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Cadmium in soybeans and the relevance to human exposure

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Introduction

Cadmium is considered a human carcinogen by the International Agency for Research on Cancer (IARC, 1993) and the US National Toxicology Program (NTP, 1997). Cadmium contamination of food crops is a persistent issue for both the agricultural industry as well as consumers. This is an issue for agriculture because cadmium can be present in soils naturally or as a result of industrial processes and can contaminate foods that are consumed by humans. Industrial wastewater used for irrigation of agricultural crops can introduce toxic metals, including cadmium, to plant roots. Some fertilizers can introduce metals into agricultural soils. For example, phosphate fertilizers contain cadmium, which can further exacerbate the amount of cadmium available for crops. For these reasons, there have been a number of studies (Benavides et al., 2005; Brown and Jones, 1975; Foy et al., 1978; Ernst et al., 1992; Das et al., 1997; Sanita di Toppi and Gabrielli, 1999; Hall, 2002; Clemens et al., 2002; Choppala et al., 2014; Newbigging et al., 2015) examining metal toxicity in crops. This short review focuses on the routes of exposure of cadmium to humans and the efforts to minimize exposure by using cadmium-excluding soybean cultivars.

1. Cadmium toxicity to humans

Piscator (1985) reviewed the main exposures to cadmium in the general population. Other than industrial exposures, the main exposure to cadmium in the general populations is through food (Friberg et al., 1974), with minimal cadmium exposures from air and drinking water (average daily intake ranges from less than 1 μg to 1–2 μg) (Sharett et al., 1982) and cigarette smoking. The Agency for Toxic Substances and Disease Registry recommends a chronic intake of cadmium below 0.1 μg/kg/day to prevent renal toxicity (ATSDR, 2012).

The main concern about cadmium toxicity is chronic exposure. For example, the onset of *itai-itai* disease, or cadmium poisoning, in Japan in the 1950s brought attention to the issue of ingesting crops grown on cadmium-contaminated soils (Kobayashi, 1978). However, Japanese rice farmers only began to show symptoms of cadmium toxicity because of the accumulation of cadmium caused by habitually consuming their own crops which were irrigated with mining wastewater. Although their symptoms did not appear for many years, sufferers of *itai-itai* disease eventually developed osteoporosis and kidney damage. Other symptoms caused by chronic exposure to elevated levels of cadmium include the development of cancer, liver failure, and the suppression of blood cell production (Waalkes, 2000). Although there are studies showing that people who ingested large amounts of cadmium-contaminated shellfish (Sharma et al., 1983; McKenzie-Parnell and Eynon, 1987; Sirot et al., 2008) or cadmium- and zinc-contaminated crops (Strehlow and Barltrop, 1988; Sarasua et al., 1995) exhibited no symptoms of cadmium poisoning,

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chronic exposure to cadmium remains a health concern for its organ toxicity and its carcinogenic effects.

2. Global cadmium production

One method to minimize cadmium uptake in soybean crops is to avoid cadmium contaminated soils; however, this is not easily done because of the vast soybean production over limited agricultural land available. For example, the maximum permissible concentration of cadmium in agricultural soils in China is 0.3 mg/kg (CEPA, 1995). However, cadmium concentrations in soils used for agriculture in China range from 0.1–2.6 mg/kg, amounting to an overall national average of 0.43 mg/kg (Wei and Yang, 2010; Liu et al., 2006a,2006b, 2007; Huang et al., 2007; Zhao et al., 2007a,2007b; Li et al., 2009; Li et al, 2008; Yang et al., 2009; Zheng, 2008; Chen and Pu, 2007). Despite this, China remains the largest producer of soybeans in Asia, producing 12.35 million metric tons over 6.8 million hectares of land as of 2014 (USDA Foreign Agricultural Service, 2015).

For comparison, about a third of the world's soybeans is produced in the United States at 108.01 million metric tons over 33.61 million hectares of land (USDA Foreign Agricultural Service, 2015). The second and third largest producers are Brazil and Argentina, producing 94.50 and 60.80 million metric tons over 31.50 and 19.30 million hectares of land, respectively. Holmgren et al. (1993) reviewed the cadmium content in U.S. soil and concluded that the U.S. had a mean of 0.265 mg/kg of dry soil, while cadmium in Brazilian soil samplings ranged from 0.3 to 1.6 mg/kg of dry soil, as estimated by Fadigas et al. (2006).

