



Daily bioaccessible levels of selected essential but toxic heavy metals from the consumption of non-dietary food sources



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ARTICLE INFO

Article history:

Received 7 January 2013

Accepted 22 August 2013

Available online 28 August 2013

Keywords:

Bioaccessible
Essential poisons
Manganese
Zinc
Rice

ABSTRACT

Researchers and regulatory bodies tend to focus on non-essential toxic elements when testing for inorganic chemical pollutants in food. Both toxic and essential elements are increasingly getting into the food chain from the extensive use agrochemicals and the use of contaminated water, raw sewage and untreated industrial effluent to irrigate crops. A holistic testing protocol for chemical contaminants in food should be the norm in order to protect human health, especially considering that the essential elements are as a matter of fact essential poisons. They are essential but are toxic above certain thresholds. Eating contaminated foods that are not considered to be dietary sources of the essential poisons may result in an inadvertent overdose, especially considering that consumers may be taking food supplements that recommended as sources of the essential elements. We measured the levels of manganese and zinc in rice and calculated the daily bioaccessible levels of the two elements. The daily bioaccessible levels were significantly higher than the recommended daily intakes in most of the samples. It has to be noted that exposure from various sources is additive, therefore, lower levels than recommended limits in one source may not guarantee safety from a particular chemical toxicant.

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1. Introduction

Rice is not considered a significant dietary source of essential elements such as manganese (Mn) and zinc (Zn), and on nutritional labels on rice, Mn and Zn are not listed, showing that they constitute a negligible portion of the nutrients in the grain. As a result, consumption of contaminated rice may result in an accidental overdose, considering that consumers will be taking supplements and foodstuffs that are considered sources of the essential elements. Researchers and regulatory bodies tend to focus on non-essential elements that are toxic when testing for heavy metal(loids) in food. However, essential elements are actually essential poisons and consumption beyond recommended daily intakes can cause adverse health effects. In this study, we focused on the levels of two essential but toxic elements, Mn and Zn, in rice. Mn and Zn occur naturally in the soil, but anthropogenic activities such as agriculture, industry, mining and waste management are increasing the levels of these metals and other heavy metal(loids) in water, air and soil to the extent of becoming health hazards to humans. The increase in the concentration of these metals in agricultural soils and irrigation water is increasing the chances of the metals getting into the food chain in levels that may be detrimental to human health.

The rice plant effectively accumulates heavy metal(loids) compared to other cereals and most terrestrial-based food crops (Carey et al., 2010; Heitkemper et al., 2009). Rice is also reportedly able to accumulate the metal(loids) in the grain and other parts of the plant at levels several-times higher than those in the soil (Tuli et al., 2010). The accumulation of heavy metal(loids) by the rice plant coupled to the fact that rice has become the staple food for over half of the world population makes it ideal as a sample to evaluate the potential threat posed by food as a source heavy metal(loid) toxicity in humans. Recent studies on heavy metal(loids) in the food chain have largely focused on arsenic in rice and fruit juices (Bhattacharya et al., 2010; Carey et al., 2010; Gilbert-Diamond et al., 2011; Heitkemper et al., 2009; Huang et al., 2012b; Narukawa and Chiba, 2010; Roberge et al., 2009; Tuli et al., 2010). In most of these studies, the levels of As were found to be higher than the recommended limits. The few studies that focused on other heavy metal(loids), in addition to As, in food reported levels that were also higher than recommended limits. In one such study by Tufuor et al. (2011), As, Pb, Cr, Ni, Cu, Zn and Fe that were found in levels that were higher than recommended limits in orange, lime and lemon fruits grown in the Abura–Asebu–Kwamankese District of Ghana. The major sources of the heavy metal(loids) in foods and beverages analyzed in all the above cited studies were reported to be mining, industrial and agricultural activities.

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Manganese uptake by humans is primarily through foodstuffs, such as spinach, tea and herbs. Other foodstuffs that are reported to contain Mn are grains and brown rice, soya beans, eggs, nuts, olive oil, green beans and oysters (<http://www.lenntech.com/periodic/elements/mn.htm#ixzz2CmFJZstt>, December 2012). It has to be noted that the proportion of Mn in brown rice very insignificant that the USDA does not even list it on the nutrient composition of brown rice. Inadvertent exposure of Mn to humans is known to occur via the inhalation of contaminated dust and fumes. As previously noted, Mn is an essential poison. Its toxic effects occur in the respiratory tract and the brain, and symptoms of toxicity include hallucinations, forgetfulness and nerve damage. An overdose of Mn is also reportedly associated with Parkinson, lung embolism and bronchitis. In men, prolonged exposure is reported to cause impotence. Mn poisoning is also causes a syndrome whose symptoms include schizophrenia, dullness, weak muscles, headaches and insomnia. On the other hand, a deficiency of Mn is reported to cause adverse health effects that include obesity, glucose intolerance, blood clotting, skin problems, lowered cholesterol levels, skeleton disorders, birth defects, changes of hair color and neurological symptoms. (<http://www.lenntech.com/periodic/elements/mn.htm#ixzz2CmFJZstt>, December 2012).

