Bull. Environ. Contam. Toxicol. (1987) 38:783–788

Environmental Contamination and Toxicology

Deposition of Cadmium in Tissues of Coturnix Quail Fed Honey Bees

Gilbert S. Stoewsand,[1] Roger A. Morse,[2] Carl A. Bache,[3] and Donald J. Lisk[3]

[1]Department of Food Science and Technology, New York State Agricultural Experiment Station, Geneva, New York 14456; [2]Department of Entomology, New York State College of Agriculture and Life Sciences, Cornell University, Ithaca, New York 14853; and [3]Toxic Chemicals Laboratory, New York State College of Agriculture and Life Sciences, Cornell University, Ithaca, New York 14853-7401

Cadmium is a metal of current toxicologic concern since it is a ubiquitous contaminant found at low concentrations throughout the environment. An excellent review of man's exposure and human health effects has been written (Commission of the European Communities 1978). It is natively present in soils in trace amounts (Bowen 1966). Additional quantities of cadmium are contributed by industrial and other human activities as air, water and food pollutants. Interest in cadmium was stimulated when Schroeder published a provocative epidemiologic study linking dietary cadmium to hypertension in the general population (Schroeder 1965).

Insects have been reported to concentrate cadmium probably through food or water intake or by contact with contaminated surfaces (Cheng et al. 1976, 1979). It is conceivable that avian species consuming such insects could concentrate cadmium in their tissues. In the work reported here, domesticated honey bees were found to contain appreciable levels of cadmium. The bees were collected in quantity and fed to Coturnix quail to study the extent to which an avian species may accumulate cadmium in liver and kidney as well as in their eggs.

MATERIALS AND METHODS

Honey bees (Apis mellifera), collected from several hives owned by a commercial beekeeper near Middlebury, Vermont in August, 1985 were found to contain appreciable cadmium. Eighty-five kilograms of the bees were collected there. After killing them by exposure to carbon dioxide they were washed thoroughly with water and freeze-dried. They were then milled to a powdery consistency and incorporated at increasing dietary levels for coturnix quail (Coturnix coturnix japonica). The proximate analysis of the honey bees is given in Table 1. Diets containing 0, 20, 35 and 50% dried bees were formulated (Table 2) to contain similar amounts of protein and fat, as determined in the proximate analysis of the dried bees (Table 1).

Send reprint request to Donald J. Lisk at the above address.

Table 1. Proximate analysis of dried bees.

Constituent	%
Protein	56.4
Fat	9.0
Crude fiber	14.2
Ash	3.0

Table 2. Composition of diets fed to Coturnix quail.

Ingredients[a]	Composition %			
Dried, ground bees	0[b]	20.0	35.0	50.0
Isolated soybean protein	32.0	20.7	12.3	4.0
Cornstarch	50.0	46.07	40.77	35.47
Cellulose	3.0	0	0	0
Corn oil	5.0	3.2	1.9	0.5

[a]Each of the diets also contained the following ingredients (%, dry wt): L-arginine-HCl (0.8); DL-methionine (0.8); glycine (0.35); choline Cl (50%)(0.4), mineral mix (6.67) and vitamin mix (1.00), Stoewsand and Robinson, (1970); antioxidant (Santoquin, Monsanto Co.)(0.0125).

[b]Basal Diet.

At one-day of age, 24 unsexed quail were assigned to each of the four dietary treatments. They were fed for 14 weeks. After killing the birds by cervical dislocation, the kidney and livers were excised for cadmium analysis. Cadmium was determined in the freeze-dried tissues by wet ashing the samples with nitric, perchloric and sulfuric acids (Pinta 1973) followed by analysis using conventional stripping voltammetry. Statistical analysis was accomplished using Duncan's multiple range test as described in Steel and Torrie (1960).

RESULTS AND DISCUSSION

Considering the range of protein content in foods, honey bees appear to be relatively high (Table 1). If their protein content is indicative of that of insects in general, it is understandable that they constitute an important dietary source for many avian species. Ozimek et al. (1985) has reported that dried honey bees contained 56.8% crude protein. The levels of most of the essential amino acids were higher in honey bee protein concentrate following removal of chitin by alkali extraction than in whole dried bees. True protein digestibility was higher in the concentrate (94.3%) than in whole dried bees (71.5%).

The concentration of cadmium in the dried honey bees and the several dietary treatments are shown in Table 3. There was no

Table 3. Cadmium content of honey bees and diets.

