FeraCol® for the control of stoats (*Mustela erminea*)

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ABSTRACT

The acceptability (proportion of stoats eating bait) and palatability (amount of bait eaten) were determined for 18 types of non-toxic baits supplied by Feral Research & Development Ltd. The baits were offered to 24 captive male stoats in paired choice tests (test bait with a hen egg). All stoats ate some bait. The average amount of the most palatable bait eaten was about 11 g (cf. about 50 g of hen egg) in 24 hours. The efficacy of 0.64% cholecalciferol with a synergist in the best bait was determined for 20 captive male stoats. On average, the stoats ate only 5.5 g of toxic bait (cf. 10.6 g of non-toxic bait, with synergist, per day in the final palatability trial). Despite the low bait consumption, 12 (60%) of the 20 stoats died within 14 days. The average time to death of these 12 stoats was 6.3 days. Two stoats were euthanased, one after 9 days and another after 28 days, because they had lost more than 40% body weight, and were considered likely to die. Consequently, it is assumed that 14 (70%) out of the 20 stoats would have died from cholecalciferol poisoning. The average time to death of these 14 stoats was 7.9 days. On average, stoats that died or were euthanased ate 6.7 g of bait (43 mg of cholecalciferol), and those that survived ate 2.7 g of bait (17 mg of cholecalciferol). Most (18 out of 20) stoats stopped feeding 1 day after eating toxic bait. The average weight loss of stoats that died was 28.3%, and of those that survived was 21.5% after 7 days. Prolonged weight loss is likely to result in higher mortality of stoats in the field than in captivity. To increase stoat mortality, the palatability of the bait, the concentration of cholecalciferol, or the level of synergist in the bait will need to be increased. Alternatively, another toxicant such as cyanide, diphacinone, zinc phosphide, or MNT could be incorporated into the bait. Whatever toxicant is used, optimising bait palatability will be advantageous.

Keywords: stoats, *Mustela erminea*, baits, poisons, cholecalciferol, synergist, pest control, New Zealand

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1. Introduction

The stoat (*Mustela erminea*) is an introduced predator that is contributing to the decline of several species of native birds in New Zealand (Dowding & Murphy 1996; Elliott et al. 1996; McLennan et al. 1996; O'Donnell 1996; O'Donnell et al. 1996; Wilson et al. 1998). Stoat numbers have traditionally been controlled using Fenn traps set in tunnels lured with hen eggs (King et al. 1994; O'Donnell et al. 1996). A toxic bait has been developed recently using sodium monofluoroacetate (1080), cholecalciferol (vitamin D_3), or diphacinone (a first-generation anticoagulant) as the active ingredient, injected into hen eggs placed in bait stations (Spurr 1996, 1999, 2000; Miller & Elliot 1997; Dilks & Lawrence 2000). A ready-to-use toxic bait would be more cost-effective, and increase the arsenal of techniques available for stoat control.

Feral Research & Development Ltd (Feral R&D), Auckland, is developing a ready-to-use bait containing cholecalciferol (with a synergist) as the active ingredient. Cholecalciferol was originally developed as a rodenticide, and is registered in New Zealand in a paste bait known as FeraCol® for control of the brushtail possum (*Trichosurus vulpecula*) (Morgan & Rhodes 2000; Eason & Wickstrom 2001). The acute oral LD_{50} estimate is 42.5 mg/kg for the Norway rat (*Rattus norvegicus*), 16.8 mg/kg for the brushtail possum, and 9.0 mg/kg for the rabbit (*Oryctolagus cuniculus*) (Eason & Wickstrom 2001). Animals normally take several days to die, but the compound has a stop-feeding action after about 24 hours. Cholecalciferol causes an increase in serum calcium concentrations, resulting in calcification in organs such as the lungs, kidneys, and heart. Excess calcification leads to organ failure and death. The bait containing cholecalciferol for stoat control will be known as 'FeraCol® for stoats'. A prototype non-toxic bait for stoats, made from egg powder and dried, granulated mouse and rat, was eaten by all seven captive stoats in a preliminary trial (J. Kerr, Feral R&D, pers. comm.). The prototype has subsequently undergone further formulation, including the addition of a synergist, and anti-mould and anti-oxidant compounds to ensure long-term stability in the field.

