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Biotransfer Possibilities of Selenium from Plants Used in Phytoremediation

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ABSTRACT

We are investigating the biotransfer of accumulated Se by the plant in several phytoremediation systems. In study *I*, we evaluated the biotransfer of Se from Indian mustard, a *Brassica* species, to the insect-cabbage looper (*Trichoplusia ni*); mortality, deterrence, and biomagnification of Se were examined. We determined that feeding behavior of food chain consumers was affected not only by the plant concentration of Se, but also by the mobility of the insects and choice of feed available. In study *II*, we examined the survival and development of beet armyworm (*Spodoptera exigua*) fed Se-enriched plant tissues from different lines of saltbush (*Atriplex* spp.) After feeding on lines of saltbush that produced high biomass and accumulated high concentrations of Se, insect growth and survival was reduced. In studies *III*, *IV*, and *V*, lambs, dairy cows, and rabbits were fed Se-enriched *Brassica* and *Medicago* (alfalfa) plants as part of their feed ration. None of the tested animals exhibited any Se toxicity symptoms, but they had increased levels of Se in most tissues sampled (*e.g.*, organs, blood, urine, feces), excluding milk. In study *VI*, we evaluated biotransfer of Se from broccoli to rats to determine efficacy of Se for reducing colon cancer. We found that Se-enriched plant material was more effective than inorganic sources of Se for preventing precancerous colon lesions. Results from all studies clearly show that Se absorbed by plants can be transferred biologically in an intentional or unintentional manner to insects and animals.

KEY WORDS: phytoremediation, biotransfer, selenium.

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I. INTRODUCTION

Phytoremediation is a plant-based technology that is being considered for managing selenium (Se) in saline soils and water in central California (Parker and Page, 1994; Terry and Zayed, 1994; Bañuelos and Meek, 1990). Plants are selected for their ability to take up large amounts of Se or for their inability to discriminate between sulfate and selenate ions. Researchers have proposed that Se-accumulating plants could be grown in Se-rich soils or with Se-rich water, harvested, and removed as Se-enriched plant material (Bañuelos, 2000). Growing crops successfully to manage soluble Se by field phytoremediation will require a wide range of knowledge related to sustainable agronomical practices, for example, irrigation, crop rotations, insect control, and product utilization. Research is needed to examine the potential biotransfer and biomagnification of Se from plants used in any phytoremediation strategy of Se (Lemly, 1985; Kay, 1984). The transferring of Se from soil to crop, from crop to insect, from insect to insect, and from insect to animal or human are pathways for Se that should be addressed when monitoring the biological fate of removed Se.

Factors affecting bioaccumulation of Se initially depend on plant species used for phytoremediation, concentration and form of available Se, feeding behavior of the insect, and amount of consumption by the insect. Selenium-enriched plant tissue consumed by the insect may not only have negative consequences for the insect (Vickerman and Trumble, 1999; Trumble *et al.,*1998) but also for the invertebrates and vertebrates that feed on them (Wu *et al.,* 1995; Barnum and Gilmer, 1988). A biotransfer of Se was responsible for the deleterious effects observed on waterfowl frequenting a Se-rich ecosystem at Kesterson Reservoir, California, USA (Ohlendorf and Hothem, 1995). Although selenium at high concentrations is potentially harmful to a biological system, at lower concentrations it is an essential trace element for normal nutrition and health of animals (Mayland, 1994) and for neuropsychological function in humans (Finley and Penland, 1998). Generally, Se deficiencies are a far greater problem than Se toxicities in animals in the U.S. (Mayland, 1994). Animal producers wishing to ensure an adequate supply of Se to their livestock have a variety of techniques at their disposal that include giving Se by injection or by incorporating Se supplements into feed rations. Bañuelos and Mayland (2000) suggested that Se-containing plant material harvested from the sites of phytoremediation can be carefully mixed with other animal feedstuffs and fed to animals in Se-deficient areas.

Selenium absorption by the animal from Se-enriched plant material may vary for many reasons, including type of animal, quantity and Se concentration of plant mixture provided, duration of feeding, and tissue or animal organ evaluated (Feng *et al.,* 1999; Yeh *et al.,* 1997; Burk *et al.,* 1995; Levander and Burk, 1994). Selenium absorption by animals from plant products containing Se has prompted research for increasing Se intake into humans (Finley and Penland, 1998). The American Dietetic Association recommends that, whenever possible, people should consume essential nutrients like Se as food material and not as inorganic supplements (Hunt, 1996).

