UC Agriculture & Natural Resources
Proceedings of the Vertebrate Pest Conference

Title
Zinc phosphide: Implications of optimal foraging theory and particle-dose analyses efficacy, acceptance, bait shyness, and non-target hazards

Permalink
https://escholarship.org/uc/item/35j5f892

Journal
Proceedings of the Vertebrate Pest Conference, 16(16)

ISSN
0507-6773

Author
Sterner, Ray T.

Publication Date
1994

eScholarship.org Powered by the California Digital Library University of California

ZINC PHOSPHIDE: IMPLICATIONS OF OPTIMAL FORAGING THEORY AND PARTICLE-DOSE ANALYSES TO EFFICACY, ACCEPTANCE, BAIT SHYNESS, AND NON-TARGET HAZARDS

RAY T. STERNER, United States Department of Agriculture, Animal Plant and Health Inspection Service, Denver Wildlife Research Center, Denver, Colorado 80225-0266.

ABSTRACT: The U.S. Department of Agriculture (USDA), Animal Plant and Health Inspection Service (APHIS) maintains six federal registrations for zinc phosphide (Zn_3P_2); three of these address the control of eight rodent species using steam-rolled oats (SRO) or wheat grains in diverse applications. Optimal foraging theory (OFT) and "particle-dose analysis" (PDA) afford predictions relevant to the efficacy, acceptance, bait shyness, and non-target hazards of these Zn_3P_2 baits. For PDA, numbers of SRO groats or whole wheat grains associated with acute oral median lethal (LD_{50}) or approximate lethal (ALD) doses of Zn_3P_2 were compared among nine target rodent and eleven non-target avian species. Key outcomes were: 1) mean ($\pm$S.D.) SRO groats and wheat grains weighed 23 ($\pm$9) and 18 ($\pm$9) mg [assumed to carry $\approx$0.46 (2.0%) and $\approx$0.33 (1.82%) mg Zn_3P_2], respectively; 2) published acute oral LD_{50} values for the target rodents ranged between 16.2 and 18.0 mg/kg, with a 42.0 mg/kg ALD cited for the white-footed mouse (*Peromyscus maniculatus*); 3) estimated minimum-maximum number of SRO groats and wheat grains needed for ingestion of the LD_{50}/ALD doses by target species were 1.6 to 39.1 and 1.7 to 3.8, respectively; and 4) estimated minimum-maximum number of SRO groats and wheat grains associated with primary LD_{50}/ALD hazards to nontarget avian species were 1.3 to 175.8 and 1.8 to 245.1, respectively. Theoretical implications of OFT and PDA to efficacy, acceptance, bait shyness, and specificity of Zn_3P_2 baits in rodent control are provided; the potential effects of food-handling time, bait-search time, predator density, social-dominance hierarchy, food-intake pattern, and bait-distribution pattern are discussed.

Proc. 16th Vertebr. Pest Conf. (W.S. Halverson & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1994.

INTRODUCTION

Gratz (1973) lists four key attributes of an acute rodenticide: 1) high toxicity; 2) high acceptability; 3) low bait shyness (i.e., high reacceptance after ingestion of a sub-lethal dose); and 4) high specificity (i.e., high target species relative to nontarget species toxicity).

Zinc phosphide (Zn_3P_2, CAS # 1314-84-7) is an acute rodenticide used in agriculture, e.g., reduce vole populations to prevent "girdling" of orchard trees, reduce prairie dog populations to prevent range destruction in the Western U.S. (Hood 1972, Marsh 1988). Although used in rodent control for $\approx$80 years (Marsh 1988), efficacy, acceptance, bait shyness, and non-target hazards issues continue to impact the registration and use of the compound.

In this paper, I present: 1) an overview of USDA/APHIS Zn_3P_2 registrations; 2) a PDA procedure for estimating consumed doses of Zn_3P_2 by target/non-target species; 3) a synopsis of OFT relevant to the control of rodents with Zn_3P_2 SRO groat/grain baits; 4) theoretical particle-dose comparisons of 2% SRO groat and 1.82% wheat grain baits for eight rodent (target) and eleven avian (nontarget) species; and 5) OFT and PDA implications to the efficacy, acceptance, bait shyness, and non-target hazard of these baits.

Zn_3P_2 REGISTRATIONS

FIFRA Section 3

Table 1 lists the products/target species/applications of the six Federal Insecticide Fungicide and Rodenticide Act (FIFRA) Section 3 Registrations for Zn_3P_2 maintained by USDA/APHIS. Altogether, these registrations target 12 species in 15 agricultural applications. Three specify use patterns for either a Zn_3P_2 2% SRO or 1.82% wheat bait to control meadow (*Microtus pennsylvanicus*), prairie (*M. ochrogaster*), pine (*Pitymys pinetorium*), and mountain voles (*M. montanus*), white-footed mice (*P. maniculatus*), black-tailed (*Cynomys ludovicianus*), white-tailed (*C. leucurus*), and Gunnison's prairie dogs (*C. gunnisoni*) (see No. 2, 3, and 5 in Table 1). The remaining three registrations target seven species using various Zn_3P_2 concentrate mixtures with apples, carrots, sweet potatoes, or meat-based baits (see No. 1, 4, and 6, plus Footnote 2, in Table 1).