Landcare Research has previously tested cholecalciferol in hen eggs for stoat control (Spurr 1999). Two out of two captive stoats died after eating 30 mg of cholecalciferol in hen eggs (approx. 0.06% cholecalciferol per egg), four out of five died after eating 50 mg of cholecalciferol in hen eggs (approx. 0.1% cholecalciferol per egg), and two out of two died after eating 100 mg of cholecalciferol in hen eggs (approx. 0.2% cholecalciferol per egg) (Spurr 1999). The two stoats that ingested 30 mg of cholecalciferol died after 20 and 27 days, respectively, and the six that ingested 50–100 mg of cholecalciferol died after an average of 8.5 days. Six of the stoats that died stopped feeding after 1 day, but two did not stop feeding until after 5 days.

Feral R&D was funded by the Department of Conservation (DOC), and subcontracted Landcare Research to determine the palatability to captive stoats of a series of non-toxic baits containing a synergist, and anti-mould and anti-oxidant compounds, and the efficacy of the best of these baits containing cholecalciferol.

2. Methods

2.1 PALATABILITY OF NON-TOXIC BAIT

The stoats used in the palatability trials were all wild-caught male stoats maintained in captivity for at least 1 month, at the Landcare Research animal facility. Female stoats were not available for the trials. The stoats were housed in cages (60 × 150 × 90 cm) under an outside shelter, and maintained on a diet of pet mince or dead day-old chickens fed once daily, with free access to water.

Eighteen types of non-toxic bait supplied by Feral R&D were offered to the stoats in five trials (February–August 2001). The baits in trials 1–3 did not contain a cholecalciferol synergist but those in trials 4 and 5 did. In each trial, three or four bait types were offered to 24 stoats in a three or four-treatment, 3- or 4-night crossover design. Four (or three) bait types were each offered to six (or eight) stoats, respectively, per night for 4 (or 3) test nights. Stoats were randomly allocated one of the possible sequences of treatments, so that over a period of 3 or 4 test nights each stoat received each bait type once. Each stoat was offered a choice of a raw hen egg and the same weight (as the hen egg) of test bait (approximately 50–70 g), with no other food available, each test night. The amount of bait and egg eaten overnight was recorded by weighing any remaining bait or eggs (including spillage onto sheets placed under the cages), and adjusting for natural weight changes (from baits and eggs placed in empty cages overnight). Normal food was offered for 2 or 3 nights between each of the 3 or 4 test nights. This design enabled a test of whether there were any residual effects (sometimes called crossover or carry-over effects) from one test night to another.

The same design was repeated in each of the five trials. Twenty-two of the 24 stoats used in each trial were the same throughout. One stoat died of natural causes and was replaced after trial 1, and a second stoat died of natural causes and was replaced after trial 4. The trials were carried out at least 5 weeks apart in an attempt to reduce any possible carry-over effects.

The bait consumption data for each trial were analysed using an analysis of variance, with factors for bait type, test night, stoat, and residual (or carry-over) effects. Inclusion of the residual effects allowed for the possibility that the bait type offered on the previous test-night might affect consumption of the bait type on the current test-night. The absolute consumption of bait was square-root transformed prior to analysis, and means and approximate standard errors back-transformed for inclusion in the tables of results. The egg-consumption raw means and standard errors are presented in the tables of results.

2.2 EFFICACY OF TOXIC BAIT

The toxic bait received from Feral R&D was bait type '1m', and nominally contained 0.75% cholecalciferol plus a cholecalciferol synergist (confidential to Feral R&D). The bait was assayed for cholecalciferol concentration by High

