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LABORATORY STUDIES OF MORE DURABLE BAITS FOR CONTROLLING POCKET GOPHERS

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ABSTRACT: A laboratory study of 68 Botta's pocket gophers (*Thomomys bottae*) was carried out to compare the preference for 20 different nontoxic baits and the preference and efficacy of 14 different toxic baits. All baits were designed to be more durable (i.e., longer lasting) than loose grain baits to increase the chance that one baiting might successfully control any new gopher invader that moved into an unoccupied burrow system. Bait types ranged from pure paraffin cubes, polyethylene bags of grain bait (plain or coated with paraffin and carrot powder), and paraffin grain baits (3.4 g and 10 g). Wide differences were found in bait preferences and in the mortality achieved by the various baits, but generally the bagged baits outperformed the others tested. Some gophers appeared to develop a tolerance for strychnine but bait shyness was not indicated. After being buried 5 months in the field, bag baits and pure paraffin blocks were in good condition, and microwaved whole wheat paraffin baits were only moderately moldy; but paraffin baits containing wheat, ground oats, microwaved oat groats, or carrot powder were mostly mildewed after 1 month underground.

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INTRODUCTION

Pocket gophers (*Thomomys* spp.) are uncommon in dense forests 11 to 80 years old, (Barnes 1974, Scrivner and Smith 1981). However, populations increase rapidly in forests opened by fire or logging (Buchner and Rorabaugh 1979). Consequently, reforestation in such areas is often severely hampered due to pocket gophers feeding on and killing young seedlings (Hooven 1971, Barnes 1973) and even occasionally killing trees up to 1 m in trunk diameter (Gross and Laacke 1984).

Many methods have been developed to control gophers (Miller and Howard 1951, Clark 1975, Marsh and Howard 1978). Poisoning gophers by placing strychnine-treated grain into openings probed into their tunnels is the method most widely used on forest lands (Canutt 1970), and more than 50,000 ac are treated annually in the western states at a cost of over $1 million (Birch 1987). This method can be relatively safe and often effective if practiced properly (Barnes 1973). However, many failures have been reported due to not being able to locate a high percentage of the gopher systems (Capp 1976), reinfestation by invading gophers (Crouch and Frank 1979), and rapid degradation of strychnine-treated grain in gopher burrows (Ray 1978, Barnes et al. 1985). Thus repeated baiting programs are often necessary in many areas (Richens 1965). More effective baits would offer one method of improving control (Julander et al. 1969).

One approach is to develop more durable (i.e., longer lasting) bait to increase the chance of a bait placement reaching more than one gopher. Even though gophers are solitary and territorial, they quickly explore other gophers' burrows once the occupant becomes inactive , e.g., killed or removed (Howard and Childs 1959, Tunberg et al. 1984). Therefore, if the remaining bait is still attractive and lethal to a gopher after the first occupant of the territory has been poisoned, it could control additional gophers living in the immediate vicinity that were missed during the initial control operation and who take over the abandoned systems. In addition, it may delay reinvasion of gophers from adjacent untreated areas. In this way, effective durable baits may not only achieve more successful control results, but also may greatly reduce the cost in time, labor, and amount of toxicant used by reducing the need for repeat baitings.

Longer-lasting baits have been used for rat control for a long time (Silver 1923, Marsh and Plesse 1960, Brooks and Rowe 1979), but have been used less frequently for controlling pocket gophers (Marsh and Plesse 1960, Tunberg et al. 1984, Marsh 1987). However, 0.5% strychnine-treated oats in plastic bags and 0.025% bromadiolone paraffin-wheat bait have been used experimentally to control Mazama pocket gophers (*T. mazama*) (Ray 1978, Tunberg et al. 1984).

