr III function is considered the best function for soil Cd threshold calculations and has been used to determine the soil Cd threshold for vegetables including potato in acidic and neutral soils based on the BAFadd-Cd-sensitive species and hazardous concentrations within the fifth percentile, reflecting the protection of 95% of species, can also be determined using the SSD (Ding, et al., 2018). The sensitivity levels of the potato varieties were similar in the acidic Weining soil and the alkaline Guiyang soil, as indicated by the BAFtotal and BAFadd, but differed from the sensitivity levels with CK treatment, as indicated by BAFck. The toxicity sensitivity of different potato varieties to the soil Cd can be directly observed from the SSD curves based on the BAFck, BAFtotal and BAFadd, which reflect the transfer capacity of heavy metals.

The RMSE represents the deviation between the prediction and the measured value, and a smaller RMSE indicates better prediction accuracy. The RMSE between the predicted and measured soil Cd threshold values for the 10 potato varieties established with BAFadd was larger than that established with BAFck and BAFtotal in the two soil types using the two functions (Table 1). This suggested that BAFtotal and BAFck were more suitable for studying the transfer of Cd from the soil to plants. The predictive accuracy of the BAFck and BAFtotal values was better in Weining and Guiyang soils, respectively. The RMSE values for the Burr III function with the BAFck and BAFtotal values were less than those for the Log-normal function in acidic Weining soil, indicating that the Burr III function was better suited for determining the soil Cd threshold for this soil type. Log-normal was more appropriate for BAFadd and BAFck in alkaline Guiyang soil. The high prediction accuracy of the soil threshold for BAFck, BAFtotal and BAFadd confirmed that the Burr III and Log-normal functions can both be applied to obtain the soil Cd threshold. However, the optimal function needs to be selected depending on the soil type and BAF calculation method. BAFadd was reported to be better for the determination of the soil Cd threshold for the safe production of rice in paddy soils (pH: 4.94–6.72) and the Burr III function is commonly used to fit SSD curves (Li L et al., 2021). The results of these studies are different from ours, in which BAFtotal was better than BAFadd, probably due to different experimental conditions and species.
As shown in Table 2, the soil Cd threshold for the Weining soil calculated with the Log-normal function was a little less than that calculated with the Burr III function using the BAFck, BAFtotal and BAFadd values. The soil Cd threshold obtained with BAFadd was higher than those obtained with BAFck and BAFtotal. The average soil Cd threshold was slightly higher than the Chinese national soil standard for Cd (0.3 mg kg\(^{-1}\)). Similarly, the soil Cd threshold in Guiyang soil calculated with the Burr III function was higher than that calculated with the Log-normal function and was slightly higher than the Chinese soil screening value for agriculture (0.6 mg kg\(^{-1}\)). The soil Cd threshold for BAFadd was lower than those for BAFck and BAFtotal. These findings differed from the results obtained for Weining soil. Some researchers have applied similar methods to determine the soil threshold for other pollutants. The soil Pb threshold was obtained for 12 root vegetable cultivars based on the SSD and the threshold values based on BAFadd were lower than the standard for Pb in the soil (Ding et al., 2016). Risk evaluation of Cd in soil-rice systems \((n = 124)\) was conducted using SSD curves from rice Cd-BAFtotal in Hunan Province, China (Yang et al., 2016b). The soil Cd threshold obtained in this study is conducive to the protection of local potatoes from Cd pollution, the evaluation of Cd pollution and the development of soil quality guidelines.

**CONCLUSION**

The BAF values for different potato varieties in acidic soil were higher than those in alkaline soil for the CK and Cd treatments. The HMR and CA5e potato varieties were quite insensitive and sensitive in acidic soil, whereas QY8 and L15 were sensitive and insensitive in alkaline soil. The soil Cd threshold values obtained with the Log-normal function using BAFck, BAFtotal and BAFadd were less than those obtained with the Burr III function in the Weining and Guiyang soils. The soil Cd threshold values were in the order BAFadd > BAFtotal > BAFck in Weining soil for the Log-normal and Burr III functions. The soil Cd threshold values were in the order BAFck > BAFtotal > BAFadd for the Guiyang soil. The RMSE for BAFtotal was less than that for BAFadd based on the two functions in the Weining and Guiyang soils, indicating that BAFtotal was more appropriate for calculating the soil threshold of Cd compared to BAFadd.

**DATA AVAILABILITY STATEMENT**

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

**AUTHOR CONTRIBUTIONS**

WL: Writing—original draft preparation, Investigation and formal analysis. XII: Investigation, Writing and Editing. JZ: Experimental formal analysis and software analysis. KL: Methodology, Writing—review and editing, Formal analysis.

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**SUPPLEMENTARY MATERIAL**

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.808362/full#supplementary-material

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