Performance Liquid Chromatography at the Landcare Research toxicology laboratory based on the method of Gehrig & Stringham (1987). Two months after the last palatability trial, the toxic bait was offered to 20 of the 24 wild-caught captive male stoats from the palatability trials. The use of the same stoats in the efficacy trial as in the non-toxic bait palatability trials is unlikely to have increased consumption of toxic bait because there was no evidence of residual (or carry-over) effects from night to night in the palatability trials (see results), and there was a gap of 2 months between the palatability and efficacy trials. Each stoat was offered 20 g of toxic bait (i.e. nominally 150 mg of cholecalciferol) for a maximum of 3 nights, in addition to half the amount of normal food. The amount of toxic bait eaten by each stoat was recorded daily, and once they had eaten more than 7 g (i.e. > 50 mg cholecalciferol) they were returned to normal diet. Consumption of normal food was also recorded daily for 1 day before and 4 weeks after toxic baiting. Natural weight changes and spillage of both toxic bait and normal food were monitored as in the palatability trials. The stoats were weighed 1 day before toxic bait was offered and at death, or weekly for 4 weeks if they survived. Time to death was recorded to the nearest day. With a sample size of 20 stoats, if all died we could be 95% certain that the death rate in the population from which these stoats were sampled would be at least 86% (from % die = $(0.05^{1/n})$ 100).

Stoats were not observed directly after being offered bait because of their shy nature and the possibility that direct observation would have compromised the results. However, 24-hour time-lapse video cameras were used to monitor two stoats (121 and 179) to obtain an indication of the toxicosis effects.

3. Results

3.1 PALATABILITY OF NON-TOXIC BAIT

In trial 1, there was strong evidence that consumption differed between the four bait types tested ($F_{3,63} = 3.61$, $P = 0.018$) (Table 1). However, pair-wise comparisons using the Bonferroni method showed that the only significant difference was between bait A and bait D ($P < 0.05$). Mean consumption was low for all bait types in comparison to eggs, and fewer stoats ate baits than ate eggs.

TABLE 1. MEAN DAILY CONSUMPTION OF DIFFERENT BAIT TYPES AND HEN EGGS OFFERED AT THE SAME TIME TO CAPTIVE MALE STOATS IN TRIAL 1.

BAIT TYPE	AMOUNT BAIT EATEN (g)		% STOATS EATING	AMOUNT EGG EATEN (g)		% STOATS EATING
	MEAN	APPROX. SE	>5 g OF BAIT	MEAN	SE	>5 g OF EGG
A	2.0	0.6	25	45.3	4.8	83
B	3.0	0.8	33	48.1	4.2	88
C	2.3	0.6	21	44.7	4.8	92
D	5.5	1.0	46	43.2	5.2	83

There was no evidence that consumption differed between the bait types in trial 2 ($F_{3,63} = 2.25$, $P = 0.09$) (Table 2), or trial 3 ($F_{2,42} = 0.77$, $P = 0.47$) (Table 3). Mean consumption was very low for all bait types in comparison to eggs, and fewer stoats ate baits than ate eggs.

TABLE 2. MEAN DAILY CONSUMPTION OF DIFFERENT BAIT TYPES AND HEN EGGS OFFERED AT THE SAME TIME TO CAPTIVE MALE STOATS IN TRIAL 2.

BAIT TYPE	AMOUNT BAIT EATEN (g)		% STOATS EATING	AMOUNT EGG EATEN (g)		% STOATS EATING
	MEAN	APPROX. SE	>5 g OF BAIT	MEAN	SE	>5 g OF EGG
A1	3.3	0.6	46	47.4	6.0	79
A2	2.4	0.5	33	50.8	5.3	83
B1	1.9	0.5	21	51.8	5.0	92
B2	1.5	0.4	17	50.2	5.3	83

In trial 4, there was strong evidence that consumption differed between the four bait types, all containing a synergist ($F_{3,60} = 4.30$, $P = 0.008$) (Table 4). However, pair-wise comparisons using the Bonferroni method showed evidence for a difference only between bait '1m' and bait '1p' ($P < 0.01$). Mean consumption was low for all bait types in comparison to eggs. However, there were no differences between the number of stoats that ate baits and the number that ate eggs.

TABLE 3. MEAN DAILY CONSUMPTION OF DIFFERENT BAIT TYPES AND HEN EGGS OFFERED AT THE SAME TIME TO CAPTIVE MALE STOATS IN TRIAL 3.