Most plants used in the phytoremediation of Se are not consumed by humans. Recently, Bañuelos (2002) demonstrated that broccoli grown for extracting Se from poor-quality water accumulated Se to safe levels (3 to 5 mg Se kg^{-1} DM) for human consumption and did not significantly accumulate B or other trace elements. Hence, broccoli grown for phytoremediation of Se may be considered a source of supplemental Se for animals or humans. Not only is broccoli an economically viable crop for growers, but research by Finley *et al.* (2000) has shown that Se in Se-enriched broccoli is readily absorbed and is effective in preventing certain forms of colon cancer in rats.

The above literature indicates that a biotransfer of Se can occur and result in either a positive or negative consequence for different biological systems. This article discusses a series of experiments that evaluated the biotransfer possibilities of Se from plants used in Se phytoremediation to insects and animals.

II. MATERIALS AND METHODS

A. Study I

Biotransfer of Se to the cabbage looper [*Trichoplusia ni* (Hübner)], a typical pest for Brassica plants, was investigated with Indian mustard (*Brassica juncea*), a species commonly used in phytoremediation. Treatments consisted of growing Indian mustard in a half-strength Hoagland nutrient solution (Hoagland and Arnon, 1950) containing either Se (1 mg Se L^{-1}, as sodium selenate) or in a no Se solution (<1 μg Se L^{-1}). The upper sections of each 4-L pot were snuggly enclosed with clear polyethylene insect cages (approximately 80 cm in height; completely enclosing plants) and containing two 10×6 cm cheesecloth sections (for air exchange). A total of five neonate larvae were transferred to two plants growing in each pot with a fine brush and allowed to feed undisturbed. Fourteen days later, cocoons containing pupae were collected from the enclosed plants and placed in large clear plastic containers at 28°C, 60% RH, and having a 14:10 h photoperiod. After emergence, adults were counted, frozen, and later analyzed for their accumulation of Se. Remaining leaves were collected from treated plants, acid digested, and analyzed for Se by atomic absorption spectrophotometry with automatic vapor accessory (Bañuelos and Akohoue, 1994).

B. Study II

The survival and development of the beet armyworm (*Spodoptera exigua)*, a general feeder and agricultural pest of economic importance in the USA, was investigated with different *Atriplex* lines (*A. semibaccata, A. hortensis, A. suberecta, A. glauca, A. spongiosa, A. nummularia, A. canescens, A. leucolada, A. mueller,* and *A. lentiformis*) and collected through both commercial sources and Western Regional Plant Introduction Stations, Pullman, WA. All plants were grown in sand cultures at the USDA Salinity Laboratory outdoor facilities in Riverside, CA, using cement containers ($2.0 \times 0.82 \times 0.85$ m). *Atriplex* species, known for their salt tolerance, were irrigated daily with Se-enriched saline-water, synthetically combined to approximate high salinity and Se levels found in saline drainage waters produced in central California. The following saline treatments are described in detail by Vickerman *et al.* (2002) and Wilson *et al.* (2000):

1. Control, containing essential nutrient concentrations and no Se, electrical conductivity (EC) ~9 dS m^{-1}.
2. Se (1 mg Se L^{-1}, added as sodium selenate) and chloride salts; EC ~37 dS m^{-1}.
3. Se (1 mg Se L^{-1}, added as sodium selenate) and sulfate and chloride salts; EC ~33 dS m^{-1}.

After approximately 90 days, leaf samples were collected from each *Atriplex* line as a source of insect food. First instar lavae were placed in containers and fed harvested *Atriplex* plant tissue *ad libitum* from each respective *Atriplex* line. Ten replicates of one insect each were tested for each of the three irrigation treatments per plant line. Insect mortality and the developmental stage of newly dead and all surviving larvae were recorded every other day. On day 30, the developmental stage of those insects that had not yet become adults was recorded, and the experiment was terminated. Plant material was analyzed for Se as described already in Study *I*.