MATERIALS AND METHODS

Ten male and 94 female adult Botta gophers (*T. bottae*) were live-trapped on or near the campus of the University of California at Davis. They were caged individually in 44 x 19 x 36-cm solid metal, screen-topped boxes containing about 6 cm of soil and cotton nest material. Room temperature of the rooms was 20 to 25 C. The rooms were kept dark except when gophers were fed or examined. When not on test, each gopher was provided Purina lab chow ad lib and apple every other day and potato once a week. To enable better recovery of uneaten baits, at least 3 days before the test all of the soil was removed from the boxes and cheese-cloth was provided as nest material. When on test, wheat was always available as an alternate food. Gophers were weighed the day before and at the end of each test.

Test Bait Preparation

The toxic grain used in the baits was prepared with either 0.5 or 1% concentrations of strychnine alkaloid following the methods prescribed in formula 2 of "Vertebrate Pest Control Handbook" (Clark 1975). To increase the durability of grain baits, we put the grain in small plastic bags or mixed the grain with melted paraffin, then let it solidify. Twenty nontoxic and 14 toxic types of baits were prepared. The "bag baits" were 4 x 2.5-cm polyethylene bags containing 2 g of 0.5% strychnine-treated grain. Some bagged baits were dipped into melted paraffin containing carrot powder. The carrot powder was made by grinding freeze-dried carrots and was used on bags or in solid paraffin baits to determine if it

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would serve as an odor or taste enhancer.

Each "paraffin bait" was made by mixing about 4 parts 0.5% strychnine grain bait with about 1 part melted paraffin (reducing strychnine concentration to about 0.32 or 0.64% where the starting bait was 1% strychnine) and pouring the mixture into 3/4-oz paper pill cups. Each of these paraffin baits weighed about 10 g. Marble-sized 3.4-g baits were also made by hand. "Paraffin block baits" consisted of either nontoxic paraffin cubes without any additives or paraffin cubes with 1% strychnine only and no grain. Each weighed 4 g. Grains used were whole wheat, oat groats, and white rice. Some grains used in bag and paraffin baits were placed in a microwave oven for 4 minutes to test the effect this treatment had on bait durability and its attractiveness to gophers.

Toxic Bait Tests

Nine of 14 different toxic baits were each tested with 6 female gophers. Toxicity tests were run for 7 days or until animals died when this occurred prior to day 7. Food consumption was measured daily. Student's two-tailed t-test and analysis of variance were used to test for differences among baits.

Nontoxic Bait Preference Test

During the nontoxic preference tests each of 20 gophers was given daily a quarter of an apple and a ceramic bowl of nontoxic whole wheat dyed red, and a bowl with a nontoxic bait: either 3 bait bags, 2 paraffin blocks, 3 marble-sized paraffin baits, or 1 10-g paraffin bait. The second bowl contained nontoxic whole wheat as an alternative food, which was dyed red to assist us in distinguishing it from the test grain. The nontoxic baits and loose whole wheat were provided daily for 2 days, thus requiring 40 days to test each of the 20 gophers with all 20 nontoxic baits. The sequence of presenting different baits to different gophers followed a Latin Square Design. The position of the 2 bowls was switched daily to avoid a position bias. Food consumption was measured and recorded daily. Two-tailed t-test and analysis of variance were the statistics used for data analysis.

Durability Study

To test the rate of durability of baits in rodent burrows 10 each of the 20 nontoxic and 14 toxic bait types were placed in 0.5-cm wire-mesh tubes (6.4 35.6 cm), which were buried separately to a depth of about 26 cm. Samples of each bait were excavated from these outdoor simulated gopher burrows monthly for 5 months and condition categorized: good (all 10 samples of each bait or bait bag intact, not affected), slightly moldy (about one-third of each bait affected), moderately moldy (two-thirds affected), and heavily moldy (each entire piece affected).

