Biotransfer of Selenium: Effects on an Insect Predator, *Podisus maculiventris*

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Accepted 3 January 2003

**Abstract.** The effects of selenium (Se) accumulation in phytophagous insects on predators in the next trophic level were investigated. The generalist predator *Podisus maculiventris* Say (Hemiptera: Pentatomidae) was fed an herbivore *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) larvae from control diet and diets at two Se levels (0, 109, and 135 μg/g sodium selenate dry weight added). Predators reared on larvae grown on diets with sodium selenate took longer to complete each developmental stage and had significantly higher mortality rates. Predators achieving the adult stage on Se-containing hosts weighed 20% less than those feeding on control larvae. Reduced adult weight of insects has been associated with reduced fitness (longevity, egg production, etc.), which would have long-term negative impacts on population dynamics. These developmental and mortality effects resulted from biotransfer of Se, not biomagnification since the trophic transfer factor was less than 1.0 (~0.85). Host larvae in Se-treatments contained significantly more total Se (9.76 and 13.0 μg/g Se dry weight host larvae) than their predators (8.34 and 11 μg/g Se dry weight predatory bugs, respectively). Host larvae and predators in the control groups did not differ in their Se content. These data demonstrate that Se in the food chain may have detrimental population level effects on insects even in the absence of biomagnification, given the host contains significantly elevated concentrations of selenium.

**Keywords:** biomagnification; biotransfer; insects; phytoremediation; selenium

**Introduction**

Selenium (Se) contamination of the environment has become a major concern in the US in the last two decades. Fish have been poisoned by Se-contaminated coal fly ash, which occurs as effluent from the combustion of coal in the generation of electricity (Besser et al., 1996; Lemly, 1996). Drainage water resulting from agricultural irrigation of seleniferous soils has also caused accumulation of Se in reservoirs in the western US, killing fish and waterfowl (Presser and Ohlendorf, 1987; Presser et al., 1994; Lemly, 1997). Herbivorous insects feeding on algae are known to bioaccumulate Se (Malchow et al., 1995; Thomas et al., 1999) and are important primary consumers in the aquatic food chain of reservoirs and ponds where bioaccumulation has occurred (Schuler et al., 1990).

Considerably less information is available for terrestrial systems even though soil contamination by Se has become a significant problem in eight western states, including 1.5 million acres of farmland (Brown et al., 1999). The potential hazards of elevated Se levels to terrestrial arthropods are not well understood. Terrestrial arthropods may be important...
in Se biomagnification or biotransfer because of their roles as herbivores that are fed upon by higher trophic level organisms. For example, at certain times of the year terrestrial invertebrates make up more than half of the diet of some predatory birds at Se-affected sites such as Kesterson Reservoir in Merced County, CA, USA (Santolo and Yamamoto, 1997), where several terrestrial bird species were found to have elevated blood-Se levels (Santolo and Yamamoto, 1999). However, unlike the insectivorous birds and fish, very little information is available on the importance of Se to predatory terrestrial insects. Such insects play a critical role in suppressing and managing populations of herbivorous insects (DeBach, 1973), and also serve as food for higher trophic levels. Thus, any effects of Se-contaminated prey on the population dynamics of predatory insects, and the potential accumulation of Se in these predators, would be likely to impact both the ecology of affected ecosystems and biologically-mediated movement of Se in contaminated areas.

Several studies have demonstrated the toxicity of Se to terrestrial insect herbivores fed Se-amended diets (Hogan and Cole, 1988; Hogan and Razniak, 1991; Trumble et al., 1998; Martin-Romero et al., 2001), and Se-irrigated plants (Bañuelos et al., 1999; Vickerman et al., 2002a,b). Selenium has been shown to accumulate preferentially in the malpighian tubules and the midgut of insects, but has been shown to increase in the rest of the body after a saturation point is reached (Simmons et al., 1988; Hogan and Razniak, 1991; Lalitha et al., 1994). Most of the previous studies on terrestrial insects have used Se as an aid to study specific insect physiological systems (Simmons et al., 1988; 1989a,b; Hogan and Razniak, 1991; Lalitha et al., 1994). Relatively few reports are available on the potential ecological consequences of Se accumulation in host plants and herbivorous insects (Bañuelos et al., 1999; Vickerman et al., 2002a,b). There is even less information on the effects of Se on the third trophic level (insect predators and parasitoids) which prey on other insects (Wu et al., 1996).

This study therefore was conducted to determine potential effects on the life cycle of a predatory insect following consumption of Se-containing prey. Our objectives were to use a model system to describe development and survival of a predatory insect fed prey larvae exposed to different concentrations of Se, and to document possible biotransfer of Se from the phytophagous prey to the insect predator.

Methods

Survival and development

Spodoptera exigua (Hübner) (Lepidoptera: Noctuidae), the beet armyworm, was chosen as a host because baseline studies on Se toxicity for this insect have been established both on artificial diets and on plants (Trumble et al., 1998; Vickerman et al., 2002b). Additionally, S. exigua is a cosmopolitan generalist herbivore and a crop pest of economic importance in areas of the USA where selenium is a problem. The host range of S. exigua includes native and introduced plants in the families Lilaceae, Fabaceae, Solanaceae, Malvaceae, Chenopodiaceae, Apiaceae, Asteraceae, and Amaranthaceae that can be found in both cultivated and uncultivated areas (Metcalf and Flint, 1962; Peterson, 1962; Pearson et al., 1989).

Beet armyworm eggs were obtained from our laboratory colony that was field collected in Ventura Co., CA, USA and maintained on artificial diet from the Bioserv Company (Frenchtown, NJ, USA). Larvae were fed three treatment levels of Se incorporated into diet: (1) a control, with no Se added; (2) level one treatment with 25 µg/g wet weight sodium selenate; and; (3) level two treatment with 31 µg/g wet weight sodium selenate (based on lethal concentration LC₇₀ LC₉₀ values from Trumble et al. (1998); wet to dry conversion, 4.350). The sodium selenate was dissolved in deionized water and mixed into the artificial diet before the agar had set up. These larvae were fed to the predatory bugs. The selected concentrations are within the wide range of Se known to occur in plants (<1–4,000 µg/g dry weight; Lauchli, 1993), and in a form known to occur within the plants (Ge et al., 1996). Plant Se concentrations vary depending on many factors including plant physiology, soil chemistry, and Se levels (Lauchli, 1993). The majority of living plants, however, are thought to accumulate Se at levels less than 100 µg/g (Bañuelos et al., 1997).

Podisus maculiventris Say (Hemiptera: Pentatomidae), the spined soldier bug, is a generalist predator native to North America that feeds mostly on hairless lepidopteran larvae including Spodoptera species (Clausen, 1972). This predatory bug has piercing, sucking mouthparts. In the first stadium these bugs often remain aggregated, feeding on plant tissue near their egg mass. From the second stadium on, these bugs are predators. Eggs were obtained from a commercial producer (Koppert Biological, Romulus,