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Risk assessment for potentially toxic metal(loid)s in potatoes in the indigenous zinc smelting area of northwestern Guizhou Province, China

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ABSTRACT

We investigated potentially toxic metal (loid)s (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; selenium, Se; and zinc, Zn) in agricultural samples (i.e., *Solanum tuberosum* L. tubers (potatoes) and their planting media) in the indigenous zinc smelting area of northwestern Guizhou Province, China. Based on the pollution index values for As, Cd, Pb and Zn, the order of the samples was as follow: slag > planting soil with slag > planting soil without slag, and the order of the samples in terms of the bioconcentration factor was the opposite. Cr, Cu and Hg were present in the planting soil with and without slag at slight pollution levels, and the other potentially toxic metal (loid)s had different degrees of contamination. Additionally, the potentially toxic metal (loid) contents in potato were under their limit values except for Cd (all samples) and Pb and Se (some samples). All bioconcentration factors for potatoes were below 0.5, and no health risk index value for potatoes was higher than 0.1. Therefore, although no significant health risk associated with potentially toxic metal (loid)s via consuming potato exists for either adult men or women in the research area, the Cd concentration in this crop should be monitored.

1. Introduction

Potentially toxic metal (loid)s include the 11 most environmentally important metal (loid)s, i.e., arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), mercury (Hg), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se) and zinc (Zn), and other less known but environmentally important elements (Alloway, 2013). We selected and analyzed eight potentially toxic metal (loid)s – As, Cd, Cr, Cu, Hg, Pb, Se and Zn – according to the potentially toxic limits for these eight metal (loid)s in cereals, legumes, tubers and their products (MAPPC, 2005), because these eight metal (loid)s are used in industry and are generally toxic (Smith and Scott, 2005).

Although indigenous zinc smelting has been banned by local governments (in 2006 in the northwestern region of Guizhou Province and in 2003 in the north of France (Batonneau et al., 2004), the environmental impacts of this process persist. The slag produced by indigenous zinc smelting has been stored in the surrounding surface soil of the smelter sites without treatment, which has resulted in serious contamination and environmental risk (Peng et al., 2018). Furthermore, this slag contains high concentrations of potentially toxic metal (loid)s that are released over long periods of time (Wu et al., 2002). Although most of the potentially toxic metal (loid)s in this slag are generally dominated by polymetallic or other phases (e.g., sulfide-rich phases) (Ettler et al., 2003; Scokart et al., 1983; Sobanska et al., 2016), they can be easily transported due to long-term natural weathering (Deng et al., 2015; Ma et al., 2015; Sobanska et al., 2016; Tyszka et al., 2014) or other processes occurring in acidic (low-pH) environments (Scokart et al., 1983; Sobanska et al., 2016; Yang et al., 2006).

Additionally, potentially toxic metal (loid) contamination, especially in food, is a very important issue for plants, animals and human beings. Potentially toxic metal (loid) pollution is a global problem because it could influence human health via respiration, food, and drinking water (Siegel, 2002). Potentially toxic metal (loid)s play a vital part role in the health of plants, animals and human beings, either directly or indirectly (Peng et al., 2017). Chronic intake of potentially toxic metal (loid)s has damaging effects on human beings and other animals (Zheng et al., 2007). Food is a dominant source of potentially toxic metal (loid) exposure (Ferrante et al., 2018). The accumulation of heavy metals in crops may create a potential public health risk (Cherfi et al., 2014; Gebrekidan et al., 2013; Nagajyoti et al., 2010; Pinto et al., 2015; Skalnaya et al., 2018; Zhang et al., 2018), because they are toxic to humans and plant tissues (Khan et al., 2015). Moreover, conditions in

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which the concentrations of these potentially toxic metal (loid)s are too high or are totally lacking can lead to adverse health effects (Erdman Jr et al., 2012; Ferrante et al., 2017a, 2017b; Fraga, 2005; Jomova and Valko, 2011; Kakkar and Jaffery, 2005; Satarug, 2018; Satarug et al., 2017; Tinkov et al., 2018; Zhang et al., 2018). Therefore, local residents might have elevated health risks from the ingestion of potentially toxic metal (loid)s via food crops grown in the indigenous zinc smelting area.

The health risks associated with potato consumption with respect to potentially toxic metal (loid)s are a very important issue. Potatoes (*Solanum tuberosum* L.), which belong to the *Solanaceae* family, are perennial herbs with edible tubers. In addition, the potato has a high nutritional value, such as a high protein content (containing 18 kinds of essential amino acids, including various amino acids that the human body cannot synthesize), abundant vitamins (including vitamin C and a variety of other vitamins that are useful for the human body), abundant dietary fiber and little fat. *Solanum tuberosum* L. is also the fourth largest food crop in the world; it plays an irreplaceable role in ensuring food security and achieving the Millennium Development Goals (Xie, 2012). According to 2016 data from the Food and Agriculture Organization (FAO) (http://faostat.fao.org/), the worldwide planting acreage and yield of *Solanum tuberosum* L. are approximately $1924.65 \times 10^4\,hm^2$ and $3.77 \times 10^8\,t$, respectively. In China, the *Solanum tuberosum* L. planting acreage is approximately $581.51 \times 10^4\,hm^2$ (accounting for 30.21% of the global planted area), and fresh potato production is approximately $0.99 \times 10^8\,t$ (26.25% the global annual production); both the planting acreage and yield of *Solanum tuberosum* L. in China ranked first in the world. The Chinese Ministry of Agriculture issued “guidance on promoting the development of the potato industry” on February 23, 2016. The potato was established as a staple food product for industrial development. Meanwhile, it is also suggested that by 2020, the potato planting area will have expanded to more than 100 million acres. The proportion of varieties suitable for staple food processing will reach 30%, and the consumption of staple food will account for 30% of the total potato consumption. Additionally, the northwestern region of Guizhou Province is also an important planting base for *Solanum tuberosum* L. in Guizhou Province.

