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Short communication

Identifying possible alternative rodenticide baits to replace strychnine baits for pocket gophers in California

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A B S T R A C T

Rodents cause substantial damage to crops in California and rodenticides have been major tools for reducing that damage. While strychnine has been heavily relied upon to control pocket gophers in California, its future availability is in question because of increased import costs. We conducted efficacy trials with captive, wild-caught Botta's pocket gophers to identify potential alternative rodenticides to strychnine. The rodenticide baits tested included three categories: acute rodenticides, first generation anticoagulant rodenticides, and combination rodenticides (containing an acute toxicant and an anticoagulant). There was a wide range of efficacies (0–100%) with these rodenticides. The first generation anticoagulants performed poorly, while a distinct regional variation in efficacy occurred with the strychnine and zinc phosphide baits. The combination baits performed the best overall, averaging 90% efficacy. We also reported on the average bait consumption and days-to-death for the various rodenticides tested. We discussed the potential advantages of combination baits and especially the potential for lower concentrations of active ingredients. Finally, we recommend that a field trial be conducted to determine the efficacy of the combination baits to control pocket gophers.

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1. Introduction

Pocket gophers cause various types of damage to agricultural and rangeland resources and to forests in North America (Witmer and Engemann, 2007). Pocket gophers (*Thomomys* spp.) are generally considered one of the most damaging wildlife pests in California (Marsh, 1992). Recent studies estimated average losses ranging from 5.3 to 8.8% across a variety of crops in California (Baldwin et al., 2013).

Primary control options for pocket gophers include trapping, burrow fumigation and baiting with rodenticides (Baldwin, 2012; Witmer and Engemann, 2007). Both trapping and burrow fumigation can be highly effective at controlling pocket gophers (Proulx, 1997; Baker, 2004), but are typically more time consuming and costly than baiting (Marsh, 1992; Engeman and Witmer, 2000). As such, baiting is often preferred by many growers, pest control advisors, and pest control operators. Three baits are used to control pocket gophers: strychnine, zinc phosphide, and first generation anticoagulants. However, there are varying efficacies for each of these rodenticide baits across a wide array of rodent species and settings (Salmon et al., 2000; Stewart et al., 2000; Bourne et al., 2002; Balliette et al., 2006; Schmit, 2008; Proulx et al., 2010).

Strychnine is an acute toxicant that has been widely used for many decades for controlling pocket gophers (Marsh, 1992). Strychnine has been the preferred bait for controlling gophers given its acute toxicity, more palatable flavor than zinc phosphide, and its effectiveness (Case and Jasch, 1994). However, in some areas, gophers have developed a behavioral resistance to strychnine baits (Marsh, 1992). More importantly though, there is now a current shortage of strychnine baits in the United States (U.S.) due to burgeoning costs of imported strychnine (B. Hazen, Wilco Distributors, Inc., *pers. comm.*). In fact, Wilco Distributors, Inc., who has been the primary importer of strychnine for pest control purposes into the U.S., recently stopped the importation of strychnine and halted all production of strychnine baits. Unless a new source of strychnine is obtained in the near future, most or all strychnine applications will cease once current supplies of strychnine are exhausted. As such, the identification of an equally or more effective bait is needed to provide individuals with a viable alternative for controlling high density gopher populations where other control options are cost prohibitive.

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Zinc phosphide is an alternative acute toxicant and has been used for pocket gopher control (e.g., Tickes et al., 1982; Proulx, 1998). Unfortunately, zinc phosphide has not typically performed as well as strychnine in field trials (e.g., Barnes et al., 1982; Proulx, 1998; but see Tickes et al., 1982), perhaps due to taste aversion (Engeman and Witmer, 2000). However, new formulations are available that may increase effectiveness potentially making the use of zinc phosphide a viable option for controlling gophers.

Anticoagulant baits (chlorophacinone and diphacinone) are also available for controlling pocket gophers. Anticoagulant baits are less toxic than strychnine and zinc phosphide, thereby reducing potential mortality from incidental ingestion of these baits by non-target species. These baits require multiple feedings over 3–5 days to control gophers. Therefore, greater amounts of bait are required with anticoagulants. As such, these baits have not always tested well (e.g., Tickes et al., 1982; Stewart et al., 2000). However, new formulations have come out that warrant efficacy testing.

Some researchers are investigating new "combination" rodenticides. These rodenticides combine an anticoagulant and an acute active ingredient (e.g., cholecalciferol). Eason et al. (2010) found that one test bait with two active ingredients, cholecalciferol and coumatetralyl, produced promising results with rats and mice. Interestingly, they were able to obtain high efficacy with lower concentrations of the active ingredients than the concentrations used when either active ingredient is used alone. Hence, there may be some synergistic effect. This is noteworthy because if lower concentrations can be effectively used, there could be a lower secondary risk of harm to non-target animals. Witmer et al. (2014) and Baldwin et al. (2016) found that a cholecalciferol plus diphacinone pelleted bait was very effective with California voles in cage and field efficacy trials, respectively. While the second generation anticoagulant, brodifacoum, is not registered for pocket gopher control in the U.S., we included it as a combination bait (combined with cholecalciferol) so that its effectiveness could be compared with the cholecalciferol plus diphacinone combination.