RESULTS

Toxic Bait Tests

Nine types of toxic baits were tested with clean wheat available for 1 week or until the gophers died, if that occurred first (Table 1). There was little difference in body weights of gophers before the tests and after they died ($t = 0.01$, $df = 43$, $p > 0.1$). Toxic bag baits (bait types 1-5, Table 1) achieved better control than paraffin grain baits (types 7 and 8), but the small paraffin baits (type 6) were quite effective. Strychnine whole wheat bag baits buried for 3 months (type 4) were as

Table 1. Mortality and consumptions of bait by groups of six female gophers (*Thomomys bottae*) which were subjected to free-choice tests daily for 1 week or until death. The free-choice offering consisted of 9 strychnine baits challenged against clean wheat. Parentheses are standard deviation.

Bait types	No. of gopher that died (n=6)	Mean total consumption (g)	Mean daily consumption by gopher that died (g)
1. 0.5% strychnine oat groats bags	5	1.70 (1.47)	0.41 (0.29)
2. 0.5% strychnine whole wheat bags	4[a]	0.35 (0.24)	0.28 (0.19)
3. 0.5% strychnine whole wheat bags dipped in carrot powder & paraffin	4	0.45 (0.30)	0.33 (0.52)
4. 0.5% strychnine whole wheat bags buried 3 months	4[a]	1.35 (2.10)	0.50 (0.43)
5. 1% strychnine whole wheat bags	6	0.22 (0.20)	0.22 (0.20)
6. Small version of 0.5% strychnine whole wheat paraffin baits	5	1.16 (1.41)	0.48 (0.38)
7. 0.5% strychnine whole wheat paraffin baits	1[b]	—	—
8. Moldy 1-month -old 0.5% strychnine paraffin baits	1[b]	—	—
9. 1% strychnine paraffin blocks	1[b]	—	—

[a]The surviving 2 gophers in tests 2 and 4 developed a "tolerance" for strychnine.
[b]Only 1 gopher died and the surviving 5 gophers later died when fed 0.5% strychnine loose grain bait in a subsequent test.

effective as fresh bag baits (type 2), and the average bait consumption was also similar.

Because none of the 0.5% strychnine bag or paraffin baits (types 1-4, 6-9) achieved 100% control (Table 1), we ran a test using 1% instead of 0.5% strychnine (type 5). All of the 6 gophers tested were dead the next day.

Only one of 6 gophers died in each test with the 0.5% strychnine whole wheat-paraffin baits (type 7) (Table 1), moldy (1-month-old) whole wheat paraffin 0.5% baits (type 8), and 1% strychnine paraffin blocks (type 9). With the 0.5% strychnine whole wheat paraffin baits (type 7), most gophers only nibbled on the bait each day, although 3 of them took 0.7 g of bait during a day and still survived, probably because they ate small amounts at intervals. One gopher died after eating only 0.45 g of bait, but the gopher only weighed 111 g, less than the weight of other gophers ($\bar{x}$=130.6 g).

The moldy bait (type 8) was poorly accepted by some individual gophers. One ate a lethal amount, 2 ate 87.1% of the total eaten by all 6 gophers, 2 ate a small amount of bait almost every day, and 1 hardly touched the baits.

Even though the strychnine concentration was 1% in the paraffin blocks (type 9), only 1 gopher died in this free-choice test. Three of the 6 gophers did not even chew on the blocks. After being tested for at least 7 days with 1% strychnine paraffin blocks (type 9), the 5 surviving gophers were given loose grain baits obtained from either fresh (type 2) or 3-month-old (type 4) 0.5% strychnine whole wheat baits. All were dead within a week, indicating a lack of any major bait shyness to strychnine by gophers.

In tests of a smaller (3.4 g) marble-sized strychnine paraffin baits (type 6) (Table 1), gophers ate more of this bait than of the larger (10-g) size (type 7), and 5 of 6 test animals died. The average total bait consumption per animal of the marble-sized baits was similar to that of oat groats bag baits (type 1).

Only 4 (8.3%) of the 48 gophers tested (6 were used in 2 tests) survived and 20 (41.7%) died within a day after their first feeding on the toxic baits. The 24 (50%) that died between 2 to 7 days after being first offered baits ate but a small amount of toxic bait each day; however, death usually occurred soon after the gophers ate the greatest amount of bait. The average time between the day of maximum daily consumption and death was 0.41 $\pm$ 1.08 days for all 44 gophers that died in the toxicant study.