Sample	Cadmium (ppm, dry wt)
Dried bees	0.51
Basal	0.02
20% bees	0.12
35% bees	0.22
50% bees	0.37

known nearby obvious sources of cadmium from which the collected bees may have derived elevated levels of cadmium. The mechanisms by which honey bees may accumulate cadmium are speculative. Contacting innumerable surfaces upon which cadmium-containing dust may have settled while foraging is one possibility. The uppermost surface of water which bees may contact in ponds, lakes or other quiescent bodies of water typically contain an imperceptibly thin layer of living and decaying organic matter in which heavy metals in aquatic systems tend to concentrate and this may also be contributory. Plants absorb cadmium present natively in soils or as pollutants. In addition, plant pollen contains considerable protein, with which cadmium may be associated and which bees consume.

The concentrations of cadmium in quail tissues, eggs and excreta are given in Table 4 and show, in general, enhanced deposition with increased levels of dietary bees. Factorial analysis of the data indicates that diet, but not sex, was a highly significant ($p < 0.005$) treatment effect on the cadmium concentration of liver and kidneys of the quail. However, a significant ($p < 0.025$) interaction between diet and sex was observed with kidney cadmium levels. This indicates the different cadmium deposition rates between the male and female quail fed the increased levels of dried bees.

Mortality was very high in the 50% bee treatment (Table 5), reaching 62.5% after only the initial week of treatment. Whole dried bees contain over 11% chitin (Ozimek, et al. 1985). This may have contributed to the poorer weight gains and increased mortality of the quail fed the 50% bee diet.

Except in the 50% bee group. No appreciable amounts of cadmium were found in the quail eggs. Sell (1975) also showed virtual absence of the transfer of cadmium to eggs from chickens fed cadmium chloride. Trace amounts of cadmium appeared in eggs only at high dietary cadmium levels which may also reduce egg production and shell thickness (Sell 1975; Leach et al. 1979).

The forms of cadmium in honey bees and quail are not known. Interestingly, accumulation of cadmium in the digestive tract and induction of a cadmium-binding protein was found in fleshfly (Sarcophaga peregrina) larvae fed a cadmium-containing diet (Aoki

Table 4. Mean cadmium concentration in liver, kidney, eggs and excreta of Japanese quail.

Dietary treatment	Liver	Kidney	Eggs[1] Whites	Eggs[1] Yolks	Excreta[2]
			Males		
Basal	0.08 ± 0.00c[3]	0.27 ± 0.03z			0.10
20% dried bees	0.30 ± 0.04b	0.82 ± 0.10yz			0.62
35% dried bees	0.49 ± 0.05a	1.37 ± 0.10wxy			0.73
50% dried bees	0.46 ± 0.01a	1.59 ± 0.08wx			1.11
			Females		
Basal	0.09 ± 0.01c	0.34 ± 0.06z	0.01	0.00	
20% dried bees	0.43 ± 0.02ab	1.49 ± 0.12wx	0.01	0.00	
35% dried bees	0.50 ± 0.10a	1.86 ± 0.43w	0.00	0.01	
50% dried bees	0.40 ± 0.06ab	1.03 ± 0.21xy	0.01	0.16	

(All values ppm, dry weight.)

[1]Eggs were a composite of those from the several replicated quail in each dietary treatment group.

[2]Excreta was a mixture from both male and female quail.

[3]Mean ± standard error; dissimilar letter superscripts indicate significant differences ($p < 0.05$) between mean values in the organ.

Table 5. Ninety-day mean weight gain, mean food intake, and mortality of quail consuming bees.

Treatment	Weight gain (g)	Food intake (g)	Mortality (%)	No. of survivors Males	No. of survivors Females
Basal	110 ± 3[a]	1016	20.8	11	8
20% bees	108 ± 4	1073	20.8	9	10
35% bees	103 ± 4	1059	56.5	7	3
50% bees	99 ± 4	1164[b]	75.0	3	3

[a]Mean ± standard error

[b]Estimate (much food was wasted)

et al. 1984). The protein was a mixture of five isoproteins with several properties characteristic of metallothionein. Similar results were reported by Suzuki et al. (1984) in the silkworm. A cadmium-containing metallothionein has also been isolated and characterized in the liver of the chicken injected intraperitoneally with cadmium chloride (Weser et al. 1973).

The oral LD_{50} of cadmium chloride in the rat is 88 mg/kg body weight (Tatken and Lewis 1983). High levels of ingested cadmium have been reported to significantly decrease intestinal calcium absorption in chickens (Fullmer et al. 1980) and iron in Coturnix quail (Fox et al. 1971) and to cause alterations in the histologic features and concentrations of various cellular constituents in parakeets (Bandyopadhyay et al. 1983). Dietary zinc (Jacobs et al. 1983) and calcium (Winkler et al. 1984) have been reported to decrease cadmium deposition in Japanese quail and chickens, respectively. Injected ascorbic acid also exhibits protection against several of the toxic symptoms of cadmium poisoning in Coturnix quail (Fox et al. 1971).