Prohibitions for use of these products within the ranges of eight endangered species (ES) of birds or rodents are stated on the "use labels;" species are: whooping crane (*Grus americana*), Attwater's greater prairie chicken (*Tympanuchus cupider attwater*), yellow-shouldered blackbird (*Agelaius xanthromus*), Puerto Rican plain pigeon (*Columba inorata wetmore*), Utah prairie dog (*Cynomys parvidens*), salt marsh harvest mouse (*Reithrodontomys ravientris*), Morro Bay kangaroo rat (*Dipodomys leermanni*), and Aleutian Canada goose (*Branta canadensis leucopareia*). All ES are cited for Registrations 1, 2, 3, 4, and 6, but only six are included on Registration 5 (depending upon identified geographical ranges of the ES and Zn_3P_2 application pattern or region of use). Certified Pesticide Applicators are also required to check/adhere to "county-by-county precautions" for other ES not specifically listed on the labels.

FIFRA Section 24(C)

Three FIFRA Section 24(C) Registrations to meet specific state applications of Zn_3P_2 are also held by APHIS (not shown in Table 1). These are: 1) Zn_3P_2 Concentrate for Marmot (*Marmota flaviventris*) and Black-tailed Jack Rabbit (*Lepus californicus*) Control

Table 1. Summary of six USDA/APHIS Zn_3P_2 Registrations (FIFRA Section 3) for rodent control; registration titles, target species, and applications cited on the "use labels" are provided.[1]

Product and Number	Target Species	Applications
1. Zinc Phosphide Concentrate (63.2%) for Mouse Control (EPA Reg. No. 56228-6)[2]	Meadow and Pine Vole (*Microtus* spp.), White-footed mouse (*Peromyscus* spp.)	Orchards/groves (non-bearing phase)
2. Zinc Phosphide (1.82%) on Wheat for Mouse Control (EPA Reg. No. 56228-3)	Meadow, Prairie, Mountain, and Pine Voles (*Microtus* spp.), White-footed mouse (*Peromyscus* spp.)	Ornamentals, orchards/groves (non-bearing phase), vineyards, rangelands, forests, lawns, golf courses, parks, nurseries, and highway medians
3. Zinc Phosphide (2.0%) on Steam-Rolled Oats for Mouse Control (EPA Reg. No. 56228-5)	(Same as #1.)	(Same as #1.)
4. Zinc Phosphide Concentrate (63.2%) for Rat Control (EPA Reg. No. 56288-7)[2]	Norway (*Rattus norvegicus*) and Roof Rat (*R. rattus*)	Rat burrows and infested areas around homes, industrial, commercial, agricultural, and public buildings (CA, NV, OR only)
5. Zinc Phosphide (2.0%) on Steam-Rolled Oats for Prairie Dog Control (EPA Reg. No. 56228-14)	Black-tailed (*Cynomys ludovicianus*), White-tailed (*C. leucurus*), and Gunnison's Prairie Dog (*C. gunnisoni*)	Rangeland--Western U.S. (ND, SD, NE, KS, OK, TX, NM, AZ, CO, MT, UT, WY only)
6. Zinc Phosphide Concentrate (63.2%) for Muskrat and Nutria Control (EPA Reg. No. 56228-9)[2]	Muskrat (*Ondatra zibethicus*) and Nutria (*Myocaster coypus*)	Floating rafts and around active burrows adjacent to sugarcane or rice fields

[1]USDA/APHIS may consolidate these registrations; the "concentrate" and "specific bait" labels will be merged into one (overall) or three (steam-rolled-oat, wheat, and concentrate) registration(s).
[2]The three "concentrate-type" products allow use of the technical product (63.2% A.I.) in bait preparations that promote efficacy of Zn_3P_2 during field operations. No. 1 mixes 6.4 g (level teaspoon) Zn_3P_2 per 1.101 1 (1 qt.) of 1.27 cm (0.5 in.) apple cubes; No. 4 mixes 28.35 g (1 oz.) Zn_3P_2 per 1.82 kg (4 lbs.) of fresh meat (e.g., hamburger, canned dog/cat food); and, No. 7 mixes 48 g (7.5 level teaspoons) Zn_3P_2 per 4.54 kg (10 lbs.) of apple eights or 5.08 cm (2 in.) pieces of carrots/sweet potatoes, plus 30 ml (1 oz.) of corn oil.

(Idaho)--rangeland use (EPA Reg. No. ID-910018); 2) Zn_3P_2 on Wheat for Mouse Control (Idaho)--grass fields/grass seed crop use (EPA Reg. No. ID-930005); and 3) Zn_3P_2 on Steam-Rolled Oats for Control of Prairie Dogs Black-Tailed (*Cynomys ludovicianus*) and Gunnison (*C. gunnisoni gunnisoni* and *C. g. zuniensis*) (New Mexico)--non-croplands and pastures use (EPA Reg. No. NM 810014).

