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Project Summary

Availability of Cadmium to Rats from Crops Grown on Cadmium Enriched Soil

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This research was initiated to enhance the understanding of the availability to animals of Cd present in edible plants. Such information is important because agricultural crops can accumulate high concentrations of the metal when grown in certain soils or with sewage sludge as a fertilizer.

Edible plants were labeled with ^{109}Cd by growing them on $^{109}CdCl_2$-treated soil. The availability of ^{109}Cd to male and female rats was determined by feeding semisynthetic diets containing either freeze-dried radioactive spinach, lettuce, soybean, carrots, tomatoes, or wheat flour, or comparable nonradioactive plant powders spiked with $^{109}CdCl$. Retention of ^{109}Cd by liver and kidney was determined after a 14-day feeding period.

With the exception of spinach, Cd accumulation by rats was not found to be significantly influenced by the form of Cd in the diet, whether supplied as plant-bound ^{109}Cd or added to nonradioactive diets as $^{109}CdCl_2$. The mean retention of Cd in liver and kidney was 0.17% of the dose consumed for males and 0.26% for females consuming diets containing wheat, soybean, carrots, lettuce, or tomatoes. While uptake and retention of Cd in rats fed ^{109}Cd-labeled spinach was generally comparable to that seen in animals fed the other labeled plant powders, the retention of Cd was significantly lower (one-third) in rats fed nonradioactive spinach diets spiked with $^{109}CdCl_2$. These results suggest that spinach grown in the absence of added Cd may contain a complexing agent which reduces the availability of added Cd.

A simple linear regression model involving the log transform of DTPA soil Cd extraction data was developed to describe the accumulation of Cd by plants. The Cd accumulated by spinach plants was mainly bound to the cell walls, accounting for 53, 47, and 98% of the Cd present in leaves, stems, and roots, respectively. Only 12-39% of the retained metal appeared in the 100,000*g* cytosol fraction in spinach leaves and stems. In the cytosol Cd was primarily bound to high molecular weight proteins with smaller quantities associated with plant constituents in the molecular weight ranges of 3,000-4,000 daltons and greater than 1,000 daltons.

This Project Summary was developed by EPA's Health Effects Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Cadmium (Cd) is a highly toxic metal that is readily accumulated by and retained in both plants and animals. Concern over the consequences of Cd pollution accelerated after chronic exposure of a rural population to the metal in Japan resulted in severe bone disease. Some research in the literature focuses attention on the possible linkage

between human hypertension and increased retention of Cd by the kidneys.

Although some Cd is absorbed via inhalation, especially in smokers, food is considered to be the major source of nonoccupational human exposure with intake via water generally thought to be of lesser importance. Water, however, may play a considerably greater role when Cd concentrations are naturally high or are increased by the water distribution system.

Recent evidence reported in the literature has shown that edible plants, among others, can accumulate substantial amounts of Cd from Cd-contaminated soils and that metal accumulation depends upon the plant species, soil composition, and Cd content of the soil. Various vegetable species, such as corn, tomato, radish, and Swiss chard, also efficiently accumulate Cd^{2+} from nutrient solutions.

Municipal sewage sludge is the end product resulting from the digestion and treatment of municipal wastes that may contain human excreta, residues from food processing, and a host of inorganic and organic constituents generated by industry. Disposal of the 100 million tons of municipal sewage sludge generated annually in this country has led to the increasing utilization of sludge as a soil conditioner and a source of nutrients for agricultural crops. Sewage sludges typically contain high concentrations of various heavy metals including Cd, with concentrations of this metal ranging between 1 to 1,500 μg Cd/g dry sludge. When edible crops are then grown on soils treated with municipal sewage sludge, they accumulate high concentrations of cadmium and other metals. Under these circumstances, leafy plants, such as lettuce, spinach, and turnip greens (tops), can accumulate Cd concentrations as high as 175 to 354 μg/g tissue. Fruit and seed tissues of plants, including turnip tuber, tomato, wheat, radish, and squash, concentrate lesser amounts of the metal, ranging from 10 to 15 μg Cd/g tissue. The Cd content of soybeans and carrots reaches 30 μg/g tissues while maximum levels in corn and rice are below 5 μg Cd/g tissue.