Moreover, *Solanum tuberosum* L. and *Zea mays* L. are two common and widely grown crops in the area surrounding the indigenous zinc smelting slag in the northwestern region of Guizhou Province. And *Solanum tuberosum* L. is usually intercropped with *Zea mays* L. In this area, some slag is commonly present in the soil in which the crops (i.e. *Solanum tuberosum* L. and *Zea mays* L.) are grown. Thus, the food safety of potatoes represents an important issue in relation to people's health and needs to be solved, especially in areas contaminated with potentially toxic metal (loid)s (i.e., the indigenous zinc smelting area in the northwestern region of Guizhou Province). Although some researchers have studied the presence of potentially toxic metal (loid)s in potato and vegetables (i.e., Cd in *Solanum tuberosum* L. (Fu et al., 2014) and Cd, Pb and Zn in vegetables (Yang et al., 2011b) in the indigenous zinc smelting area; Cd of potato in Weining County (Zhang et al., 2017); 12 elements (Briki et al., 2015) and 10 elements (Shao et al., 2018) in vegetables in Hezhang County), few have focused on evaluating the potentially toxic metal (loid)s present in potato grown in different planting media, especially indigenous zinc smelting slag. Therefore, in this study, the distribution analysis and risk assessment of eight potentially toxic metal (loid)s – As, Cd, Cr, Cu, Hg, Pb, Se and Zn – in *Solanum tuberosum* L. tubers (potatoes) grown in different planting environments were carried out in the indigenous zinc smelting area in the northwestern region of Guizhou Province, China. The aim was to better understand the contamination of the cultivated area and the impact on crops and to develop some recommendations for improving crops in the research area.

2. Materials and methods

2.1. Research area

The research area in this study is mainly in Weining and Hezhang Counties, northwestern Guizhou Province, where concentrated indigenous zinc smelting occurred. The area has elevations ranging from 1185 to 2901 m, and an average elevation of more than 2000 m (CCCBPGP, 1995). The region features a humid subtropical climate: the annual average sunshine ranges from 1380.5 to 1769.8 h, the temperature ranges from 10.5 to 13.4°C, the average annual rainfall ranges from 849.2 to 934.8 mm, and the frost-free period lasts for more than 209 days (CCCBPGP, 1995). In addition, the research area exhibits clear plateau climatic characteristics, such as small annual changes in air temperature and large diurnal changes in air temperature. The large diurnal change in air temperature is conducive to the accumulation of dry crop matterial. In Weining County especially, there covers more than 80% of the area at elevations above 2000 m, which is suitable for planting *Solanum tuberosum* L. and sweet beet crops. Therefore, Weining County is an important planting area for *Solanum tuberosum* L. and sweet beets. Moreover, there is a long history of planting *Solanum tuberosum* L. in Weining County. As early as April 2008, Weining County was awarded the title of “potato town of South China” by the Potato Specialized Committee of China's Food Industry Association.

2.2. Collecting samples

In August 2015, we collected a total of 38 samples of potatoes and their planting media (i.e., indigenous zinc smelting slag, planting soil with slag and planting soil without slag around the slag pile; samples were collected from a depth range from 0 to 20 cm) from 19 different sampling sites in the indigenous zinc smelting area (Fig. 1). These sampling sites (i.e., Bojigou: BJG, Xingfayingpanzai: XFYPZ, Xingfa: XF, Jiaomeiba: JMB, Yingpanzai: YPZ, Caoziping: CZP, Huangjiazai: HJZ, Lianmincun: LMC, Lushanxingzhuangcun: LSXZC, Liangshuigou: LSG, Fuweijiaohuachang: FWJHC, two sampling sites in Leijiaping: LJP and Yancangliangshuijing: YCLSJ, and three sampling sites in Chayuan: CY) were located near some typical piles of indigenous zinc smelting slag and its surrounding soils planted with *Solanum tuberosum* L. The planting media included 9 samples of indigenous zinc smelting slag, 4 samples of planting soil with slag, and 6 samples of planting soil without slag around the slag pile, as shown in Table 1.

2.3. Sample analyses

The methods and preparation of the sample analyses followed those in the references (Peng et al., 2018, 2017).

2.3.1. Analysis of the planting media samples

The samples of the planting media (slag, planting soil with slag and planting soil without slag from locations around the slag pile; each sample was approximately 1 kg) were halved by applying the quartering method after removing foreign substances. One-half of each sample was dried at 30 °C to a constant weight in a thermostatic air-blower-driven drying closet and then sieved with a 10-mesh nylon sieve. The pH of each dry sieved sample (10.00 g of sample mixed with 25 ml deionized water) was determined by a pen pH meter (SX620 type, Instrument Factory of Shanghai Sanxin, Shanghai, China). In addition, we sent 100 g of each dry samples to an accredited laboratory (ALS Minerals – ALS Chemex (Guangzhou) Co. Ltd.) to determine the concentrations of potentially toxic metal (loid) (As, Cd, Cr, Cu, Hg, Pb and Zn) (Peng et al., 2018, 2017). The simple analysis procedure for the planting media samples was as follows (Peng et al., 2018).

One hundred grams of each of the dry samples was gently disaggregated with a rubber hammer and sieved through an 80-mesh sieve (0.18 mm) to remove other foreign substances (e.g., gravel, iron