C. Study III

The biotransfer of Se to lambs was investigated with freshly harvested Se-enriched canola (*Brassica napus*). A total of 10 purebred Southdown lambs were either fed daily Se-enriched canola harvested from a Se-phytoremediation site, or fed control canola (low Se content) during January to April 1998. Field-grown canola was irrigated with a saline effluent (EC of 6 dS m^{-1}) containing 75 to 100 μg Se L^{-1} that was collected on a farm site in the westside of central California. After 75 days of growth, canola was hand-harvested every other day and fed to lambs from the 15^{th} to 74^{th} Julian day. A total 37.2 kg of Se-enriched canola was fed to each lamb with a mean plant concentration of 2.53 mg Se kg^{-1} DM. After 64 days of using canola feed, the animals were killed, and select tissues were sampled and analyzed for Se as described in Study *I*.

D. Study IV

The biotransfer of Se to dairy cows was investigated with dried Se-enriched canola fed as part of their daily ration. A total of eight late-lactating dairy cows were either fed dried Se-enriched canola harvested from the same field site used in Study *III* or fed additional non-Se alfalfa during April and May 1999. Those cows receiving Se-enriched canola as part of their rations were first fed Se-enriched canola followed by alfalfa and lastly by grains. Each cow was fed daily 3.7 kg DM of Se-enriched canola containing an average concentration of 3.75 mg Se kg^{-1} for 14 days. Blood, milk, and excreta samples were collected and analyzed for Se as described in Study *I*.

E. Study V

The biotransfer of Se to rabbits was investigated with harvested Se-enriched alfalfa (*Medicago sativa* var. Salado) during March to May 2001. A total of 18 post-weaned Dutch rabbits (equal numbers of does and bucks) were fed alfalfa harvested from Se-phytoremediation sites with one of the following plant Se concentrations (in mg kg^{-1} DM):

1. control-alfalfa (0.05)
2. low Se-alfalfa (0.80)
3. high Se-alfalfa (6.62)

Alfalfa was harvested, dried, shredded, analyzed for Se, and equal amounts of alfalfa were placed in the feed dish of each individually caged rabbit. Excreta samples were collected on a weekly basis. Blood samples were collected prior to feeding rabbits alfalfa treatments and at last feeding. A total of 3.5 kg of each respective alfalfa was fed to each rabbit. After 35 days of feeding alfalfa, the rabbits were killed, and select tissues were sampled and analyzed for Se as described in Study *I*.

F. Study VI

The biotransfer of Se and its effect on indicators of colon cancer in rats was investigated with Se-enriched broccoli and inorganic sources of Se. Broccoli (*Brassica oleracea* var. Emperor) was grown in 6-L containers to which 10 mL of 5.2 mmol L^{-1} sodium selenate solution was added biweekly 14 d before heads began to form. When the heads became visible, the Se solution was increased to 20 mL biweekly until heads were fully formed. Fully formed heads were harvested, immediately frozen and lyophilized. Broccoli tissue concentrations averaged 500 μg Se g^{-1} DM. Eighty F-344 inbred rats (weanling males) were maintained in accordance with the NIH guidelines for use of laboratory animals (NRC, 1985). The basal diets for rats was supplemented with the following treatments:

1. No inorganic Se as selenite and no broccoli was added;
2. 2.0 mg Se kg^{-1} diet added as selenite;
3. 2.0 mg Se kg^{-1} diet added as selenite and low Se broccoli (0.1 mg Se kg^{-1} diet; obtained from local supermarket);
4. 2.0 mg Se kg^{-1} diet added as Se-enriched broccoli.

Rats were fed their respective diet treatments for 3 weeks and then injected with the carcinogen, dimethyl hydrazine (DMH, 25 mg kg^{-1} body) as two subcutaneous injections on consecutive weeks. After continuing their diet treatment for another 8 weeks, rats were killed by cardiac puncture after ketamine/xylazine anesthesia. Tissue was removed and analyzed later for Se as described in detail by Finley *et al.* (2000).

III. RESULTS/DISCUSSION

A. Study I

The cabbage looper larvae readily fed on the control mustard leaves (containing no Se) compared with leaves from Se-treated plants. Fewer leaves remained on "control plants" compared with Se-treated plants. Concentrations of leaf Se were less than 0.5 mg Se kg^{-1} DM in control plants and as high as 465 mg Se kg^{-1} DM in Se-treated plants (Table 1). There were fewer pupae collected from Se-treated plants

TABLE 1. Selenium concentrations in leaf and adult insects and dry matter of emerged adults (moths) collected from Se-treated Indian mustard†.