The objective of this study was to identify effective new formulations of rodenticides for the control of Botta's pocket gophers. These rodenticides contained combinations of active ingredients or new formulations of existing active ingredients. We hypothesized that some of the test baits would exhibit a high efficacy (≥80% mortality) when presented to the pocket gophers.

2. Methods

Botta's pocket gophers (*Thomomys bottae*; henceforth, gophers) were live-trapped in California for this study and transported to the United States Department of Agriculture's (USDA) National Wildlife Research Center (NWRC), Fort Collins, Colorado. The gophers came from two regions of California: the southern group was from the San Diego County area, and the northern group was from the Sonoma County area. In the southern region, gophers were from areas where rodenticide baits have been heavily used for decades, whereas the gophers from the northern region were from areas where there is little rodenticide use with kill-trapping being used more so. Gophers were kept in individually numbered plastic cages in an animal room at NWRC and were fed a maintenance diet of rodent chow pellets and carrot chunks, and received water *ad libitum*. They were provided with bedding, a den tube, and wood blocks to chew on. There were four rounds of trials with various treatment groups of five animals each. Animals were randomly assigned to treatment groups for the two-choice trials. The 12 different rodenticide formulations used in the trials are listed in Table 1. Some of the baits are registered, commercial baits. Others were experimental baits formulated by one of three rodenticide companies. While the formulations varied (and are proprietary), all 3 companies have many years of experience in manufacturing effective, palatable rodenticide baits. There was also a control group of five gophers maintained on the maintenance diet. Both males and females were included in each group. The gophers were of various ages because their initial weights varied from 44 g to 120 g. Experimental rodenticide baits were generally tested on both gopher groups from the southern region and from the northern region.

The weight, sex, cage number, and treatment of each gopher was recorded before the initiation of a trial. On Day 1 of the trial, a bowl of pre-weighed rodenticide bait was added to the appropriate cages. All animals continued to receive the maintenance diet. For the next ten days, maintenance diet materials were added daily to the cages, whereas rodenticide baits were added as needed so that the gophers always had access to bait during the exposure period. All new bait was weighed before being added to the cages so that the total consumption could be determined at the end of the exposure period. At the end of the 10-day rodenticide exposure

Table 1
Rodenticide treatments, percent efficacy by region, average bait consumption by surviving and non-surviving gophers, and average days-to-death of non-surviving gophers.

Rodenticide Type	% Efficacy, Southern Region (No. dead/no. in group)	% Efficacy, Northern Region (No. dead/no. in group)	Ave. Bait Consumption g (S.D.), Survivors	Ave. Bait Consumption g (S.D.), Non-survivors	Ave. Days-to-Death (S.D.) for Non-survivors
0.01% chlorophacinone, coated grain	40% (2/5)	60% (3/5)	24.9 (6.2)	24.3 (7.1)	9.6 (4.6)
0.005% chlorophacinone, pellet	40% (2/5)	60% (3/5)	27.3 (11.8)	20.3 (16.9)	6.2 (3.0)
0.005% diphacinone, pellet	0% (0/5)	N/A (= not applicable)	15.6 (7.9)	N/A	N/A
0.005% diphacinone, pellet	40% (2/5)	20% (1/5)	2.7 (1.5)	5.4 (6.1)	15.3 (3.5)
0.03% cholecalciferol + 0.0025% brodifacoum, pellet	100% (5/5)	N/A	N/A	5.1 (1.1)	10.8 (4.0)
0.015% cholecalciferol + 0.0025% brodifacoum, pellet	100% (5/5)	100% (5/5)	N/A	7.0 (8.0)	6.4 (2.8)
0.03% cholecalciferol + 0.005% diphacinone, pellet	60% (3/5)	100% (5/5)	7.2 (3.4)	6.5 (2.7)	5.3 (3.6)
0.5% strychnine, coated grain	0% (0/5)	100% (5/5)	15.8 (3.4)	2.7 (4.6)	1.0 (1.2)
0.5% strychnine, coated grain	20% (1/5)	100% (5/5)	13.3 (9.8)	2.3 (0.7)	1.0 (0.6)
2.0% zinc phosphide, pellet	60% (3/5)	40% (2/5)	1.0 (0.3)	0.8 (0.4)	0.8 (0.4)
2.0% zinc phosphide, pellet	0% (0/5)	80% (4/5)	0.5 (0.8)	1.3 (0.8)	1.5 (0.6)
0.075% cholecalciferol, pellet	40% (2/5)	N/A	4.9 (4.7)	5.8 (5.7)	3.5 (0.7)

Table 2
Comparisons of efficacy, days to death, and bait consumption across the three categories of rodenticide.