BAIT TYPE	AMOUNT BAIT EATEN (g)		% STOATS EATING	AMOUNT EGG EATEN (g)		% STOATS EATING
	MEAN	APPROX. SE	>5 g OF BAIT	MEAN	SE	>5 g OF EGG
1h	2.7	1.0	33	53.0	3.5	92
1i	2.6	1.0	33	48.8	3.8	88
1j	4.1	1.2	42	50.1	4.0	88

TABLE 4. MEAN DAILY CONSUMPTION OF DIFFERENT BAIT TYPES AND HEN EGGS OFFERED AT THE SAME TIME TO CAPTIVE MALE STOATS IN TRIAL 4.

BAIT TYPE	AMOUNT BAIT EATEN (g)		% STOATS EATING	AMOUNT EGG EATEN (g)		% STOATS EATING
	MEAN	APPROX. SE	>5 g OF BAIT	MEAN	SE	>5 g OF EGG
1m	14.9	1.9	71	42.7	5.1	79
1n	10.1	1.6	61	43.5	4.8	83
1p	7.3	1.3	70	52.7	3.1	96
1q	11.4	1.7	70	42.4	5.5	78

In trial 5, there was no evidence that consumption differed between bait types (all containing a synergist) ($F_{3,63}$ = 0.10, P = 0.96) (Table 5). Mean consumption was low for all bait types in comparison to eggs. However, there were no differences between the number of stoats that ate baits and the number that ate eggs.

TABLE 5. MEAN DAILY CONSUMPTION OF DIFFERENT BAIT TYPES AND HEN EGGS OFFERED AT THE SAME TIME TO CAPTIVE MALE STOATS IN TRIAL 5.

BAIT TYPE	AMOUNT BAIT EATEN (g)		% STOATS EATING	AMOUNT EGG EATEN (g)		% STOATS EATING
	MEAN	APPROX. SE	>5 g OF BAIT	MEAN	SE	>5 g OF EGG
1m	10.3	1.4	75	53.8	4.8	92
1r	10.8	1.5	67	51.3	4.1	92
1s	11.1	1.5	75	43.8	5.7	88
1t	10.1	1.4	67	47.4	4.9	88

In trials 1–3 there was strong evidence for differences in bait consumption between days (P < 0.01 for all three trials), and some evidence in trial 5 (P = 0.025), but with no obvious trend over time. There was no evidence for differences in bait consumption between days in trial 4 ($F_{3,60}$ = 2.00, P = 0.12). In all five trials, there was strong evidence for differences in bait consumption between stoats (P < 0.001 for all trials) but no evidence for residual (or carry-over) effects (P > 0.2 for all trials).

Overall, total mean egg consumption was similar in all trials. However, total mean bait consumption was higher in trials 4 and 5 than in the first three trials. Bait type '1m' was the most palatable bait in trial 4 and equally the most palatable bait in trial 5. Mean daily bait consumption in trial 5 was 10.6 g. Acceptability (proportion of stoats eating bait) was also higher in trials 4 and 5 (70%) than in the first three trials (32%). All stoats preferred hen eggs to baits (Table 6). Mean bait consumption across all trials was 7.8 g (SE = 1.2) compared with mean egg consumption of 46.6 g (SE = 2.7).

TABLE 6. MEAN DAILY CONSUMPTION OF BAITS (ALL TYPES COMBINED) AND HEN EGGS OFFERED AT THE SAME TIME TO INDIVIDUAL CAPTIVE MALE STOATS (ALL TRIALS COMBINED).