One additional ES is specifically mentioned on the 24(C) labels; precaution for the black-footed ferret (*Mustela nigripes*) occurs on NM-810014.

Zn_3P_2 TOXICITY

The toxicity of Zn_3P_2 is attributed to the release of phosphine (PH_3) gas as a result of hydrolysis with stomach acids. Death results from reduced electron transport due to cytochrome oxidase interactions in cell mitochondria causing a cessation of cellular respiration (Murphy 1986, Hazardous Substance Databank 1994).

Minimum-maximum LD_{50}/ALD doses cited for some mammalian and avian groups are: rodents 6.8 to 40.0 mg/kg, canids 40.0(ALD) to 93.0 mg/kg, gallinaceous birds 8.8 to 26.7 mg/kg, passerines 23.7 to 178.0 mg/kg, raptors >20.0 mg/kg, and waterfowl 7.5 to 67.4 mg/kg (see Johnson and Fagerstone in press). Doses differ and vary greatly between/within species or studies. Primary hazards of grain baits are a main concern for gallinaceous birds, passerines, and waterfowl; whereas, indirect primary hazards via undigested Zn_3P_2 loads in gastrointestinal (GI) tracts of target species (carcasses) can be a concern for canids, felids, and raptors (see Marsh 1988, Tkadlec and Rychnovsky 1990). A key attribute of the rodenticide's toxicity is the illness effect associated with hydrolysis; this relates to bait shyness as discussed by Gratz (1973). The prolonged, slow, small quantity, intermittent consumption of Zn_3P_2 bait causes GI disturbance (illness) and subsequent bait shyness (i.e., sub-lethal aversion). While this reduces the risk of nontarget poisoning, it also decreases the chance for sufficient bait acceptance by target species.

OPTIMAL FORAGING THEORY (OFT)

Assumptions

OFT affords numerous predictions for the effectiveness of acute rodenticide applications, especially hypotheses about granivorous rodents and grain baits (see Kamil and Sargent 1981, Kamil et al. 1987). The key assumption of OFT states that a foraging animal is motivated to maximize net energy gained per unit time feeding (Schoener 1987). Other relevant assumptions include: 1) animals make probabilistic-type decisions about the availability of foods in the environment (i.e., "patches" of food resources must afford sufficient energy returns during feeding or else "search behaviors" are initiated); 2) "switches" to alternative foods (baits) by animals are based upon declines in energy yields from preferred foods; 3) local predation factors (e.g., predator densities, predator-rodent encounters) are inversely related to the time expended by rodents in food-search and above-ground activities; and 4) handling times of specific food items affect ingestion rates and energy yields.

Derivations to Acute Rodenticides

OFT offers numerous hypotheses relevant to efficacy, acceptance, bait shyness, and non-target hazard issues surrounding Zn_3P_2 bait applications. Bait formulation/delivery and rodent foraging behavior must be examined relative to rodent-control methods.

That olfaction, search rate, bait distribution, and habitat density affect bait pick up by rodents has been discussed (Reidinger and Mason 1983); however, other factors also must be considered. Highly odor-sensitive, fast-searching rodents have greater likelihoods of discovering dispersed bait particles than odor-insensitive, slow-searching rodents. This alludes to the need for highly palatable, energy laden, alternative bait products. Under conditions of high bait density (e.g., 10 lbs/acre broadcast), target/nontarget species should find, handle, and consume larger numbers of individual bait particles than under low bait density applications (e.g., 2 lbs./acre broadcast)---the formulation/distribution of baits impacts the probability of bait encounters by target/nontarget species. Behaviorally, encounters with predators or predator signs have been shown to decrease the number of food-search bouts, but to increase rates or gaits of above-ground ambulation, by granivorous desert rodents (Reichman 1981).

The toxicity of individual baits to the target/nontarget species affects efficacy/hazard. Use of "single-/few-particle-lethal baits" reduces the foraging time and particle ingestions needed to deliver a cumulative lethal dose to given animals; whereas, use of "multiple-particle-lethal baits" increases the required foraging time, bait-handling time, and particle ingestions needed for lethal dose delivery. These dose characteristics are species specific; still, single-/few-particle-lethal baits should be associated with relatively small species or extremely toxic rodenticides. I contend that multiple-particle-lethal baits increase the probability for onset of hydrolysis-induced GI effects in rodents via intermittent, small quantity intakes and lead to bait shyness. Interruptions of feeding bouts are more likely for rodent species (and individual animals) that require multiple particles for receipt of a cumulative lethal dose.