The major sources of Zn are protein-rich foods such as beef, lamb, pork, crabmeat, turkey, chicken, lobster, clams and salmon. Zinc deficiency causes a loss of appetite, taste and smell. Inadequate Zn also causes skin sores, slow wound healing and birth defects while an overdose is reported to cause stomach cramps, skin irritations, vomiting, nausea and anemia (<http://www.lenntech.com/periodic/elements/mn.htm#ixzz2CmFJZstt>, December 2012; <http://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/>, 2012). At sufficiently high levels, Zn can damage the pancreas, disrupt protein metabolism and can cause arteriosclerosis. Zinc can be passed from mother to fetus as well as from mother to child via blood and breast milk respectively hence can be a serious threat to both the unborn and newborn (<http://www.lenntech.com/periodic/elements/mn.htm#ixzz2CmFJZstt>, December 2012; <http://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/>, 2012).

Levels of essential elements in foods have been known to meet health requirements without any risk of overdoses. However, the current trends in environmental pollution, primarily a result of industrialization, urbanization, mining and agriculture, suggest potential risks from essential element toxicity via the food chain as well as via other sources. In some countries, agricultural crops are being irrigated with untreated industrial and sewage effluents as well as freshwater that is contaminate by heavy metal(loids) from landfills leachates, acid mine drainage and untreated effluents from industry and sewerage plants. Agricultural soils are also being contaminated by the extensive use of agro-chemicals. Also, in some countries, crops are being grown near or around landfills, mines and industry, urban dwellings and highways where soils are obviously highly contaminated. These agricultural practices seem to be more widespread in countries that are some of the major producers of food for the world population. Whether such practices are a result of blatant negligence, high cost of food production and/or the need to meet the needs for the growing world population with limited resources remains to be established. The reality is that these agricultural practices pose a significant health threat to humans.

There is no doubt that the world population is growing while resources such as land are dwindling (<http://www.un.org/News/Press/docs/2005/pop918.doc.htm>, December 2012; http://www.worldbank.org/depweb/english/beyond/beyondco/beg_03.pdf, December 2012). As a matter of fact, the world population is projected to reach 9.1 billion by 2050 from the current 6.5 billion. The growing world population has to be matched by growths in agriculture, industrialization and urbanization. Unfortunately,

resources, particularly land, are not limitless. Numerous researchers in the countries were the above mentioned are prevalent have all concluded that such practices are the principal sources of food contamination by chemical toxicants. Consumers from countries where safer agriculture is practiced are equally at risk of potential heavy metal(loid) toxicity through the food chain because of the globalized food market.

According to the US Department of Agriculture (USDA), US food imports have increased steadily as a result of intra-industry trade and increased demand for diverse foods for the ethnically diverse US population (<http://www.ers.usda.gov/Data/FoodImports/>, December 2012). The dollar value of agricultural food imported into the US from 1999 to 2011 increased from \$41017.6 M to \$102505.1 M, an increase of about 150%. Rice is now considered one of the major staple foods for the world population, with people in Asia reportedly to consuming an average of 450 g rice a day (Rahman and Hasegawa, 2011). The value of rice and rice flour zimported into the US increased by 230% (\$191.5–\$631.0 M) from 1999 to 2011 (<http://www.ers.usda.gov/Data/FoodImports/>, December 2012). The major suppliers of rice and rice flour are for the US market are Thailand (65.5%), India (19.6%), Pakistan (2.6%), Brazil (2.6%) and Italy (2.3%). The rest of the world contributes the remaining 7.7% (<http://www.ers.usda.gov/Data/FoodImports/>, December 2012). With this level of food distribution across the world and the level of pollution in some of the countries that are major sources of food for the world population, it is both prudent and imperative that food be routinely tested for chemical toxicants to protect human health. The major goal of this study was, therefore, to determine the levels of essential toxic elements, Mn and Zn, in rice food products imported into the United States and to establish the possible sources of the contamination.

2. Materials and methods

2.1. Samples

Rice food samples were purchased in Supermarkets from the following NJ counties: Monmouth, Passaic, Bergen, Atlantic and Mercer; one of each type from each county, and then categorized according to the country of origin. The samples dried for at least 24 h in an oven at 104 °C before being ground into a powder using a KRUPS F203 grinder and then stored in plastic bags under moisture-free conditions till analysis. Certified reference samples, 1568a (rice powder) and 2710a (Montana Soil), were obtained from the National Institute of Standards and Technology (NIST).

2.2. Equipment

A handheld X-Ray Fluorescence Spectrometer (XRF Innov-X Systems) was used for total metal analysis.

2.3. XRF analysis

Lead levels in the finely ground and well mixed rice samples and the reference samples, SRM 1568a and SRM 2710a were analyzed using an Innov-X Systems handheld XRF Instrument. Analysis of each sample was done in triplicate.

3. Results and discussion

The accuracy of the XRF measurements was evaluated and validated using NIST Standard Reference Materials (SRM) before and in between sample measurements. The average concentration of Mn in the SRM 1568a, as measured by XRF, was 21.3 ± 0.6 mg/kg. This was statistically the same as the certified value of 20.0 ± 1.6 mg/kg Mn at the 95% confidence level, with a percent recovery of 107 ± 9 . The certified value for Zn in the SRM 1568a of 19.4 ± 0.5 mg/kg was statistically the same as the XRF measured value of 23.7 ± 1.2 mg/kg at 98% confidence level. The percent recovery was $122 \pm 6.9\%$. We also checked the validity of the XRF measurements for Zn using SRM2710a (Montana Soil). A measurement for Zn in the SRM yielded an average concentration of

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