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Interaction between cadmium and atrazine during uptake by rice seedlings (*Oryza sativa* L.)

Yu-Hong Su [a,b], Yong-Guan Zhu [a,*], Ai-Jun Lin [a], Xu-Hong Zhang [a]

[a] *Research Center for Eco-environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China*
[b] *Department of Chemistry, Xinjiang University, Urumqi 830046, China*

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Abstract

The uptake of atrazine by rice seedlings (*Oryza sativa* L.) through plant roots from nutrient solution was investigated in the presence and absence of Cd^{2+} over an exposure period of four weeks. It was found that both atrazine and Cd^{2+} were toxic to rice seedlings. Both shoot and root biomasses decreased when the seedlings were exposed to increasing atrazine or Cd^{2+} concentrations in nutrient solutions. In the absence of Cd^{2+}, a linear relationship was observed between atrazine concentrations in roots/shoots and in external solution, and more atrazine is concentrated in roots than in shoots. When atrazine and Cd^{2+} concentrations in solution were maintained at mole ratio of 1:1, the accumulation of atrazine by seedlings was less and the seedling biomass was greater than found with other ratios, such as 1:2 or 2:1. Therefore, the formation of the complex between atrazine and Cd^{2+} reduced the individual toxicities. Analyses of data with the quasi-equilibrium partition model indicated that the atrazine concentrations in rice seedlings and external water were close to equilibrium. In the presence of Cd^{2+}, however, the measured bioconcentration factor (BCF) of atrazine with roots and shoots were considerably greater. The latter findings resulted presumably from the atrazine–Cd^{2+} complex formation that led to a large apparent BCF.

Keywords: Atrazine; Cadmium; Rice seedlings; Uptake; Bioconcentration factor

1. Introduction

There has been a considerable interest in understanding the uptake of organic contaminants by plants during the last two decades (Briggs et al., 1982; Trapp and Matthies, 1995; Weiss, 2000; Chiou et al., 2001; Li et al., 2002; Trapp, 2004). Plants could be exposed to contaminants in different ways. Organic contaminants may enter plant roots by passive and/or active processes and then translocate with plant transpiration stream to other plant components (Briggs et al., 1982; Chiou et al., 2001; Trapp, 2004). Passive transport, which proceeds in the direction of decreasing chemical potential, consists of a series of partitions between plant water and plant organic matter within various plant components (Chiou et al., 2001). It has been found to be largely responsible for the uptake of nonionic compounds (Briggs et al., 1982; Chiou et al., 2001). Active transport, which may proceed against the chemical potential gradient, occurs for certain nutrients and other (inorganic and organic) ions (Trapp, 2004).

Atrazine is a member of the triazine-herbicide family, used widely in agriculture and commonly found as a

* Corresponding author. Tel.: +86 10 6293 6940; fax: +86 10 6292 3563.
E-mail address: ygzhu@mail.rcees.ac.cn (Y.-G. Zhu).

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pollutant in soil and (ground) water (Belluck et al., 1991; Burkart and Kolpin, 1993). It has become a special concern due to its large quantity of use and potential for transport and accumulation. The risk of atrazine to the exposed population included acute and chronic health effects, as well as an increased risk in cancer (Sielken, 1987; Bennett et al., 1999). Earlier reports indicate that atrazine might persist for long periods of time in soil and groundwater (McKone and Bogen, 1991; Finley et al., 1994; Gu et al., 2003). As a herbicide, atrazine inhibits photosynthesis by displacing the secondary quinone acceptor of the electron transport chain from its binding site (Hirschberg and McIntosh, 1983). Atrazine is commonly applied to fields of corns, sorghums, sugar canes, nut orchards, and macadamias. In China, the atrazine application to rotation fields significantly affects the growth of rice; the rice seedlings may take up great concentrations of atrazine from soils. Cadmium (Cd) is a widely occurring metal pollutant. Emissions of Cd from human activities have been estimated to be about 30000 t annually (Di Toppi et al., 1998). Soil contamination with Cd due to irrigation with Cd-contaminated wastewater or to fertilizing and mining/smelting activities poses a long-term risk to humans and animals, which has received increasing attention worldwide. Cadmium is highly toxic to humans as well as plants (McLaughlin and Singh, 1999).