PARTICLE-DOSE ANALYSIS (PDA)

Assumptions

For current purposes, PDA is a theoretical approach to investigating the "particle toxicity" of a rodenticide. It involves estimates of specific numbers of treated grains needed for ingestion of LD_{50} or ALD doses by target/nontarget species. Present analyses are limited to the 2.0% Zn_3P_2 SRO and 1.82% Zn_3P_2 wheat grain baits cited under the Section 3 Registrations (see No. 2, 3, and 5 in Table 1). Assumptions of PDA are that: 1) a sufficient number of toxic bait particles for delivery of lethal doses are available to the target/nontarget animals as a result of baiting schemes; 2) acute oral LD_{50} and ALD doses are directly related to lethal concentration (LC) doses under conditions of uninterrupted feeding; and 3) accurate nominal formulation and homogeneous adherence of Zn_3P_2 (technical product) to each bait particle occurs.

Formulas

To conduct the present analyses, 100 SRO groats and 100 wheat grains were weighed. Although SRO groats is not the actual registered product (groats refer to the hulled SRO), weights of these products are essentially equal. Mean ($\pm$S.D.) weights of groat and wheat particles were 23 ($\pm$9) and 18 ($\pm$9) mg, respectively. Assuming homogeneous distribution of Zn_3P_2 on groats/grains, the general particle-dose formula is:

$$\text{Particle } Zn_3P_2 = [\text{Mean Particle Weight (mg) X } Z_3P_2 \text{ Concentration } (\%)].$$

Substituting the 23 and 18 mg mean weights for the registered 2% SRO groat and 1.82% wheat baits, mean particle Zn_3P_2 is estimated at 0.46 and 0.33 mg, respectively.

The theoretical LD_{50}/ALD particle-dose formula is:

$$\text{Particles to } LD_{50}/\text{ALD} = \frac{\text{Species } LD_{50} \text{ or ALD (mg/kg) x body weight (kg)}}{\text{Mean Particle } Zn_3P_2 \text{ (mg)}}$$

where the mean amounts of Zn_3P_2 are 0.46 mg/SRO groat and 0.33 mg/wheat grain, respectively. For example, consider the hypothetical case of a 0.5 kg rodent species found to have an LD_{50} of 10 mg/kg and baited with 2% SRO groats; computation yields [(10 mg/kg X 0.5 kg) ÷ 0.46 mg] or that 10.9 groats must be ingested by each rodent to lethally dose ≈50% of the rodents.

THEORETICAL EFFICACY AND ACCEPTANCE

Some Definitions

"Theoretical particle efficacy" refers to the calculated number of groat/grain particles associated with ingestion of lethal acute oral doses of Zn_3P_2 by target species. This differs greatly from "actual particle efficacy" which refers to the numbers of grains ingested during the natural foraging bouts of particular species and from "product performance efficacy" which refers to the field reduction in rodent activity following bait application(s). For the latter term, Pesticide Assessment Guidelines (PAGs) for Subdivision G, Product Performance Tests (§ 96-12) set a minimum 70%-reduction-in-rodent-activity criterion for registration of agricultural rodenticides (Schneider 1982).

PDA Comparison for Target Species: Efficacy and Acceptance

Table 2 presents typical body weights, reported LD_{50}/ALD values, and computed theoretical numbers of 2% SRO groat or 1.82% wheat grains associated with acute oral doses of Zn_3P_2 for the nine target species listed in these three bait registrations. Zn_3P_2 is highly toxic to these species. Published minimum-maximum LD_{50} values are 16.2 to 18.0 mg/kg (i.e., prairie vole vs. meadow vole and black-tailed prairie dog), while a lone ALD of 42.0 mg/kg was found for white-footed mouse. For the two rodents listed on both SRO and wheat labels (meadow vole and white-footed mouse), more of the lighter/less-toxic wheat grains are required to attain LD_{50}/ALD doses than the heavier/more-toxic SRO groats; however, body weight interacts with toxicity to determine number of particles associated with the published doses. Whereas short-term intake of ≈1-3 and ≈2-4 particles of SRO groats and wheat grains should prove lethal to ≈50% of target voles and ≈100% (ALD) of white-footed mice (deer mice), respectively, short-term consumption of ≈40 SRO groats is expected to cause death in ≈50% of prairie dogs.

OFT and PDA Implications: Efficacy and Acceptance

OFT and PDA offer several implications to the efficacy and acceptance of Zn_3P_2 groat/grain baits:

1) Specific forms of Zn_3P_2 baits are "best viewed" as a case of diet selection rather than an optimal energy source; palatable, preferred formulations of baits are essential to cause target rodents to "switch" to alternative foods.
2) Timing of bait applications should coincide with non-crop cycles because acceptance of alternative foods should occur more readily at times when the preferred fo.age is depleted/harvested.
3) Zn_3P_2 is expected to be most efficacious for voles and mice, rodents for which the groats/grains are 1 to 4 particle lethal.
4) Aerial or mechanical broadcast which distributes particles widely should also prove effective for voles and mice ($\leq$ 4 particles lethal); whereas, localized dense applications (e.g., site baiting at burrow openings) with small amounts of bait (e.g., ≈10 g equals 435 SRO groats or 556 wheat grains) should be more effective with prairie dogs that require >38 particles for median lethality. Interestingly, many of these implications characterize current baiting techniques.