Rodenticde Category	No. of Formulations	Ave. % Efficacy[a] (S.E.)	Ave. Days to Death[a] (S.E.)	Ave. Grams Bait Consumption[a] (S.E.)
Acute Rodenticides	5	50.0 (7.5)[B]	1.6 (1.3)[A]	2.6 (2.3)[A]
Combination Rodenticides	3	93.3 (9.7)[A]	7.5 (1.6)[B]	6.2 (3.0)[AB]
Ist Generation Anticoagulant Rodenticides	4	32.5 (8.4)[B]	10.4 (1.6)[B]	16.7 (3.0)[B]
ANOVA Result		$F_{2,9}$ 11.61	$F_{2,8}$ 10.01	$F_{2,8}$ 7.12
P value		0.0032	0.0067	0.0167

[a] Averages in each column with the same letter are not significantly different.

period, gophers were placed in clean cages and put back on the maintenance diet for a 14-day post-exposure period. The uneaten rodenticide baits in the dirty cages was collected and weighed to determine the amount consumed by gophers.

Gophers were examined twice daily by the study staff and their condition and any mortalities were recorded. Dead gophers were placed in individual, labeled zip-lock bags and refrigerated for later necropsy. When necropsied, those provided with anticoagulants were examined for signs of anticoagulant poisoning (Stone et al., 1999); all surviving gophers were ultimately euthanized and incinerated at the end of the study.

The efficacy, the days-to-death, and the bait consumption were compared across the three rodenticide categories (first generation anticoagulants, acute toxicants, and combinations (containing both an anticoagulant and an acute toxicant) with ANOVA tests. Tukey's all-pairwise comparisons tests were used to determine differences between the means of rodenticide categories. We used the analytical software, Statistix 9 (Tallahassee FL), to analyze the data.

3. Results

The efficacy of the rodenticides used in the trials varied widely from 0% to 100% (Table 1). The three rodenticide categories varied significantly in efficacy with the combination bait group having a significantly higher average efficacy (93%; Table 2). No control animals died during the trials.

In addition to the variation in efficacy across rodenticide categories, there was also a substantial regional difference in the efficacy level of some of the rodenticides (Table 1). This was especially evident with both strychnine baits and one of the zinc phosphide baits. The efficacy of these acute rodenticide baits was significantly lower ($F_{1,4} = 84.5$, $P = 0.001$) for gophers from the southern region (6.7%) versus those from the northern region (93.3%).

The days-to-death for gophers that died during the trials varied by rodenticide category. Gophers in the acute rodenticide group (1.6 days) had a significantly shorter days-to-death than those in the anticoagulant group (10.4 days) and the combination group (7.5 days; Table 2).

The average amount of bait consumed in the 10-day exposure period by gophers that died during the trials varied significantly by rodenticide category (Table 2). Significantly more first generation anticoagulant baits were consumed (16.7 g) than the acute toxicant baits (2.6 g). The consumption of combination baits (6.2 g) did not vary from the acute bait consumption nor from the anticoagulant bait consumption. The pattern closely resembles the pattern for the days-to-death (Table 2).

4. Discussion

The first generation anticoagulants were not very effective and had a lengthy days-to-death (often considered inhumane). The low efficacy has been attributed to overuse and the development of resistance in many rodent populations (Salmon and Lawrence, 2006). Also, gophers often will not eat much anticoagulant bait when other preferred foods are available. Hence, the advantage of a more toxic bait that only requires a small amount to be consumed.

We also found a regional difference in the efficacy of two of the strychnine baits and one of the zinc phosphide baits with much lower efficacy in the southern region versus the northern region, perhaps a result of overuse of these baits in the southern region. This can lead to bait shyness (i.e., consuming a sub-lethal dose and then not feeding on that bait again), a decreasing palatability issue, and/or an increased tolerance to the active ingredient (Marsh, 1992).

The most efficacious of the experimental rodenticide baits tested in this study were the combination baits. Interestingly, both the bait containing diphacinone alone and the bait containing cholecalciferol alone had much lower efficacies than our combination baits containing both active ingredients. This may have resulted, in part, from the lower concentration of cholecalciferol in our combination bait (0.03%) than in the cholecalciferol-alone bait (0.075%). Cholecalciferol is known to pose some palatability issues (Prescott et al., 1992), but high concentrations ($\geq$0.1%) are often needed for adequate efficacy with pocket gophers (Witmer et al., 1995). The lower concentrations of one or both active ingredients may be an additional benefit from combination baits because of lower costs and less toxicant being put into the environment. Future studies should evaluate the potential to also reduce the concentration of the anticoagulant in the combination bait. Finally, with regard to the humaneness issue, we note that the average days-to-death of the combination bait, while still higher than that of the acute baits, was somewhat lower than that of the first generation baits. We note, however, that the days-to-death is only one measure of humaneness; other aspects include whether or not certain symptoms occur such as excessive bleeding or convulsions. We recommend that a field efficacy study of the combination baits be conducted in agricultural fields infested with pocket gophers.

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