Treatment	Leaf Se conc.‡ mg Se kg^{-1} DM	Total emerged moths§ (#)	Moth dry weight (mg DM insect^{-1})	Moth Se conc. (μg Se kg^{-1})
Replicate 1				
Control	<1	36	47(4)	4(.3)
+Se	465(12)	16	43(2)	2675(76)
Replicate I1				
Control	<1	45	54(3)	2(.2)
+Se	401(14)	15	40(3)	3173(105)
Replicate II1				
Control	<1	34	35(3)	2(.2)
+Se	443(18)	12	32(2)	2730(82)

†Values are the means followed by the standard error in parenthesis from a maximum of nine replications per treatment.

‡Composite leaf sample from Indian mustard was collected and analyzed from each pot.

§Total number of hatched moths collected from all replications for each respective treatment.

compared with control plants, 14 vs. 38, respectively. The larvae may have avoided feeding upon leaves with high Se concentrations. Due to the obvious need for food, the larvae enclosed on the "Se-treated plants" may have resorted to a form of cannibalism. Selective feeding on Se-enriched media by some insects has been suggested by Vickerman and Trumble (1999) and Trumble *et al.* (1998). Johnson and Bañuelos (unpublished) observed that Indian meal moth larvae (*Plodia interpunctella*) avoided a Se-rich diet (>100 mg Se kg^{-1} DM). Similarly, studies with other metals, for example, Cd, Hg, and Ni, demonstrated that insects feed less on metal-enriched plants (Jamil and Hussain, 1992; Reeves *et al.,* 1981). Bioaccumulation of Se was observed in surviving cabbage loopers confined to a no-choice environment. Mean Se concentrations in the developed moths were 2960 μg Se kg^{-1} DM feeding upon Se-treated plants compared with 3 μg Se kg^{-1} DM in moths feeding on control plants (Table 1). Under field conditions, phytophagous insects may, however, avoid feeding on Se-rich crops and thus reduce the likelihood of a biotransfer from plant Se to insect.

B. Study II

Selenium concentrations in the plant tissues were greatest in the Cl-dominated irrigation treatment (Table 2). High background sulfate strongly reduces Se accumulation in many plant species (Bell *et al.,* 1992). Selenium concentrations in leaves from all *Atriplex* plant lines ranged as follows in mg kg^{-1} DM for the saline irrigation treatments: (1) control-0.08-0.50; (2) Se + Cl-27.00-82.80; and (3) Se + Cl + SO_4-1.15-3.20 (Table 2). The development stage at death varied for insects depending on plant line of *Atriplex* and the Se-irrigation treatment. The presence of Se in irrigation water increased plant resistance to the insect tested in this model system. Although the plant lines *A. suberecta*, *A. glauca*, *A. nummularia*, *A. canescens*, and *A. lentiformis* significantly suppressed insect survival with both Se-enriched irrigation treatments (Table 2), they were considered less desirable for phytoremediation because of their low biomass production (Vickerman *et al.,* 2002). Among the tested *Atriplex* lines, further investigation should include *A. hortensis* (a producer of high biomass) for use in phytoremediation in areas with high salinity. The overall results suggest that some *Atriplex* plant lines, *A. hortensis* and *A. spongiosa*, would unlikely host significant populations of *S. exiqua*. Moreover, these plant lines could improve grower participation in phytoremediation of Se by potentially reducing local populations of a key insect pest.

C. Study III

Lambs readily consumed the Se-enriched leaves of fresh canola. Significant differences in total live weight were not observed between treatments at the end of the study (data not shown). Animals were fed a total of 45 kg DM of Se-enriched canola and 49 kg DM control canola as a daily ration for 60 days. Plant tissue concentrations ranged from 2.0 to 3.63 mg Se kg^{-1} DM for Se-enriched canola. Cattle and lambs may consume seleniferous plant tissues up to 5 mg kg^{-1} without suffering from Se toxicity (Mayland, 1994). Between the two treatments, Se concentrations were greatest in all tissue and samples collected from lambs fed Se-enriched canola (Table 3). Because mean blood EDTA Se levels were less than 0.5 mg Se L^{-1} for lambs fed Se-enriched canola (Table 3), the amount of Se provided to the lambs by canola safely increased blood Se levels. The liver and other glandular tissue absorbed Se similarly, as reported by Miller *et al.* (1988). The kidneys contained the highest tissue Se concentration among all organs tested. Selenium not absorbed by the selected organs may have been excreted as urine or feces because some rumen microorganisms transformed Se into biologically unavailable forms of Se (Mayland, 1994). Despite the effective biotransfer of Se from canola to lambs, it is important

TABLE 2. Comparison of day at death for *S. exigua* larvae fed *Atriplex* plant lines irrigated with Se-enriched saline water treatment.