THEORETICAL BAIT SHYNESS

Historical Background

The term "bait shyness" was coined by Rzoska (1953). In a set of five experiments with white and brown rats, he noted that survivors of initial presentations of arsenic, red squill, and barium carbonate baits developed "a cautious attitude towards food (and poison bait) experienced previously with harmful effects". Rzoska (1953) stated four main results:

1) An identical poison bait was refused on successive occasions.
2) A new poison in a base harmfully experienced was rejected.
3) An experienced poison in a new base was accepted.
4) A new poison in a new base was accepted.

Rodent Feeding Patterns

Laboratory studies have characterized the food-ingestion patterns of rodents (e.g., Le Magnen 1971, Sterner 1982). For example, data indicate that the majority of rats eat ≈70% of their daily food intake as 8 to 12 "meals" during the nocturnal portion of the diurnal cycle. In addition, several investigators have reported a positive correlation between the size of a meal and the length of the subsequent inter-meal interval (Le Magnen 1972, Panksepp 1973). Such evidence has implications to Zn_3P_2-particle baits.

Table 2. Theoretical particles of Zn_3P_2 SRO groats and wheat grains associated with LD_{50}/ALD doses for eight target rodents cited on use labels.[1]

Species	Typical Body Weight (kg)	Zn_3P_2 LD_{50} or ALD (mg/kg)	Particles to LD_{50} or ALD: SRO Groats (2.0%)	Particles to LD_{50} or ALD: Wheat Grains (1.82%)
Pine Vole[2]	0.03	-	-	-
Meadow Vole	0.04	18.0	1.6	2.2
Prairie Vole	0.035	16.2		1.7
Mountain Vole[2]	0.06	-		-
White-footed Mouse	0.03	42.0 (ALD)	2.7 (ALD)	3.8 (ALD)
Black-tailed Prairie Dog	1.0	18.0	39.1	
White-tailed Prairie Dog[2]	1.0	-	-	
Gunnison's Prairie Dog[2]	1.0	-	-	

[1]LD_{50}/ALD values from Johnson and Fagerstone (in press); dual values for the same species reflect multiple reports of acute oral toxicity cited in the literature. Mean Zn_3P_2/SRO groat is 0.46 mg (2.0%), and mean Zn_3P_2/wheat grain is 0.33 mg (1.82%).
[2]Published LD50/ALD values not found or not available. (Note--Blanks indicate that the species is not listed as a target for that bait.

Figure 1 is a plot of the three-day, minute-by-minute, single-choice (ground chow) food intake measurements obtained for eight albino rats using a computerized food-intake measurement system (Sterner 1982). Note the distinctive patterns evident for the various animals. The top four records show that these rats ate larger, less frequent meals followed by pronounced "non-feeding bouts". In contrast, the bottom four records indicate that these rats ate smaller, more frequent, more intermittent amounts of chow. I call these "meal-eater patterns" and "nibbler patterns," respectively. Whether these were acquired from feeding experiences or genetically-transmitted behaviors is uncertain; nevertheless, the implication is clear. Certain rodents within target species appear more likely than others to ingest multiple particles of Zn_3P_2 groats/grains than others. "Meal-eaters" should ingest lethal doses of rodenticides frequently, with "nibblers" being likely candidates for bait shyness. Prebaiting is viewed to enhance meal characteristics.

PDA Comparison for Target Species: Bait shyness

Although Zn_3P_2 is often described as a "single-dose" rodenticide (Gratz 1973), this term requires careful definition. It refers to the one-time ingestion of a lethal dose by rodents, not the single-particle-lethal attribute sought for some acute rodenticides.

Data in Table 2 suggest that bait-handling times and particle-ingestion rates differ among the target species. A hierarchy of particles needed for lethality is evident. More groat/grain particles are required for lethal dose ingestions by prairie dogs than by white-footed mice and voles. This relates to the onset of bait shyness. Essentially, longer bait-ingestion sessions and greater food-handling times associated with multiple-particle-dose ingestions are expected to correlate with greater frequencies of bait shyness in and prairie dogs (38 to 58 particle lethal doses) than in mice and voles (2 to 4 particle lethal doses). This would be aggravated by broadcast applications for prairie dog control where foraging for large numbers of particles would allow ample time for onset of Zn_3P_2 hydrolysis in the GI tract before fatal doses had been ingested by rodents.

OFT and PDA Implications: Bait shyness

A number of theoretical implications concerning Zn_3P_2-induced bait shyness effects can be derived from OFT and PDA:

1) Species that require more or longer bait-particle handling are predicted to display greater frequency of bait shyness due to greater chances for interruptions of feeding and onset of GI disturbance.

2) Increased predation is predicted to increase the frequency of bait shyness of target rodents by causing shorter, faster above-ground food searches and reduced meal size (nibbling).

