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# The Challenges and Solutions for Cadmium-contaminated Rice in China: A Critical Review

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The wide occurrence of Cd-contaminated rice in southern China poses significant public health risk and deserves immediate action, which arises primarily from extensive metal (including Cd) contamination of paddies with the fast expansion of nonferrous metal mining and smelting activities. Accumulation of Cd in rice grains can be reduced by removing Cd from the contaminated paddy soils, reducing its bioavailability, and controlling its uptake by rice plants. Although a range of measures can be taken to rehabilitate Cd-contaminated lands, including soil replacement and turnover, chemical washing, and phytoremediation, they are either too expensive and/or too slow. Various amendment materials, including lime, animal manures, and biochar, can be used to immobilize Cd in soils, but such fixation approach can only temporarily reduce Cd availability to rice uptake. Cultivation of alternative crops with low Cd accumulation in edible plant parts is impractical on large scales due to extensive contamination and food security concerns in southern China. Transgenic techniques can help develop rice cultivars with low Cd accumulation in grains, but little public acceptance is expected for such products. As an alternative, selection and development of low-Cd rice varieties and hybrids through plant biotechnology and breeding, particularly, by integration of marker-assisted selection (MAS) with traditional breeding, could be a practical and acceptable option that would allow continued rice production in soils with high bioavailability of Cd. Plant biotechnology and breeding can also help develop Cd-hyperaccumulating rice varieties, which can greatly facilitate phytoremediation of contaminated paddies. To eliminate the long-term risk of Cd entering the food chain, soils contaminated by Cd should be cleaned up when cost-effective remediation measures are available.


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## 1. Introduction

Rice is the most widely consumed cereal grain on earth and is a staple food for over half of the world's population. The global rice production was over 740 million tonnes in 2014, with Asian countries, including China, Thailand, Japan, and Indonesia dominating the global rice production (Fig. 1a). Cultivated since ancient times, rice has long been a major staple food for people in southern China, and rice production has increasingly spread to the more arid north regions over the past several decades. The average rice consumption in China was 219 g/capita/day (Fig. 1b), almost 50% higher than the global average (148 g/capita/day). It should be noted that the residents of southern China have a rice-heavy diet, while those living in the north have a wheat-heavy one. As a result, the daily rice consumption of the people living in rice farming areas of southern China is actually much higher

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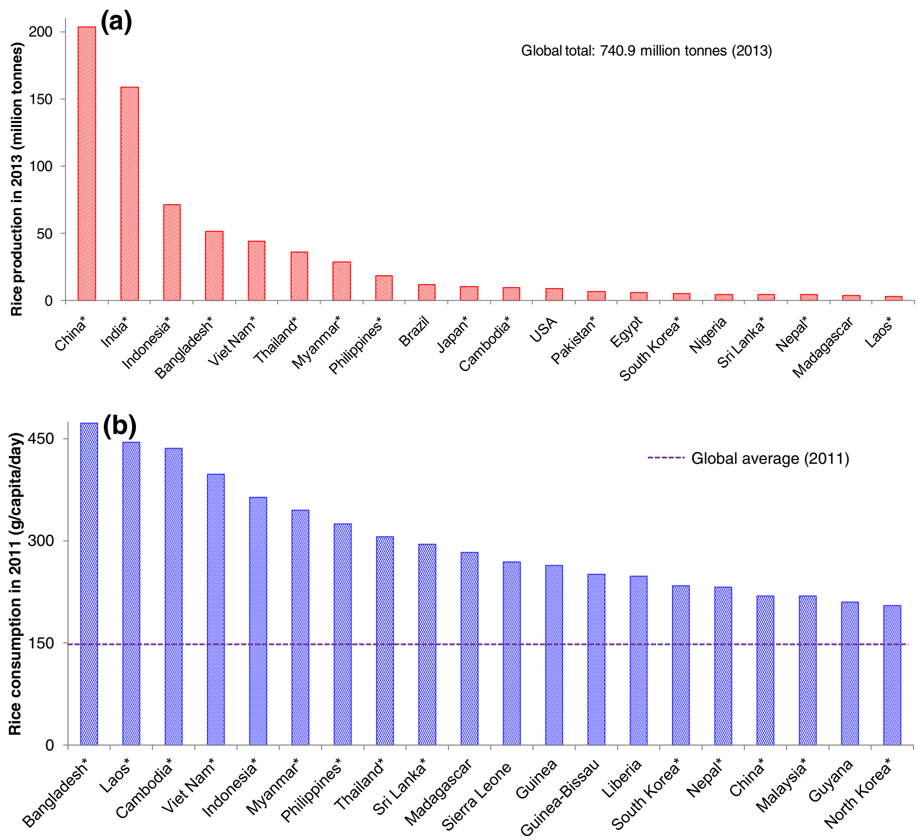