STOAT	WEIGHT	NUMBER OF BAIT/DAYS	% BAITS >5 g EATEN	% EGGS >5 g EATEN	AMOUNT (g) BAIT EATEN PER DAY	AMOUNT (g) EGG EATEN PER DAY
101	359	19	32	100	4.4	52.0
103	410	19	16	100	2.2	46.7
105	405	19	63	68	12.4	25.3
107	337	19	58	79	10.5	29.2
108	416	19	58	95	8.8	47.5
109	349	19	21	100	2.9	60.1
111	321	19	26	89	3.4	44.3
113	402	19	42	63	6.7	26.3
114	353	19	21	89	2.6	47.0
121	292	19	95	53	22.3	29.4
122	224	12	7	20	0.6	13.8
125	348	19	63	79	8.0	44.3
126	335	19	63	100	8.8	62.3
127	441	19	47	95	9.2	59.3
128	277	4	0	100	0.1	59.6
129	386	19	21	100	2.6	51.1
131	444	19	53	84	7.6	45.8
133	394	19	37	84	3.6	48.7
135	385	19	79	100	15.6	55.3
137	252	19	58	89	7.8	48.2
141	384	19	95	100	22.2	57.6
158	277	19	11	100	0.8	58.9
161	477	15	27	27	3.7	28.1
163	349	19	79	100	12.7	59.0
164	330	19	42	84	5.3	46.1
179	358	4	100	100	16.8	65.6

3.2 EFFICACY OF TOXIC BAIT

The toxic bait, with synergist, was found to contain 0.64% cholecalciferol. Twelve (60%) of the 20 stoats offered the toxic bait died, and two were humanely euthanased because they had lost more than 40% of their body weight and were considered likely to die (Table 7). Consequently, it is assumed that 14 (70%) of the 20 stoats died. The average time to death of the 12 stoats that died naturally was 6.3 days, and for the 14 stoats that died naturally or were

euthanased was 7.9 days after first dosing. The remaining six stoats, and the four stoats from the non-toxic bait palatability trials not offered toxic bait, were all still alive after 28 days.

All 20 stoats ate some toxic bait (Table 7). The mean total amount of toxic bait eaten was 5.5 g (SE = 1.1). Stoats that died ate 6.7 ± 1.4 g and those that survived ate 2.7 ± 0.8 g of bait ($F_{1,18}$ = 4.57, P = 0.047). As the bait contained 0.64% cholecalciferol, stoats that died ingested an average of 43 mg of cholecalciferol (6.7 g of bait H, 0.64% cholecalciferol), and those that survived ingested an average of only 17 mg of cholecalciferol (2.7 g bait H, 0.64% cholecalciferol). However, there was considerable overlap in the amount of cholecalciferol ingested by those that died and those that survived (Table 7).

TABLE 7. FATE OF CAPTIVE MALE STOATS OFFERED BAIT CONTAINING 0.64% CHOLECALCIFEROL WITH SYNERGIST.

STOAT NO.	STOAT WT. (g)	BAIT EATEN (g)	CHOLE-CALCIFEROL EATEN (mg)	DAYS TO DEATH	WEIGHT LOSS AT DEATH (%)	WEIGHT LOSS OF SURVIVORS 1 WEEK (%)	WEIGHT LOSS OF SURVIVORS 3 WKS (%)	WEIGHT LOSS OF SURVIVORS 4 WKS (%)
103	410	6.0	38			21.7	25.8	20.2
105	405	4.8	31	5	23.7			
107	337	0.9	6			25.8	26.1	24.0
108	416	0.2	1			21.6	13.2	11.3
109	349	8.1	52	8	41.3			
111	321	9.9	63	6	31.5			
113	402	4.1	26			28.1	24.1	31.1
121	292	18.8	120	4	18.5			
125	348	4.0	26			16.7	10.1	8.9
126	335	6.1	39	9*	44.2			
127	441	2.2	14	4	11.8			
129	386	6.3	40	13	50.5			
131	444	2.2	14	11	40.1			
133	394	2.4	15	4	12.7			
135	385	1.9	12	4	14.0			
141	384	4.2	27	6	27.1			
161	477	1.2	8			15.1	13.4	11.7
163	349	2.1	13	28*	46.1			
164	330	10.2	65	4	9.1			
179	358	13.9	89	6	25.1			
Average	378	5.5	35	7.9	28.3	21.5	18.8	17.9

* stoats euthanased

Most (18 out of 20) stoats stopped feeding one day after eating toxic bait. Two stopped feeding two days after. Of the fourteen stoats that died or were euthanased, seven did not resume feeding, and died on average 4.7 days after eating toxic bait. The other seven resumed eating their normal food after 5.5 days, but died 11.3 days after eating toxic bait. The six stoats that survived resumed eating normal food 4.8 days after eating toxic bait.