Species†	Plant Line #	Mean day of death with treatment‡: Control	Se/Cl (days)	$Se/Cl/SO_4$	Plant Se Conc. with treatment: Control	Se/Cl ($mg\ kg^{-1}$ DM)	$Se/Cl/SO_4$
A. semibaccata	299488	21.0	19.4	16.0	0.30	33.8	2.3
A. hortensis	379088	20.4	17.4	15.6	0.08	40.8	3.0
A. suberecta	368854	23.8	23.6	16.8	0.10	33.4	1.4
A. glauca	glauca	23.0	16.6	9.2	0.16	61.5	1.6
A. spongiosa	415862	21.4	19.8	19.6	0.10	39.7	2.0
A. nummularia	419463	16.4	9.2	17.6	0.10	33.2	1.7
A. canescens	canescens	30.0	15.2	12.4	0.15	48.2	2.0
A. leucolada	398707	25.8	23.0	28.2	0.40	39.1	3.2
A. mueller	380751	27.4	24.6	30.0	0.40	40.1	1.7
A. lentiformis	330661	28.4	26.8	12.2	0.16	45.0	1.2

†Ten replicates of each plant line were grown with respective irrigation treatment.

‡Ten replicates of one insect each were tested for each of the three irrigation treatments per plant line.

to strictly monitor the Se concentrations in canola to determine the amount that can be safely fed to lambs (Bañuelos and Mayland, 2000).

D. Study IV

The cows did not avoid consuming the Se-enriched canola as part of their ration. There was no significant difference in total live weight between cows in both treatments. Selenium concentrations were slightly greater in blood, urine, and fecal samples from cows fed Se-enriched canola as part of a daily ration (Table 4) (Bañuelos and Mayland, 2000). Selenium concentrations were not significantly different between milk samples from cows fed Se-enriched canola or fed alfalfa (Table 4). Other studies have reported that Se levels in cow's milk decrease with increasing Se intake (Miller *et al.,* 1988). Thus, unless Se in plant material is fed at higher levels and for a longer duration, selenium's transfer into milk was too low to pose a potential hazard to human health or to be detected. Sulfur-rich canola should, however, only be provided as a part of a cow's daily ration, because of potential

TABLE 3. Mean selenium concentrations in different tissues and blood of lambs fed seleniferous and nonseleniferous canola.

Tissue	Se concentration in tissue of lambs fed canola:	
	Se-enriched	Control
	----------------($\mu g\ kg^{-1}$)-------------	
Heart	682 (14)[a]	360 (11)
Liver	809 (42)	438 (25)
Kidney	2100 (99)	1507 (59)
Spleen	525 (66)	216 (10)
Muscle	213 (11)	68 (4)
Toenail	227 (27)	98 (20)
Blood[b]	278 (10)	83 (1)
Urine[c]	301 (50)	ND[d]
Feces[e]	358 (63)	29 (5)

[b]Mean blood-EDTA Se concentration was 50 μg^{-1} kg at onset of study.

[c]Mean Se concentration was 15 $\mu g\ kg^{-1}$ at onset of study.

[d]ND-not detected

[e]Mean Se concentration was 10 $\mu g\ kg^{-1}$ at onset of study.

[a]Means followed by the standard error in parenthesis.

interference on copper absorption if sulfur content exceeds 0.4% in feed. Leaves from canola grown under a high sulfate salinity condition contained up to 1% sulfur. Due to sulfur's potential negative impact on taste, sulfur concentrations should be monitored in milk from cows fed canola.

E. Study V

The rabbits did not avoid consuming the Se-enriched alfalfa, irrespective of the plant Se concentration. There were no significant differences in total live weight among the rabbits in all three treatments (data not shown). Symptoms of Se toxicity, for example, loss of hair, diarrhea, lack of appetite, smell of volatile Se, was not

TABLE 4. Selenium concentrations in milk, blood, and excreta from cows fed seleniforous canola and nonseleniferous alfalfa.