**Fig. 1.** The top 20 countries in (a) rice production and (b) per capita consumption (data from FAOSTAT, 2015). Asian countries (denoted by star symbol) produce and consume ~90% of the world's rice.

than the national average. In particular, the rural populations with relatively low incomes, who eat less meat compared to the richer groups, rely on rice for most of their daily calorie intakes. In addition, rice farming is also an important source of income for the elderly and women in the remote villages of southern China. Despite the trend of mechanization in grain crop cultivation and harvesting over the past decade, the traditional labor-intensive hand methods are still widely practiced for rice cultivation, especially in the mountainous and remote areas of the south, where non-agricultural employment opportunities are scarce.

Cadmium (Cd) is one of the most mobile and potentially bioavailable soil elements. Although it is not known to be essential to plant growth or biological systems, Cd is absorbed by the roots of agricultural crops and transported to the above ground tissues (including grains), and this process depends on the availability of Cd in the soil as well as the plant's genetic characteristics (Grant et al., 1998, 2008; McLaughlin et al., 1999; Roberts, 2014). Compared to other cereals, rice tends to accumulate more Cd, and is the major source of dietary Cd intake in rice-eating populations (Arao et al., 2010; Grant et al., 2008; Meharg et al., 2013). Being a human carcinogen and one of the most toxic heavy metals to humans, exposure to Cd causes primarily kidney damage, and can bring adverse health effects on the pulmonary, cardiovascular, and musculoskeletal systems as well (U.S. Department of Health and Human Services, 2012). With the Cd exposure from foods governed by both its contents in dietary items and their consumption rates (Meharg et al., 2013), the health risk from consumption of Cd-contaminated rice is of particular concern in the regions and subpopulations relying on rice for most of their caloric intake. Therefore, it is important to control the uptake and accumulation of Cd in rice grains to reduce the potential health risk for the populations with a rice-heavy diet.

The world's first documented incidence of mass poisoning by Cd, the Itai-Itai disease that occurred in Japan, first brought global public attention to the problem of Cd-contaminated rice in the 1950s (Nogawa and Kido, 1993). The rice paddies in the Toyama Prefecture was contaminated by heavy metals, including Cd, through irrigation with water from the Jinzu River and its tributaries, which had been contaminated by the upstream mining operations (Nogawa and Kido, 1993). Local residents suffered from long-term exposure to Cd from consumption of the rice that contained elevated levels of Cd. Unfortunately, the history almost repeated again half a century later on much larger scales, although much less severe, in many parts of southern China. The rapid industrial development and lack of sufficient environmental protection over the past three decades has resulted in widespread heavy metal pollution in China, particularly in the areas surrounding metal mining sites and smelting facilities (Cai et al., 1998; Cheng and Hu, 2010; Cheng et al., 2009; Hu et al., 2013; Jin et al., 2002; Wang et al., 2011). With vast arable lands contaminated by heavy metals and irrigation of some fields by industrial wastewaters, consumption of contaminated food crops has become a major exposure route of heavy metals for the general population in China (Khan et al., 2008). As the Cd introduced into the paddy soils is efficiently uptaken by the rice plants and accumulated in the grains, rice containing excessive levels of Cd raises wide food safety concerns in China, where the quantity and quality of food supply is already considered one of the most pressing problems.

The scale and severity of Cd-contaminated rice problem in southern China poses a major public health threat and requires immediate action to protect the health of rice-eating population. This review presents an overview on the occurrence of Cd-contaminated rice and the associated health risk in China, and discusses the potentials of various approaches for mitigating this problem. The causes of the widespread Cd contamination of rice paddies, which are primarily related to nonferrous metal mining and processing activities, are first discussed. The contents of Cd found in the grains of rice samples taken from fields and