March 1990

ACQUIRED STRYCHNINE TOLERANCE BY POCKET GOPHERS

Ling Ling Lee
University of California - Davis

Walter E. Howard
University of California - Davis

Rex E. Marsh
University of California - Davis

ACQUIRED STRYCHNINE TOLERANCE BY POCKET GOPHERS

LING LING LEE, WALTER E. HOWARD, and **REX E. MARSH,** Wildlife and Fisheries Biology, University of California, Davis, California 95616.

ABSTRACT: Four adult female Botta's pocket gophers (Thomomys bottae) that had survived many normally potentially lethal doses of strychnine alkaloid in another experiment (Lee 1986) were examined further. These individuals freely consumed 0.5% strychnine bait, and 3 of them also 1% strychnine bait, for long periods without dying, whether or not nontoxic alternate bait was present. After 1 gopher (#5) was taken off its 1% strychnine wheat diet for 44 days, it lost its physiological tolerance to strychnine and died the first day when again exposed to a free choice of nontoxic and 1% strychnine wheat. It consumed only 7 mg/kg of strychnine before dying, whereas another gopher (#42) was able to survive on a mean daily consumption of 275.8 mg/kg of strychnine in a no-choice situation over a period of 28 days. This is almost 40 times the lethal dose of the other animal.

Proc. 14th Vertebr. Pest Conf. (L.R. Davis and R.E. Marsh, Eds.)
Published at Univ. of Calif., Davis. 1990.

INTRODUCTION

Pocket gophers (Thomomys sp.) are a serious pest in agriculture and forestry and are normally controlled with the use of strychnine alkaloid-treated grain baits. Strychnine is the leading rodenticide for pocket gopher control in agriculture and forestry; however, in recent years it seems to be failing to give the former high degree of control in some situations (Tickes et al. 1982). The reasons for this are not known but several factors are under suspicion. This study investigates two types of acquired strychnine tolerance in gophers and some related factors that may help explain why control results are sometimes poor. Bait acceptance and strychnine concentrations are two other factors not addressed in this study.

One type of acquired tolerance to strychnine is a physiological tolerance. After a gopher ingests a series of sublethal doses, it can tolerate increasingly higher doses of strychnine. Such strychnine tolerance has been shown to occur with other rodent species, pigs, and dogs (Hale 1909, Schwartze 1922).

Another type of acquired tolerance that is demonstrated in this study, is a feeding strategy gophers have or acquire which enables them to consume what normally is in excess of a lethal amount of strychnine by eating sublethal amounts periodically throughout each 24-hour period. Apparently shortly after a gopher ingests a sublethal amount of strychnine in one feeding, absorption begins, and it is excreted in the urine or detoxified in the liver (Crabtree 1962). Since there is little sustained cumulative effect, gophers can safely exceed their single acute lethal dose to strychnine by consuming sublethal doses at short intervals of 1 or 2 hours. With such a feeding strategy, a gopher can daily consume what would otherwise be equivalent to many times a lethal dose.

It is also known that pocket gophers (possibly not all individuals) do not object to strychnine or its bitter taste. Certainly many do not develop the typical bait/poison shyness other rodents frequently exhibit after they eat a sublethal dose of a toxic substance during their first or subsequent encounter (Howard et al. 1968, Marsh and Howard 1978).

METHODS

Four of the 10 adult female Botta's pocket gophers (T. bottae) used in this report were strychnine-tolerant survivors derived from 48 female gophers that had been offered different types of strychnine bait in previous tests (Lee 1986). In those free-choice tests 20 (41.7%) of the 48 gophers ate a lethal dose of either 0.5 or 1% strychnine-treated wheat the first day it was offered, and an additional 24 (50%) died as a result of subsequent feedings over a period of 2 to 7 days. The 4 (8.3%) animals included here had survived all the former strychnine tests and, in this study along with 6 additional naive gophers, were offered additional strychnine bait in free-choice and no-choice tests. The 6 additional naive gophers were used initially to study the frequency of feeding and amount of nontoxic and toxic food eaten over time when monitored hourly over 24-hour periods.