Julian day of tissue sampling	Treatment[†]	Se Concentrations in: Milk	Blood	Urine	Feces
		----------μg L^{-1}			----------
121	Alfalfa/Grain	31 (1)[‡]	63 (2)	23 (1)	35 (1)
	Canola	32 (1)	65 (2)	21 (1)	38 (1)
130	Alfalfa/Grain	42 (1)	65 (2)	24 (1)	46 (2)
	Canola	43 (2)	62 (2)	25 (1)	48 (2)
141	Alfalfa/Grain	54 (2)	67 (2)	33 (1)	48 (1)
	Canola	57 (2)	88 (3)	48 (1)	67 (2)
145	Alfalfa/Grain	65 (3)	65 (2)	31 (1)	52 (1)
	Canola	71 (2)	90 (3)	59 (2)	73 (2)

[†]Mean plant Se concentrations were in mg Se kg^{-1} DM: 0.11(alfalfa), 0.24 (grains), and 3.75 (canola), respectively.

[‡]Values represent mean from four replications followed by standard error in parenthesis.

observed on any rabbits, except for one rabbit in the high Se alfalfa treatment. Selenium concentrations significantly increased in all tissues (as high as 57 and 16 mg kg^{-1} in liver and kidneys, respectively), feces, and blood in proportion to Se concentrations in alfalfa treatment (Table 5). Our results confirmed that similar to other organisms, once Se is in the rabbit, it mainly accumulates in both kidney and liver (Caurant, 1994). Selenium in alfalfa appears to be highly bioavailable for rabbits; the Se concentrations measured in all tissues from rabbits fed high Se alfalfa far exceed concentrations reported by Diaz-Alarcon *et al.* (1996).

TABLE 5. Mean selenium concentrations in different tissues and blood of rabbits fed seleniferous and nonseleniferous alfalfa.

Tissue Sampled	Se concentration in tissue of rabbits fed: Control alfalfa[†]	Low Se alfalfa[†]	High Se alfalfa[†]
	--------(mg Se kg^{-1})--------		
Heart	0.84 (.06)[‡]	2.94 (.18)	4.95 (.34)
Liver	2.61 (.39)	12.79 (1.8)	57.14 (3.5)
Kidney	2.44 (.18)	4.59 (.39)	15.99 (2.1)
Muscle	0.45 (.05)	3.38 (.25)	5.32 (.40)
Feces[§]	0.12 (.04)	0.99 (.15)	3.11 (.25)
Blood[¶]	0.15 (.03)	0.55 (.05)	2.12 (.20)

† Mean alfalfa Se concentrations were in mg Se kg^{-1} DM: 0.05 (control alfalfa), 0.80 (low Se alfalfa), and 6.62 (high Se alfalfa). Prior to feeding rabbits alfalfa treatments, they were initially fed rabbit feed pellets (0.50 mg Se kg^{-1}) after they were weaned.

‡ Values represent the mean from six replications followed by standard error in parenthesis.

§ Samples were collected on a weekly basis; the mean concentration from all collections is presented.

¶ Mean blood-EDTA Se concentration was 0.23 mg Se kg^{-1} at onset of study for all rabbits.