3) Social dominance relationships affecting specific rodent species are predicted to increase bait

shyness via social disruption of subordinates during foraging/feeding (especially at bait stations); dominant rodents should be more likely to ingest fatal doses.

4) Aerial or mechanical broadcast should prove effective for voles and mice (widely dispersed particles, but $\leq$4 particles lethal); however, these bait applications would be expected to increase the frequency of bait shyness for prairie dogs because of the increased likelihood for spaced, interrupted intakes during foraging for $\geq$39 particles.

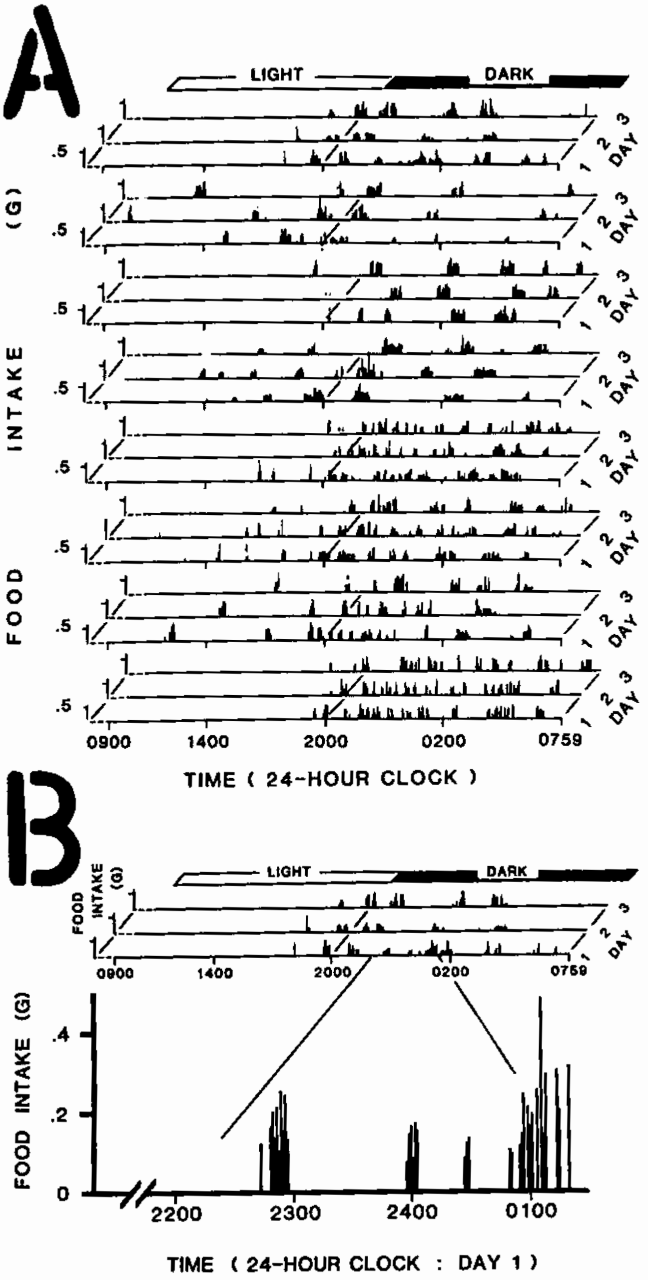

Figure 1. (A) Minute-by-minute food-intake patterns of eight albino rats during continuous three-day ad libitum, single-choice feeding tests (Rat 1 = top...Rat 8 = bottom). (Note--The dashed portion of each abscissa refers to a one-hour maintenance period between 0800-0859 hours daily; no food measurements were recorded during this period.) (B) Enlargement of the consumption by Rat 1 between 2200 and 0130 hours of Day 1. (Reprinted courtesy of The Psychonomic Society from Sterner 1982.)

THEORETICAL NONTARGET HAZARDS

PDA Comparison for Nontarget Species: Primary Hazards

Table 3 presents LD_{50}/ALD values and PDA calculations of the SRO groat and wheat grain baits for 11 nontarget avian species. Two features of these data are obvious: the wide variability in particle-dose estimates both within and between species and the high toxicity of Zn_3P_2 to these species. The first feature mirrors the large range in LD_{50}/ALD values reported by different investigators for the same or different species (Johnson and Fagerstone in press). The second feature reflects the relatively non-specific action of Zn_3P_2 (Gratz 1973, Hood 1982, Marsh 1988, Johnson and Fagerstone in press).