All 10 pocket gophers used in the study were trapped on or near the University of California, Davis. They were housed individually in 44xl9x36-cm solid metal, open-topped cages containing 6 cm of soil. At least 3 days before each test the soil was removed and a piece of cheesecloth was provided as nesting material so all uneaten bait could be readily recovered. Room temperatures remained at 20 to 25°C. The rooms were kept dark except when the animals were fed or examined. Their maintenance diet consisted of 5 pieces of Purina Rodent Laboratory Chow, half an apple every other day, and a large piece of potato each week. The gophers were weighed at the beginning and end of each test. During each test, except as noted below, the gophers were given daily a quarter of an apple to provide moisture, and in the free-choice tests, two ceramic food bowls, one with ad lib. amounts of clean wheat and the other strychnine baits. The position of bowls was switched daily to rule out any position bias. In no-choice tests only strychnine-treated grain and apple were provided.

RESULTS

The part of this study that tested the degree of physiological tolerance pocket gophers can acquire to strychnine only included 4 animals. Rather than sacrifice large numbers of gophers, this number seemed adequate to clearly substantiate that some pocket gophers can consume substantial amounts of strychnine by developing a physiological tolerance to strychnine and by incorporating multiple feedings during each 24-hour period. For example, mean daily consumption for animal #42, when offered 1% strychnine-treated wheat over a 28-day period, was 275.8 mg/kg (Table 1). In contrast, the LD_{99} is estimated to be only 17 mg/kg

(Miller 1953), or 6% of 275.8. Of the 44 gophers that died from strychnine in Lee's (1986) study, the average amount consumed in the last feeding, usually the day before death, was 19.1 mg/kg, with a range of 3.6 to 63.6. In the current study, gopher #5 died after eating only 0.7 mg/kg of strychnine under a free-choice feeding situation, but this happened after it had been on alternate food for 44 days (Table 1), causing an extinction of its acquired physiological tolerance for strychnine.

When feeding on 1% strychnine bait with alternate food available, the mean daily consumption of strychnine for gopher #5 was 57.2 mg/kg over 13 days; for #38, 23 mg/kg over 7 days; and for #42, 42.2 mg/kg over 13 days (Table 1). Without alternate food available, the daily consumption of strychnine for #1 increased from 79.9 to 139.9 mg/kg (mean was 118.5 mg/kg) while on a diet of 0.5% strychnine wheat for 21 days. When on a diet of 1% strychnine wheat in a no-choice situation for 9 days, the mean daily consumption of strychnine was 127.1 mg/kg for #38, and 275.8 mg/kg for #42 over 28 days. For animal #42, the daily consumption of strychnine ranged from 46.9 to 312.5 mg/kg.

To determine whether extinction of physiological tolerance for strychnine occurs, gopher #5 was kept on just clean alternate food for 44 days, then offered 1% strychnine bait in a free-choice situation. On the first day the animal showed no aversion to strychnine and ate 7 mg/kg of the 1% strychnine bait and died, which is only 12% of the mean daily consumption of strychnine that it had survived earlier for 13 days.

The amount of nontoxic wheat and strychnine-treated wheat eaten by the 6 gophers was measured each hour of 24-hour periods (Fig. 1). A piece of apple was provided in all tests to provide moisture. A gopher that was fed just nontoxic grain consumed some wheat during 15 of the 24 hours (Fig. la). Three other gophers not shown gave similar results, eating food during 10, 15, and 21 of the 24 hours, respectively.

Table 1. Amount of strychnine-coated whole wheat and alternate food of clean wheat consumed by 4 female pocket gophers (Thomomys bottae) that had acquired a tolerance for strychnine in earlier tests (Lee 1986). Apple was available for moisture.

Animal No. (Body wt., g)	Strychnine concentration (%)	No. consecutive test days	Mean daily consumption		
			Nontoxic wheat (g)	Toxic bait grams (SE)	Strychnine[a] mg/kg (range)
1 (144)	0.5[b]	32	3.19	0.86 (0.36)	30.0 (0-45.14)
	0[b]	45	NA	-	-
	0.5	21	-	3.38 (0.59)	118.5[c] (79.86-138.89)
5 (143)	0.5[b]	18	3.46	0.65 (0.31)	22.5 (0-45.14)
	1.0[b]	13	1.88	0.78 (0.52)	57.2 (0-139.86)
	0[b]	44	NA		
	1.0[b]	1	0.20	0.10	7.0[d] ( )
38 (96)	0.5[b]	8	6.60	0.23 (0.15)	12.0 (0-20.83)
	1.0[b]	7	5.44	0.22 (0.10)	23.0 (10.42-93.75)
	1.0	9	-	1.22 (0.23)	127.1 (93.75-156.25)
	1.0[b]	10	3.76	0	0.0
	1.0	15	-	0.63 (0.44)	65.6[c] (0-218.75)
42 (128)	0.5[b]	3	3.74	0.31 (0.21)	12.1 (0-19.53)
	1.0[b]	13	3.98	0.54 (0.20)	42.2 (15.63-70.31)
	1.0	28	-	3.5 (0.43)	275.8[c] (46.88-312.50)