Among the 28 gophers that did not die after the first day of a toxicant test, only 3 stopped eating strychnine bait, 7 ate toxic baits on some days but not others, and 12 continued to eat toxic bait daily until they eventually died. However, 4 developed a tolerance to strychnine and could daily consume many times the normal lethal dose and still survive. The reported approximate LD_{50} for Northern pocket gophers (*T. talpoides*) is 8.3 mg per kg body weight (Denver Wildlife Research study cited by Clark 1975), and we assume that *T. bottae* would be in that same range of susceptibility.

Nontoxic Bait Preference Test

During the 2-day preference tests of nontoxic baits, the average body weights of 20 gophers before and after the test were not different ($t = 0.07$, $df = 19$, $p > 0.1$). Because consumption of the alternate food (clean wheat) and of durable baits was not significantly different on day 1 from that of day 2 for each animal with the same bait ($t = 0.4$ for wheat, $t = 0.03$ for bait, both $df = 399$, both $p > 0.1$), the data were lumped together for both days.

The consumption of nontoxic bait by the 20 gophers differed with the different bait ($F = 8.52$, $df = 19,342$, $p < 0.0001$). Based on the Tukey procedure for pairwise comparison with family coefficient of 95%, bag baits were consumed significantly more than paraffin baits. Packaging may have had only a minor effect on bait consumption.

Paraffin baits with ground oats and crimped oats were eaten slightly more than other paraffin baits, but the daily consumption of all types of paraffin baits was significantly lower than that of clean wheat (all $p > 0.1$). This suggests that paraffin may discourage consumption of baits in free-choice situations. The addition of carrot powder did not make baits significantly more attractive. Most gophers would chew and crumble paraffin blocks but ingest little, and 4 gophers did not eat any pure paraffin. Based on Tukey pairwise comparison, the alternate clean wheat was eaten more when paired with paraffin baits and paraffin blocks than when paired with bag baits.

Two male gophers did not eat 6 of the 10 types of bag baits tested. One also did not eat 3 of the 8 types of paraffin baits offered. One female ate 0.8 g of microwaved oat groats from the bags but did not eat any of the other 9 types of bag baits offered. The other 17 gophers tasted all the types of durable baits. For more details see Lee (1986).

Durability Study

Bag baits and pure paraffin blocks without any additive were in good condition after 5 months underground. After 1 month almost all of the paraffin grain baits and the pure paraffin blocks containing carrot powder had started to mildew and some were also damaged by insects; the paraffin baits containing ground oats and microwaved oat groats were heavily mildewed; the paraffin baits containing plain or microwaved whole wheat were least mildewed. This suggests that whole wheat will last longer underground than oat groats.

Bag baits that had been dipped in a mixture of melted paraffin and carrot powder were slightly moldy on the outside on the fifth month but the contents were still in good condition. Both nontoxic and microwaved whole wheat paraffin baits were only moderately moldy after 5 months, but those containing strychnine were slightly to moderately moldy by the fourth month and heavily mildewed by the fifth month.

DISCUSSION

The advantage of using bag baits for controlling pocket gophers is that they remain intact and toxic for a long time in moist gopher burrows if unopened, and thus retain the potential of controlling invading gophers. In the laboratory they were well accepted; more were consumed than large paraffin baits, and sometimes even more than loose wheat grain. However, under field conditions any bag that a gopher opens before dying would probably soon become ineffective, as the bait deteriorates due to burrow humidity and moisture. In a field study, Ray (1978) reported a 72% reduction of gopher (*T. mazama*) activity 6 months after baiting with bag baits containing 0.5% strychnine-coated oats. Tests using 1% strychnine are needed.

