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Soil arsenic availability and the transfer of soil arsenic to crops in suburban areas in Fujian Province, southeast China

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Abstract

The bioavailability, soil-to-plant transfer and associated health risks of arsenic in soils collected from paddy rice fields and vegetable fields in suburban areas of some major cities of Fujian Province were investigated. The total soil concentrations of arsenic ranged from 1.29 to 25.28 mg kg^{-1} with a mean of 6.09 mg kg^{-1}. Available (NaH_2PO_4-extractable) arsenic content accounted for 0.7–38.2% of total soil arsenic and was significantly correlated with total soil arsenic content. For the vegetable soils, the available fraction (ratio of available As to total As) of arsenic decreased with decreasing silt (particle size 0.02–0.002 mm) and free iron (DCB extractable) contents and with increasing soil pH and organic matter content. The available fraction of arsenic in the paddy rice soils increased with increasing free iron and organic matter contents and decreasing soil pH and silt content. The correlation of NaH_2PO_4-extractable arsenic with the arsenic concentration of the vegetables was much better than that of total As. The transfer factor based on the soil available arsenic (TF_{avail}) was chosen to compare the accumulation ability of the various crops. The TF_{avail} values of rice grains (air-dried weight basis) ranged between 0.068 and 0.44 and were higher than those of the vegetables, ranging from 0.001 to 0.12. The accumulation ability of the crops decreased in the order of rice > radish > water spinach > celery > onion > taro > leaf mustard > fragrant-flowered garlic > pakchoi > Chinese cabbage > lettuce > garlic > cowpea > cauliflower > bottle gourd > towel gourd > eggplant. Daily consumption of rice and other As-rich vegetables could result in an excessive intake of arsenic, based on the provisional tolerable intake for adults for arsenic recommended by WHO.

Keywords: Arsenic; Rice; Vegetable; Soil; Transfer factor

1. Introduction

Arsenic is a contaminant of public concern because of its highly toxic carcinogenic properties to human beings. The oral intake of food and beverages is the most significant pathway of exposure to As for healthy humans while that of water may be the major source in areas where drinking water contains >50 μg As l^{-1} (WHO, 2001). The arsenic concentrations of most rivers and lakes are below 10 μg l^{-1} and those of groundwater average about 1–2 μg l^{-1}, except in areas with volcanic rock and sulfide mineral deposits (WHO, 2001). It is thus deduced that food is one of the most important sources from which humans intake arsenic. Soil arsenic is the major source for the As uptake of crops. Besides its natural origins, soil As may also come from

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anthropogenic activities, such as mining, smelting, application of wastes, animal manures and As-bearing pesticides, wood preservation, and irrigation of As-contaminated wastewater (Alam et al., 2003; Baroni et al., 2004; Bech et al., 1997; Camm et al., 2004; Dutré et al., 1998; Flynn et al., 2002; Mandal and Suzuki, 2002; Pongratz, 1998; Warren et al., 2003).

The arsenic concentrations in the edible parts of crops depend on the availability of soil As and the ability of a crop to take up As and to translocate it to the target organs. The availability of soil arsenic is determined by soil properties, notably mineral composition, organic matter content, pH, redox potential and phosphate content (Caetano and Vale, 2002; Cao and Ma, 2004; Mandal and Suzuki, 2002; Tu and Ma, 2003; Warren et al., 2003). Flooding of soils generally increases As availability, whereas the increase in the redox potential of flooded soils generally reduces As availability to plants (Mandal and Suzuki, 2002; McBride, 1994). Because of the strong adsorption by Fe, Mn and Al oxides/hydroxides and clays (Fordham and Norrish, 1983; Hale et al., 1997; Mandal and Suzuki, 2002; McBride, 1994; Voigt et al., 1996), the availability of arsenic in soils is generally low. The As extracted by 0.01 mol l^{-1} $CaCl_2$, and 0.05 mol l^{-1} $(NH_4)_2SO_4$ is reported to account for less than 1% of total arsenic (Szakova et al., 2005). The water-soluble fraction of arsenic of As-contaminated soils in Cornwall mining sites, UK was between 0.3% and 1.7% of total arsenic (Camm et al., 2004). The available As extracted by 0.43 mol l^{-1} solution of acetic acid in an As-contaminated area in southern Tuscany (Italy) was between 0.1% and 1.8% of total As (Baroni et al., 2004). The NH_4-OAc-EDTA-extractable As in soils around a copper mine in Northern Peru accounted for 0.05–0.43% of the total As content (Bech et al., 1997).