[a]For T. bottae the approximate LD_{50} is 6.9 mg/kg, for LD_{99} 17 mg/kg (Miller 1953).
[b]Nontoxic wheat was also available in addition to the strychnine bait.
[c]Alive at end of the test.
[d]Died first day the 1% toxic bait was offered again.

When a strychnine-naive gopher was offered 0.5% strychnine-treated wheat for the first time, it fed but twice during the 24 hours (Fig. 1b). A second gopher with the same experience also fed but twice at 8 hours apart. After feeding on strychnine-treated wheat and apple for 2 months, their hourly feeding pattern of the toxic bait was again recorded. As shown in Fig. 1c, the same gopher as in Fig. 1b now had a feeding pattern similar to those feeding on nontoxic wheat (Fig. 1a), except the daily total food consumption of these two animals was lower than with the control gophers ($t = 6.8$, $df = 4$, $p<0.001$). While feeding on the strychnine bait these two animals fed during 15 (Fig. 1c) and 18 of the 24 hours, respectively. Therefore, gophers experienced in feeding on strychnine eventually return to a feeding frequency not very different from those of gophers feeding on nontoxic food ($X^2 = 2.14$, $df = 5$, $p>0.7$).

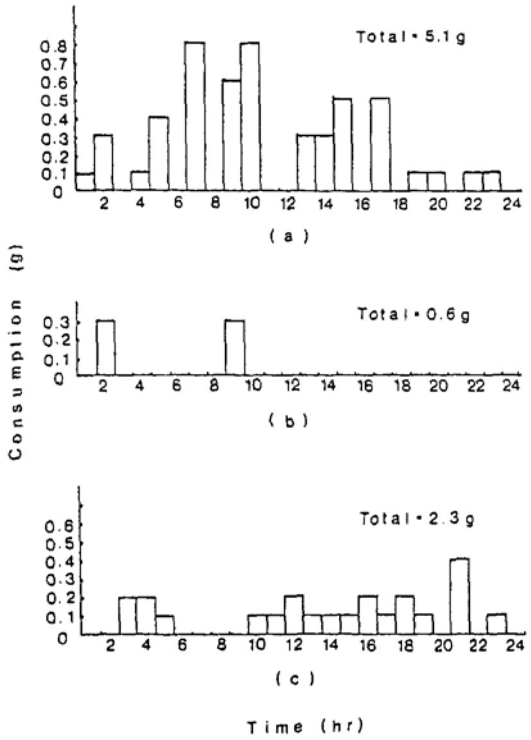

Figure 1. Amount of nontoxic and strychnine-treated wheat consumed each hour by pocket gophers (Thomomys bottae) during 24 hours. (a) Consumption of nontoxic wheat, (b) of 0.5% strychnine-treated wheat at first exposure by a different gopher, and (c) of 0.55 strychnine wheat by gopher in (b) after it had developed a "tolerance" for strychnine. Apple was provided for moisture in all tests.

DISCUSSION

Individual variation of bait acceptance, behavior, and susceptibility to strychnine among gophers has been reported before (Hungerford 1976, Anthony et al. 1984). Since strychnine can be metabolized and excreted in urine by rats and guinea pigs within a short period of time (Hale 1909, Schwartze 1922), a gopher can tolerate more strychnine over a 24-hour period if it feeds frequently throughout the day. This is supported in this test. Various studies on the daily activity pattern of pocket gophers (Thomomys spp.) indicate that gophers are neither nocturnal, diurnal, or crepuscular, and are active throughout the 24-hour period (Gettinger 1975, 1984; Vleck 1979, Andersen and MacMahon 1981, Hickman 1984), although these studies do not mention the specific feeding pattern of gophers. Their natural feeding pattern of not ingesting a large amount of food at any one time (Fig. la), may help gophers survive various kinds of toxic food items found naturally in their habitats.