With nontarget avian species, foraging behavior is probably a more important consideration than either LD_{50}/ALD or body weight. For example, certain species of gallinaceous birds may not forage or spend much time in habitats listed on the "use labels" (e.g., rangelands). Thus, the current comparison must be treated cautiously. Nevertheless, as for the target rodents, more of the lighter, less-toxic wheat grains than the heavier/more-toxic SRO groats are required to produce mortality in nontarget species; but, as before, body weight determines particle to lethal dose within species. Fewest particles are estimated to produce mortality for the house sparrow, with $\approx$1 to 3 and $\approx$2 to 5 groats and grains estimated to cause $\approx$100% mortality in adults of this species, respectively. Minimum and maximum SRO groat particles for $\approx$50% lethality of the remaining bird species varied from 3.6 (red-winged blackbird) to 175.8 (mallard duck), depending upon which published LD_{50} was utilized. Similar estimates involving wheat grains vary from 5.0 (red-winged blackbird) to 245.1 (mallard duck). Noteworthy, are particle estimates for bobwhite and California quail ($\approx$5 and $\approx$7 SRO groats and wheat grains, respectively), and ring-necked pheasant ($\approx$19-58 and $\approx$27-79 SRO groats and wheat grains, respectively); these species yield very low particle estimates and have been cited as at risk of primary hazards from Zn_3P_2 groat/grain bait applications (see Johnson and Fagerstone In Press). The PDA values for waterfowl (i.e.,Canada goose, snow goose, and mallard duck) range between $\approx$34 particles (SRO groats, mallard duck) to $\approx$245 (wheat grains, mallard duck), and waterfowl have been historically cited as species at risk of greatest primary hazard (Marsh 1988, Johnson and Fagerstone in press).

Table 3. Theoretical particles of SRO groats and wheat grains to LD_{50}/ALD for 11 selected non-target avian species (primary hazard).[1]

Species[2]	Typical Body Weight (kg)	Zn_3P_2 LD_{50} (mg/kg)	Particles to LD_{50}	
			SRO Groats (2.0%)	Wheat Grains (1.82%)
Canada Goose	5.0	12.0	130.4	181.8
Snow Goose	3.0	8.8	57.4	80.0
Mallard Duck	1.2	13.0-67.4	33.9-175.8	47.3-245.1
Northern Bobwhite Quail	0.17	12.9	4.8	6.6
California Quail	0.17	13.5	5.0	7.0
Ring-necked Pheasant	1.0	8.8-26.7	19.1-58.0	26.7-78.8
Domestic Chicken	1.5	24.0-26.0	78.3-84.8	109.1-118.2
Mourning Dove	0.13	34.2	9.7	13.5
House Sparrow	0.03	20-50 (ALD)	1.3-3.3 (ALD)	1.8-4.5 (ALD)
Red-winged Blackbird	0.07	23.7-178.0	3.6-27.1	5.0-37.8
Horned Lark	0.07	47.2	7.2	10.0

[1]LD_{50}/ALD values from Johnson and Fagerstone (in press); dual values for the same species reflect multiple reports of acute oral toxicity cited in the literature. Mean Zn_3P_2/SRO groat is 0.46 mg (2.0% of 23 mg), and mean Zn_3P_2/wheat grain is 0.33 mg (1.82% of 18 mg).

[2]The scientific names for the listed nontarget species are: Canada goose (*Branta canadensis*), snow goose (*Chen caerulescens*), mallard duck (*Anas platyrhynchos*), northern bobwhite quail (*Colinus virginianus*), California quail (*Callipepla californica*), ring-necked pheasant (*Phasianus colchicus*), domestic chicken (*Gallus gallus*), mourning dove (*Zenaida macroura*), house sparrow (*Passer domesticus*), red-winged blackbird (*Agelaius phoeniceus*), and horned lark (*Eremophila alpestris*).

OFT and PDA Implications: Nontarget Hazards

OFT and PDA results imply that the high, nonspecific toxicity of Zn_3P_2 to avian species warrants detailed studies/analyses of specific nontarget avian foraging patterns related to the registered applications. Mitigations to limit bait-application times, exposure patterns, and local uses must be carefully devised and followed to reduce nontarget primary hazards of groat/grain particles in all Zn_3P_2 applications.

CONCLUSIONS

Zn_3P_2 is an acute rodenticide that has been used safely for years. Recent outbreaks of Hantavirus Pulmonary Syndrome (HPS) have demonstrated the often unexpected need for acute rodenticides (Childs 1994). Published acute oral toxicity values coupled with PDA comparisons confirm that Zn_3P_2 groat/grain baits are highly toxic to the target species--attribute 1 of an effective acute rodenticide (Gratz 1973). OFT and PDA suggest that Zn_3P_2 will be most efficacious for voles/mice --species requiring $\leq$4 particles to ingest a lethal dose. Aerial or mechanical broadcast bait application which distributes particles widely should prove effective for these rodents; whereas, localized, site baitings at burrow openings with small amounts of bait ($\approx$10 g; 435 SRO groats) should be more effective with prairie dogs--a species requiring $\geq$39 particles for $\approx$50% lethality.

Avoidance of Zn_3P_2-induced bait shyness depends upon rodent consumption of sufficient lethal groats/grains in a relatively short feeding bout--attributes 2 and 3 of Gratz (1973). PDA suggests that bait shyness is less probable in voles/mice that require only two to four particles of bait but more likely in prairie dogs that must ingest $\geq$39 particles, probably over a longer time span. OFT implies that rodents which can forage uninterrupted (absence of predators, lack of social dominance hierarchies, etc.) have greater chances for consuming larger, grain-bait meals (lethal doses of Zn_3P_2).