Although numerous papers have dealt with the toxicity and fate of atrazine and Cd in the environment (Shimabukuoro et al., 1970; Liu et al., 1999; Katz et al., 2000; Wiegand et al., 2000; Zhao et al., 2003), few studies focused on their effects as mixtures. In fact, atrazine contains five electron-donor atoms that could potentially participate in the formation of metal/atrazine complexes. Previous studies (Martin et al., 1998; Meng and Carper, 2000) showed that Ca, Mg, Pb, Zn, Cd, and Cu can complex with both monomeric and dimeric atrazine in both anhydrous and hydrated forms (with one or two water molecules). The effect of atrazine–metal complexation on the plant uptake of atrazine and metals must be taken into account to address the biogeochemical cycle of pollutants, since these metals are ubiquitous. In this study, we investigated the atrazine toxicity to and accumulation by rice plants in nutrient solution and the effect of atrazine–Cd association on their individual uptakes by rice seedlings.

2. Materials and methods

2.1. Preparation of rice seedlings

Seeds of rice, China Giyou-1, were disinfected in 10% H_2O_2 (w:w) solution for 10 min, followed by thorough washing with de-ionized water. The seeds were germinated in moist perlite. After three weeks, uniform seedlings were selected and transplanted to PVC pots (7.5-cm diameter and 14-cm high, one plant per pot) containing 500 ml nutrient solution. The compositions of nutrient solutions for uptake studies of atrazine (ATR) and Cd as single and in mixture were as follows: 5 mM NH_4NO_3, 12 mM KH_2PO_4, 2 mM K_2SO_4, 4 mM $CaCl_2$, 1.5 mM $MgSO_4$, 100 μM Fe(III)-ethylenediaminetetraacetic acid (EDTA), 10 μM H_3BO_4, 1.0 μM $ZnSO_4$, 1.0 μM $CuSO_4$, 5.0 μM $MnSO_4$, 0.5 μM Na_2MoO_4, and 0.2 μM $CoSO_4$. The nutrient solution was a modification of Long Ashton Formula after Zhu et al. (1999) with the pH maintained at 5.5 using 0.1 M KOH or HCl solution (Trostle et al., 2001). The seedlings were allowed to grow in the nutrient solution for one week before use for uptake studies.

2.2. Treatments with atrazine and Cd

Chemicals used for plant uptake, such as $Cd(NO_3)_2$, $CaCl_2$, NH_4NO_3, were all of analytical grade; ATR was provided by Chem. Service, Inc. The purities of all chemicals are more than 98%. In Series 1 experiment, rice seedlings were exposed to nutrient solutions with initial ATR concentrations at 0, 0.5, 1.0, and 2.0 μM without added Cd. In Series 2 experiment, seedlings were exposed to nutrient solutions with initial concentration of ATR at 0, 0.5, and 1.0 μM and Cd^{2+} [as $Cd(NO_3)_2$] at 0.5 μM. In Series 3 experiment, seedlings were exposed to nutrient solutions with initial concentration of ATR at 0, 0.5, and 1.0 μM and Cd^{2+} [as $Cd(NO_3)_2$] at 1.0 μM. Each treatment was conducted with four replicates. The exposure periods for all these series were four weeks. Nutrient solutions with corresponding ATR and/or Cd^{2+} concentrations were replaced twice per week. Near the end of this four-week exposure period, the added ATR or Cd concentrations in nutrient solutions stayed largely unchanged with time, i.e., the concentrations in solutions and seedlings were essentially at equilibrium. The experiments were carried out in a controlled environment growth chamber with a 14-h light period (260–350 $\mu mol\ m^{-2}\ s^{-1}$) and temperatures of 25 °C day and 20 °C night. The relative humidity was 70%.

2.3. Analyses of contaminants with plants

2.3.1. Harvest

After plants were harvested, they were washed with deionized water and blotted dry, and then sectioned into roots and shoots. Fresh weights of both roots and shoots were recorded immediately. In the treatments with ATR, fresh subsamples (0.6–2.6 g) were taken for ATR analysis, the rest were dried in an oven at 70 °C for 48 h and the dry weights were recorded. Plant water contents (f_{pw}) and organic-matter contents (f_{pom}) were determined accordingly.