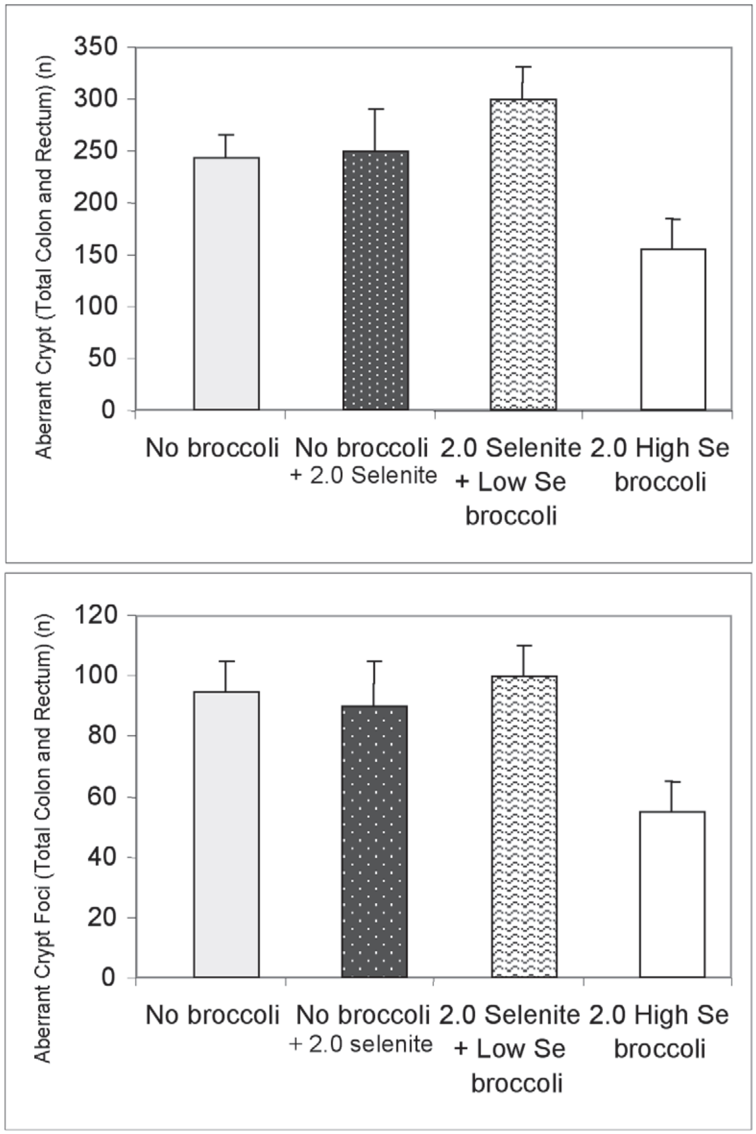

FIGURE 1. Effect of dietary form and amount of Se on the occurrence of preneoplastic lesions in the colons of rats administered dimethy hydrazine (DMH). Rats were fed diets that contained no low Se broccoli, 2.0 mg kg^{-1} Se as selenate and two Se broccoli or 2.0 mg kg^{-1} Se supplied as high Se broccoli. Rats were fed the diets for 3 wk, injected twice with DMH and then continued to consume the diets for an additional 8 wk. Figures show numbers of aberrant crypts (A) and aberrant crypt foci (B) in the total colon and rectum. Values are means ±SEM; n = 18.

F. Study VI

Dietary treatments with different sources of Se significantly altered Se status in plasma and liver Se concentrations of rats (Finley *et al.,* 2000). Comparisons of Se treatment showed that rats fed 2 mg Se kg^{-1} diet as broccoli had significantly fewer AC (aberrant crypt) and fewer ACF (aberrant crypt foci) compared with following treatments: low selenite ($P<0.04$), high selenite and no broccoli ($P<0.03$), high selenite and low Se broccoli ($P<0.005$) (Figure 1). Both AC and ACF are used as preneoplastic indicators of colon cancer. High Se broccoli was more effective than selenite or broccoli alone for inhibiting preneoplastic lesions in the colons of rats (Finley *et al*. 2000). A recently published article (Irion, 1999) hypothesized that Se in *Brassica* species may be effective against certain cancers. Because Se undergoes different metabolic transformations when absorbed by plants, the anticarcinogenic properties of high Se broccoli may be a result of the unique chemical forms of selenoproteins in broccoli. Current research by Finley is evaluating the associated health benefits for humans consuming broccoli grown in Se-rich soils.

IV. CONCLUSION

These studies demonstrate that Se absorbed by plants used in phytoremediation can be transferred biologically in an intentional or unintentional manner to insects and animals. Plants enriched with Se may inadvertently discourage the infestation by some insects species or the bioaccumulation of Se by insects feeding on the plants may exert deleterious effects on birds and mammals that eat the insects. Depending on plant Se concentrations, harvested plants used in phytoremediation of Se may be carefully used as part of a feed ration for animal producers wishing to ensure essential levels of Se for lambs and dairy cows. Blending harvested plant material high in Se with low Se plant material is strongly encouraged to reduce an excessive accumulation of Se in liver, kidneys, blood, and other tissues of rabbits. Lastly, the health benefits of Se, including some cancer protection in rats, may be promoted by increasing the dietary supply of plant-bound Se.

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