Because of the accumulation of high concentrations of toxic metals, especially Cd, in edible plants, the disposal of sewage or sewage-sludge on croplands or the use of high Cd fertilizers may pose a serious hazard to human or animal health. Similarly, crops grown on soils naturally high in Cd could also concentrate dangerously high levels of the metal. To assess the degree of hazard from such accumulations, however, it is first necessary to determine the biological availability of Cd to animals fed diets containing various grains and vegetables. This project was, therefore, initiated to compare the absorption of ^{109}Cd by rats fed diets containing six species of edible plants grown on ^{109}CD-treated soils, fed similar diets spiked with $^{109}Cd^{2+}$, or supplied with $^{109}Cd^{2+}$ in their drinking water. In other experiments the distribution and nature of the binding sites for ^{109}Cd in spinach was examined.

Conclusions

The results of experimental studies performed with ^{109}Cd-labeled plants indicate that Cd retention by rats fed diets containing low levels of Cd is generally not influenced by the form of Cd, whether plant-bound or added as inorganic Cd^{2+} ($CdCl_2$). Cd retention is influenced by plant species, but the difference was not large between animals fed diets containing freeze-dried wheat, soybean, carrot, lettuce, or tomato powders. As observed by other researchers previously, retention of Cd by female rats was generally higher than by males. In rats fed a freeze-dried spinach diet spiked with $CdCl_2$, retention of Cd was significantly reduced compared with that seen in rats fed $CdCl_2$-spiked semisynthetic diet or a Cd-bound spinach diet. These latter results suggest that spinach grown on low Cd soils may contain metal complexing agents capable of binding added inorganic Cd and influencing its availability. Addition of calcium oxalate, which is present in high concentrations in spinach, to a semisynthetic diet spiked with $CdCl_2$ significantly reduced Cd retention in rats.

Accumulation of Cd by container-grown plants can be adequately described by a simple linear regression model involving the log transformation of DPTA soil Cd extraction data. Generation of regression coefficients specific to the plant species and cultural conditions used permitted the use of published data to predict Cd concentrations in five plant species grown to maturity in the present study.

In spinach plants, most of the accumulated Cd is bound to the cell wall fraction, especially in roots. A relatively small percentage of the Cd, about 40%, is present in the cytosol fractions of leaves and stems. This soluble Cd is mainly bound to high molecular weight proteins but some of the metal is associated with plant constituents in the 3,000-4,000 dalton and greater than 1,000 dalton molecular weight ranges.

Recommendations

Although the results of the present study generally show little difference in the availability to rats of bound Cd in different edible plants, it is possible that some vegetables, fruits, or grains contain binding or chelating constituents that markedly influence the absorption of Cd by animals. Additional research is, therefore, needed to extend these studies to include additonal species of edible plants. Of perhaps greater importance, however, is the need for subsequent studies to demonstrate conclusively that the relative availability of plant-bound Cd to rats accurately reflects the degree of absorption of the metal by man. Since published values on the percentage Cd uptake by man are generally much higher than those found in the rat, it may turn out that the rat is a poor model for Cd absorption in man and that some other laboratory animal species should be used.

Additional research is also needed on the nature of Cd binding ligands in plants, particularly the low molecular weight constituents. The binding components from several plant species need to be isolated, characterized and identified. A better understanding of how Cd is bound in plants could help considerably in explaining the small but significant differences seen in Cd retention in animals fed different Cd-bound plant diets.

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The complete report entitled "Availability of Cadmium to Rats from Crops Grown on Cadmium Enriched Soil," (Order No. PB 87-212 353/AS; Cost: $18.95, subject to change) will be available only from:
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