The average weight loss of stoats that died was 28.3%, after an average of 7.9 days (Table 7). The average weight loss of the six stoats that survived for at least

28 days was 21.5% after 7 days, 18.8% after 21 days, and 17.9% after 28 days. Five of the six stoats had started gaining weight, but one was still losing weight after 28 days. The four stoats not offered toxic bait did not lose any weight (average weight was 310 g beforehand, 318 g on day 21, and 333 g on day 28), and did not stop eating their food over this period.

Few signs of toxicosis were observed in the two stoats videoed, although one was more active than the other throughout. Stoat 121 spent only a few minutes (mean 6.5 ± 1.9 min.) out of its nest box each day. On the fourth night after eating the bait it lay curled up (normal resting posture) at 0213 hours, after which no further movement was seen, and it was dead when checked later that morning. Stoat 179 was much more active throughout, spending a mean of 79 ± 17 minutes out of its nest box, mainly at night. For the first two nights after eating the bait it was active for more than 1.5 hours. However, it spent only 50 minutes out of its nest box on the next four nights. On the night it died (six nights after eating bait), its movements were much slower than on previous nights and it appeared uncoordinated (e.g. falling when it tried to climb a branch in the cage).

4. Discussion

The results of the non-toxic bait palatability trials were encouraging because all stoats ate some bait. However, overall, the stoats did not eat anywhere near as much bait as they ate hen eggs. Only two out of the twenty-six stoats ate more than 20 g of bait per day, whereas all except one stoat ate more than 20 g of egg per day. The stoats in these trials were all males. It is not known whether females would eat baits more or less readily than the males did. Females appear to eat hen eggs less often than males do (Murphy et al. 1992). Future trials should investigate bait consumption by female stoats.

In the efficacy trial, stoats ate on average only 5.5 g of toxic bait, compared with 10.6 g of non-toxic bait per day in the final bait-palatability trial. It is possible that the stoats detected the cholecalciferol or synergist in the bait, or that the cholecalciferol caused the stoats to stop feeding before they ingested a lethal dose. Cholecalciferol can cause bait aversion in rodents (Marsh & Tunberg 1986), and in possums bait-consumption declined when the cholecalciferol concentration approached 0.8% (Jolly et al. 1995). Despite the low bait consumption, the results of the efficacy trial reported here were encouraging, and consistent with the results obtained in previous efficacy trials with cholecalciferol in hen eggs (Spurr 1999). In the present trial, stoats that died or were euthanased ingested an average of 43 mg of cholecalciferol whereas stoats that survived ingested an average of only 17 mg of cholecalciferol. However, some stoats died after ingesting as little as 12 mg of cholecalciferol, while others survived after ingesting as much as 38 mg of cholecalciferol. Similar variability in susceptibility to cholecalciferol has been found in possums (Morgan & Milne 2002).

Prolonged weight loss is likely to result in higher mortality of stoats in the field than in captivity. Captive stoats were housed in ideal conditions and supplied with adequate food and water. Wild stoats would be less likely to survive prolonged weight loss because they are exposed to greater environmental extremes and have to hunt for food.

The pattern of toxicosis after cholecalciferol poisoning observed in stoats was similar to that described for possums (O'Connor et al. 2001). The primary symptoms seen in possums were inappetance and general listlessness, and these were also observed in stoats. However, stoats appeared more active than possums and some stoats also regained their appetite after a few days.

To increase stoat mortality, either the palatability of the bait, the concentration of cholecalciferol, or the level of cholecalciferol-synergist in the bait will need to be increased. The first option is preferable because cholecalciferol is expensive, and an increase in cholecalciferol or synergist concentration may make the bait less palatable to stoats, as indicated by the differing consumption of non-toxic versus toxic bait in this study. Alternatively, another toxicant such as cyanide, diphacinone, zinc phosphide, or mustelid new toxicant (MNT) could be incorporated into the bait. Whatever toxicant is used, optimising bait palatability will be advantageous.

5. Acknowledgements

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