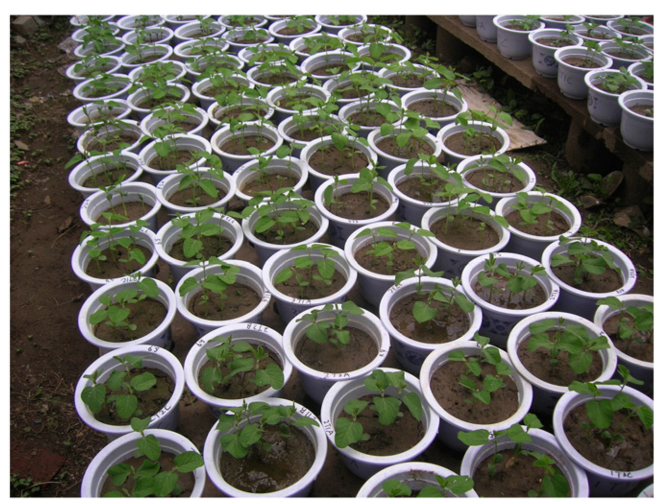
3. Efforts in reducing cadmium in soybeans

The disparity in the high quantity of soybean production and the shortage of low-cadmium containing agricultural soil available translates to a need for soybean producers to develop methods to reduce cadmium in crops when grown on cadmium-contaminated soils. One method is using cadmium-excluding cultivars or low cadmium accumulators (Zhang et al., 2014; Greger and Löfstedt, 2004). Cultivars are agricultural crops specifically grown to enhance desired qualities (properties), such as tolerance to growing in cadmium enriched environments and reduced cadmium uptake (Hernandez-Allica et al., 2008). The selection of these qualities enables the sustainability of crops grown on soil contaminated with cadmium without contamination of the food. Another method is phytoremediation (Sooksawat et al., 2013; Li et al., 2014), where plants with increased cadmium uptake and accumulation are planted in cadmium-enriched soils to remove cadmium from soil. Plants can be genetically modified to incorporate cadmium-binding proteins to improve the efficiency of phytoremediation (Dhankher et al., 2002; Lugon-Moulin et al., 2004). However, more research is necessary to improve this technology and the efficiency of phytoremediation (Murakami and Ae, 2009). Other options to remove cadmium from the soil are being explored, such as using genetically modified bacteria (Valls and de Lorenzo, 2002; Bang et al., 2000a,2000b) or cadmium-biosorbent fungi (Jarosz et al., 2002; Simonovicova et al., 2002) to remediate the soil. Lastly, another solution is to simply avoid using cadmium-enriched wastewater from industrial processes and mining as irrigation; however, using alternative irrigation methods can be too costly.

Despite these efforts to reduce cadmium exposure, it remains necessary to choose low cadmium containing soils for agriculture. However, it is difficult to find soils completely devoid of cadmium because it is naturally present in the environment, and industrial processes that have cadmium byproducts also contribute to its abundance. For this reason, continued efforts to reduce cadmium in crops are still being explored. A recent publication by Zhi et al. (2015) examined the cadmium content in Chinese soybean cultivars grown on soils with low and moderate cadmium contamination.

4. Investigating cadmium excluding soybean cultivars

To select effective cadmium-excluding soybean cultivars, Zhi et al. (2015) chose five Chinese soybeans cultivars (Shennong 10, Tiefeng 31, Tiedou 36, Tiefeng 37 and Liaodou 21) as candidates. They collected the soils for testing from the surface layer (0–20 cm) of three different fields. This is in contrast to artificially simulated soils, which are equilibrated for a short period of time, and do not reflect the true metal forms in industrially or naturally contaminated soils (Komarek et al., 2007). Zhi et al. established soils containing a cadmium concentration of 0.15 mg/kg as controls, and considered 0.75 mg/kg and 1.12 mg/kg as low and moderate cadmium-contaminated soils, respectively. The five soybean cultivars were cultivated in open field conditions without additional fertilizers. After 4 months of cultivation, the plants were harvested and separated into roots, stems, leaves, pods, and seeds to analyze cadmium and mineral elements (cadmium, copper, iron, magnesium, manganese, and zinc).



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