Finally, a review of reported LD_{50}/ALD values for nontarget species indicates that Zn_3P_2 is not highly specific--attribute 4 of Gratz (1973). Safe use relies heavily upon selective, mitigation procedures linked with appropriate baiting techniques. Studies of the foraging patterns of nontarget species in relation to groat/grain preference and consumption are needed to further improve the selectivity of these techniques.

ACKNOWLEDGMENTS

Thanks to Donald Elias, Kathleen Fagerstone, Edward Schafer, Jr., and Stephen Shumake for helpful critiques of the manuscript, and to Carol Schafer and Mary Cameron for the preparation of slides used during the presentation of this paper.

LITERATURE CITED

CHILDS, J. E., T. G. KSIAZEK, P. E. ROLLIN, J. W. KREBS, S. ZAKI, S. T. NICHOL, C. J. PETERS, and G.E. GLASS. 1994. Hantaviruses and their rodent reservoirs in the United States. Proc. Vertebr. Pest Conf. 16:188-191.

GRATZ, N. G. 1973. A critical review of currently used single-dose rodenticides. Bull. Wld. Hlth. Org. 48:469-477.

HAZARDOUS SUBSTANCE DATABANK [Databank Online]. 1993. Phosphine; CAS No. 7803-51-2. Natl. Lib. Med., Bethesda, MD. 13 pp.

HOOD, G. A. 1972. Zinc phosphide--a new look at an old rodenticide for field rodents. Proc. Vertebr. Pest Conf. 5: 85-92.

JOHNSON, G. D., and K. A. FAGERSTONE. In Press. Primary and secondary hazards of zinc phosphide to nontarget wildlife--a review of the literature. U.S. Dept. Agric./Anim. Plant Hlth. Inspect. Ser./Denver Wildl. Res. Rept., No. 4. xx pp.

KAMIL, A. C., J. R. KREBS, and H. R. PULLIAM. 1987. Foraging behavior. Plenumress, New York, NY. 676 pp.

KAMIL, A. C., and T. D. SARGENT. 1981. Foraging behavior: Ecological, ethological, and psychological approaches. Garland STPM Press, New York, NY. 534 pp.

LE MAGNEN, J. 1971. Advances in studies on the physiological control and regulation of food intake. Pages 204-253 *in* E. M. Stellar and J. M. Sprague, eds. Progress in Physiological Psychology (Vol. 4). Academic Press, New York, NY.

LE MAGNEN, J. 1972. Regulation of food intake: Physiologic-biochemical aspects (peripheral regulatory factors). Adv. Psychosom. Med. 7:73-79.

MARSH, R. E. 1988. Relevant characteristics of zinc phosphide as a rodenticide. U.S. Forest Serv. Gen. Tech. Rept. RM-154. p. 70-74.

MURPHY, S. D. 1986. Toxic effects of pesticides. Pages 566-567 *in* C.D. Klaassen, M.O. Amdur, and J. Doull, eds. Casarett and Doull's Toxicology: The Basic Science of Poisons, Third Ed., MacMillan, New York, NY.

PANKSEEP, J. 1973. Reanalysis of feeding patterns in the rat. J. Compar. Physiol. Psychol. 82:78-94.

REICHMAN, O. J. 1981. Factors influencing foraging in desert rodents. Pages 195-213 *in* A. C. Kamil and T. D. Sargent, eds. Foraging Behavior: Ecological, Ethological, and Psychological Approaches, Garland STPM Press, New York, NY.

REIDINGER, R. F. JR., and J. R. MASON. 1983. Exploitable characteristics of neophobia and food aversions for improvements in rodent and bird control. Pages 20-39 *in* D. E. Kaukeinen, ed. Vertebrate Pest Control and Management Materials: Fourth Symposium, ASTM STP 817, Amer. Soc. Testing Materials, Philadelphia, PA.

RZOSKA, J. 1953. Bait shyness, a study in rat behaviour. Brit. J. Anim. Behav. 1(4):128-135.

SCHNEIDER, B. A. 1982. Pesticide assessment guidelines, subdivision G--product performance. PB83-153924. Natl. Tech. Infor. Serv., Springfield, VA. p. 313-315.

SCHOENER, T. W. 1987. A brief history of optimal foraging ecology. Pages 5-67 *in* A. C. Kamil and T. D. Sargent, eds. Foraging Behavior, Plenum Press, New York, NY.

STERNER, R. T. 1982. A microcomputer-based system for continuous measurement of rodent food intake. Behav. Res. Meth. Instru. 14(6):526-531.

TKADLEC, E., and B. RYCHNOVSKY. 1990. Residues of Zn_3P_2 in the common vole (*Microtus arvalis*) and secondary poisoning hazards to predators. Folia Zool., 39(2): 147-156.