Paraffin grain baits not only mildewed within a few weeks, but in these studies they were also less effective in

poisoning gophers in free-choice laboratory tests, possibly due to the lower concentration of strychnine (0.32 or 0.64%) in paraffin baits. Some gophers apparently did not ingest a lethal amount before sensing symptoms and stopped feeding for a few hours. When gophers consume only a sublethal amount of strychnine in each feeding, the chance of developing a physiological tolerance is increased (Lee 1986, Lee et al. 1990).

Acceptance of the marble-sized paraffin grain bait (about 3.4 g) was better than the larger baits. Barnes et al. suggested (1982) that small pieces of zinc phosphide carrot bait were more effective than large pieces for gopher control. Miller and Howard (1951) considered size of carrot bait an unimportant factor in the effectiveness of strychnine baits. They pointed out that gophers may cache rather than immediately eat large pieces of carrot, whereas they are more likely to promptly eat small pieces. In one of our field studies on Mountain pocket gophers (*T. monticola*), the small paraffin baits achieved excellent control and were even more satisfactory than bag baits (unpublished). Differing from laboratory free-choice tests, the success of the marble-sized baits in the field could be because other food items were not as readily available or because this was a different species of gopher.

Reichman and Rebar (1985) reported that kangaroo rats (*Dipodomys spectabilis*), which cache much food in underground burrows, actually preferred slightly moldy seeds. *T. bottae* was also noted in a laboratory study to sometimes eat more moldy paraffin baits than unmoldy ones (Wang and Marsh, pers. comm.). This, however, was not found in our studies. Presumably the type or types of mold growing on the baits make a difference. According to Reichman and Rebar (1985), the kangaroo rats did not take all moldy seeds; they apparently chose the moldy seed that was beneficial and avoided the harmful ones.

Gophers have a well-developed sense of smell (Nevo 1979). Hungerford (1976) reported that gophers (*T. talpoides*) were attracted by the odor of fresh carrot juice. In our study, powder made from freeze-dried carrots was not an attractant. Perhaps dehydrated carrots had lost their volatiles and thus their smell. Moreover, the paraffin and carrot powder outside of bag baits mildewed within a month. This may have discouraged certain gophers from feeding on the baits. Ray (1978) successfully used a combination of carrot flour, parsley, and barley flakes as an attractant for bag baits.

The development of bait resistance by gophers has been suggested, especially in areas where control with strychnine has been practiced repeatedly for many years (Tickes et al. 1982, Tickes 1983). Anthony et al. (1984) reported 1 gopher (*T. mazama*) survived after eating over 125 mg of strychnine during 4 days. In our study, the 4 gophers that developed a feeding "tolerance" for strychnine alkaloid gradually were able to live exclusively on 0.5% and even 1% strychnine bait and apple.

Individual variation together with the development of a "tolerance" for the toxicant might be part of the reason why control programs with strychnine baits often fail. Gophers do not object to the bitter taste of strychnine and usually do not develop a strong aversion to it (Howard et al. 1968).

Several problems need to be studied further, such as how to slow the rate at which gophers open multiple bags and how to increase the effectiveness and durability of marble-sized paraffin baits. Further tests are needed to determine whether increasing the concentration of strychnine in baits to 1% will improve their efficacy and prevent gophers from opening so many bags before they die. If so, less baits would have to be put into each burrow. The less-palatable paraffin baits might be more effective if they had a higher strychnine concentration. The sooner the first territory occupant dies, the better is the chance that the next gopher will move in and be controlled by the remaining and still-palatable baits. Such a management approach would actually increase the control of more gophers with less total bait.

SUMMARY

In free-choice laboratory preference tests, nontoxic bag baits were consumed more than large or small paraffin baits. None of the toxic baits of 0.5% strychnine alkaloid achieved a 100% kill, and 4 gophers actually developed a "tolerance" for both 0.5 and 1% strychnine bait which, after a time, they could feed on exclusively except for pieces of apple to supply moisture (Lee et al. 1990).After being buried for 3 months, bag baits remained intact and moderately effective in poisoning Botta gophers. Paraffin baits became moldy and less acceptable and effective after 1 month but lasted longer than loose grain.

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