We have suspected for years that gophers develop a physiological tolerance to strychnine and have known they do not readily develop aversions to strychnine (Howard et al. 1968), but we have never before confirmed how their periodic feeding strategy enables them to survive so much strychnine. Anthony et al. (1984) reported that 1 gopher (T. mazama) survived after eating over 125 mg of strychnine during 4 days, or 31.25 mg/day. The greatest amount consumed on any one day by gopher #42 was 40 mg.

The response of these gophers is different from that of rats (Rattus norvegicus), which often refuse to eat any mixture that has previously caused them to be sick (Rzoska 1953). Howard et al. (1968) also reported that while Norway rats readily detect and avoid solutions containing as little as 0.05% strychnine sulfate, pocket gophers never completely avoided 0.5% strychnine sulfate solution even though they became obviously ill. Also, as noted by Marsh and Howard (1978), after gophers consume a sublethal amount of strychnine bait, they are more likely to develop some shyness to the bait material rather than to strychnine.

This acquired tolerance to strychnine may be brought about more readily and reach high levels in some gophers because it was discovered that pocket gophers normally consume relatively small amounts of food at any given period and feed frequently throughout the 24-hour period. Substantial amounts of strychnine can therefore be safely consumed by feeding at intervals so the strychnine consumed in one feeding is excreted in urine or metabolized, or nearly so, before engaging in another feeding bout. This project also confirms that pocket gophers do not demonstrate the typical bait/poison shyness (aversion) to strychnine that other rodents do after they consume a sublethal dose of a toxicant.

ACKNOWLEDGMENTS

This research was funded by the U.S. Forest Service, National Agricultural Impact Assessment Program (NAPIAP), and Cooperative Agreement PSW-83-008CA with Pacific Southwest Forest and Range Experiment Station. The Weyerhaeuser Company, Centralia, Washington, also helped support this study.

LITERATURE CITED

ANDERSON, D. C, and J. A. MacMAHON. 1981. Population dynamics and bioenergetics of a fossorial herbivore, Thomomys talpoides (Rodentia: Geomyidae), in a spruce-fir sere. Ecol. Monogr. 51:179-202.

ANTHONY, R. M., G. D. LINDSEY, and J. EVANS. 1984. Hazards to golden-mantled ground squirrels and associated secondary hazard potential from strychnine baiting for forest pocket gophers. Vertebr. Pest Conf. 11:5-31.

CRABTREE, D. G. 1962. Review of current vertebrate pesticides. Vertebr. Pest Control Conf. 1:327-362.

GETTINGER, R. D. 1975. Metabolism and thermoregulations of a fossorial rodent, the northern

pocket gophers (Thomomys talpoides). Physiol. Zool. 49:311-322.
GETTINGER, R. D. 1984. A field study of activity patterns of Thomomys bottae. J. Mamm. 65:76-84.
HALE, W. 1909. Studies in tolerance, No. II--Strychnine. J. Pharm. Exp. Therap. 1:39-47.
HICKMAN, G. C. 1984. Effects of temperature and light on the locomotory activity of captive pocket gophers. Acta Theriol. 29:259-271.
HOWARD, W. E., S. D. PALMATEER, and M. NACHMAN. 1968. Aversion to strychnine sulfate by Norway rats, roof rats and pocket gophers. Toxic. Appl. Pharm. 12:229-241.
HUNGERFORD, K. E. 1976. Food preference and food location by pocket gophers in Idaho. Vertebr. Pest Conf. 7:131-138.
LEE, L. L. 1986. Laboratory and field studies of behavioral and population responses of pocket gophers (Thomomys sp.) to durable baits. Ph.D. thesis, Univ. Calif., Davis. 115 pp.
MARSH, R. E., and W. E. HOWARD. 1978. Vertebrate pest control manual: pocket gopher. Pest Control 46:30-32.
MILLER, M. A. 1953. Experimental studies on poisoning pocket gophers. Hilgardia 22:131-166.
RZOSKA, J. 1953. Bait shyness, a study in rat behavior. Brit. J. Anim. Behav. 1:128-135.
SCHWARTZE, E. W. 1922. Observations upon the resistance of the rat to consecutive injections of strychnine. J. Pharm. Exp. Therap. 19:49-58.
TICKES, B. R., L. K. CHEATH, and J. L. STAIR. 1982. A comparison of selected rodenticides for the control of the common valley gopher (Thomomys bottae). Vertebr. Pest Conf. 10:201-204.
VLECK, D. 1979. The energy cost of burrowing by the pocket gopher Thomomys bottae. Physiol. Zool. 52:122-136.