Because of the relative low availability of soil As, the As concentrations in plants are also low and variable. The arsenic concentration in plants varies from less than 0.01 to about 5 μg g^{-1} (dry weight basis) (Mandal and Suzuki, 2002). Warren et al. (2003) reported that the As concentrations of crops collected from a former As smelter in UK ranged between <0.08 and 21.3 mg kg^{-1} in dry matter. Food composites (potato skin, leaves of vegetables, rice, wheat, cumin, turmeric powder, and cereals, etc.) collected from As-affected areas of the Murshidabad district, West Bengal, contained 7–373 μg As kg^{-1} (Roychowdhury et al., 2002). The As concentration also varied between plant organs. The As concentration (mg kg^{-1}) in root, leaves, leaves and shoots, shoots, fruit and seed of crops and vegetables of cultivated sites in two former Sb-mining areas and in an old quarry were 0.34–13.25, <0.02–6.95, <0.02–2.53, <0.02–0.82, <0.02–0.44, respectively (Baroni et al., 2004). Roots accumulate more As than other organs. Vegetables from a heavily As-polluted area in Bangladesh containing the highest mean As concentrations (μg g^{-1}) are snake gourd (0.489), ghotkol (0.446), taro (0.440), green papaya (0.389), elephant foot (0.338) and bottle ground leaf (0.306), respectively (Alam et al., 2003). Liao et al. (2005) found that rice grains collected from the areas within 2 km of four industrial districts contained 0.5–7.5 mg As kg^{-1} and suggested that As-contaminated rice may pose serious health risk to humans.

The transfer of arsenic from soils to the edible parts of plants is a key step in the route of As entry into the human food chain. The typical soil-to-plant transfer factors for As summarized by Kloke et al. (1984) varied from 0.01 to 0.1. The transfer factors of arsenic for various vegetables by Warren et al. (2003) were from 0.0007 to 0.032. Those reported by Alam et al. (2003) from a heavily As-contaminated village in Samta for ladies finger, potato, ash gourd, brinjal, green papaya, ghotkol and snake gourd were 0.001, 0.006, 0.006, 0.014, 0.030, 0.034 and 0.038, respectively. On the contrary, Roychowdhury et al. (2005) found approximately 3.1–13.1%, 0.54–4.08% and 0.36–3.45% of arsenic in roots, stems and leaves of plants from As-contaminated soils in Bengal, India, respectively. The transfer factors depend not only on the plant species, but also on the As concentration and its availability in the soil. Alam et al. (2003) observed that transfer factors tended to decrease with increasing soil concentrations. Warren et al. (2003) attributed the lower transfer factors to the difference in the arsenic sources between their study and previously published work.

Most of the published papers on the As transfer from soil to plant refer to heavily As-contaminated soils. However, most of food consumption originates from crops grown near cities in fields that are not heavily contaminated with As. Although some studies have indicated that rice may pose a serious As risk to people there are relatively few studies on the As transfer from soil to rice. It is therefore essential to study the transfer of arsenic from soil to the edible parts of vegetables and rice grown on the fields near cities in order to evaluate better the health and ecological risks. The objectives of this work were: (i) to measure the transfer of As from soils to the edible parts of various vegetables and rice grains grown in suburban areas; (ii) to assess the potential health risks of As in the edible parts of rice and vegetables.