In summary, it appears that if insects, in general, contain concentrations of cadmium comparable to those of the honey bees used in this study, their consumption by wild birds could constitute an appreciable source of deposited cadmium in avian tissues. Other modifying factors would include the percentage of insects in the diets of such birds and their dietary content of other constituents such as calcium, iron and ascorbic acid which may affect the efficiency of cadmium deposition in tissues. Concerning the consumption of honey bees by birds, it has been reported that the Philippine spine-tail swift is a honey bee predator and although this results in many stings in the mouth and muscular stomach of the bird, it does not appear to be a deterrent to their predatory habit (Morse and Laigo 1969).

Acknowledgments. The authors thank the Department of Avian Sciences at Cornell University for generously supplying the quail and J. L. Anderson and C. M. Reid for their assistance in this investigation. This study was supported in part by NSF grant PCM-8119757 entitled Pesticide Proofing Honey Bees Through Enzyme Induction.

REFERENCES

Aoki Y, Suzuki KT, Kubota K (1984) Accumulation of cadmium and induction of its binding protein in the digestive tract of fleshfly (Sarcophaga peregrina) larvae. Comp Biochem Physiol 77C:279-282

Bandyopadhyay R, Ghosh T, Chattopadhyay R, Bhattacharyay T, Sarkar A (1983) Some changes in liver after cadmium chloride administration in male rose-ringed parakeet, Psittacula krameri borealis. Comp Physiol Ecol 8:279-281

Bowen HJM (1966) Trace elements in biochemistry. Academic Press, New York

Cheng L, Alexander GV, Franco PJ (1976) Cadmium and other heavy metals in sea-skaters. Water, Air, Soil Pollut 6:33-38

Cheng L, Franco PJ, Schulz-Baldes M (1979) Heavy metals in the sea-skater Halobates robustus from Galapagos Islands: Concentrations in nature and uptake experiments, with special reference to cadmium. Marine Biol 54:201-206

Commission of the European Communities: Criteria (Dose/Effect Relationships) for Cadmium. (1978) Pergamon, Oxford

Fox MRS, Fry BE, Jr.,Harland BF, Schertel ME, Weeks CE (1971) Effect of ascorbic acid on cadmium toxicity in the young coturnix. J Nutr 101:1295-1306

Fullmer CS, Oku T, Wasserman RH (1980) Effect of cadmium administration on intestinal calcium absorption and vitamin D-dependent calcium-binding protein. Environ Res 22:386-399

Jacobs RM, Jones AOL, Fox MRS, Lener J (1983) Effects of dietary zinc, manganese, and copper on tissue accumulation of cadmium by Japanese quail. Proc Soc Exp Biol Med 172:34-38

Leach RM, Jr., Wang KW-L, Baker DE (1979) Cadmium and the food chain: The effect of dietary cadmium on tissue composition in chicks and laying hens. J Nutr 109:437-443

Morse RA, Laigo FM (1969) The Philippine spine-tailed swift, Chaetura dubia McGregor as a honey bee predator. Philippine Entomol 1:138-143

Ozimek L, Sauer WC, Kozikowski V, Ryan JK, Jorgensen H, Jelen P (1985) Nutritive value of protein extracted from honey bees. J Food Sci 50:1327-1332

Pinta M (1973) Detection and determination of trace elements. Ann Arbor Science Publishers, Ann Arbor, 588 pp

Schroeder HA (1965) Cadmium as a factor in hypertension. J Chronic Dis 18:647-656

Sell JL (1975) Cadmium and the laying hen: Apparent absorption, tissue distribution and virtual absence of transfer into eggs. Poultry Sci 54:1674-1675

Steel RDG, Torrie JH (1960) Principles and procedures of statistics. McGraw-Hill, New York, pp 194-229

Stoewsand GS, Robinson WB (1970) Reproductive response of Japanese quail to varietal grape diets. J Enol Viticult 21:174-178

Suzuki KT, Aoki Y, Nishikawa M, Masui H, Matsubara F (1984) Effect of cadmium-feeding on tissue concentrations of elements in germ-free silkworm (Bombyx mori) larvae and distribution of cadmium in the alimentary canal. Comp Biochem Physiol 79C:249-253

Tatken RL, Lewis RJ (eds) (1983) Registry of toxic effects of chemical substances, 1981-82 edition. U.S. Dept of Health & Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, Ohio 45226

Weser UT, Rupp H, Donay F, Linnemann F, Voelter W, Voetsch W, Jung G (1973) Characterization of Cd, Zn-thionein (metallothionein) isolated from rat and chicken liver. Eur J Biochem 39:127-140

Winkler VC, Rambeck WA, Kollmer WE, Zucker H (1984) Der Einfluss der Calcium-, Phosphor- und Vitamin D-Zulfuhr auf die Cadmium-Retention in Leber und Nieren beim washsenden Huhn. Z Tierphysiol, Tierernährg u Futtermittelkde 51:250-256

Received August 17, 1986; accepted December 29, 1986