Toxicity of cholecalciferol to rats in a multi-species bait

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Abstract: The effectiveness of Feracol®, a possum control paste bait containing 0.8% cholecalciferol, as a rodenticide has been assessed in cage and field trials. Caged rats were provided with toxic bait in choice and no-choice tests. Feracol® was readily eaten when presented as the sole food source or with other food, and was effective at killing rats in both situations. Wild-caught and laboratory rats ($n = 35$), comprising both ship (*Rattus rattus*) and Norway rats (*R. norvegicus*), were presented with 30 g of Feracol® alone or with an equivalent toxic bait over 48 h. Thirty-four rats died in an average of 4.0 days. Having established that the paste, originally designed for possum control, is also an effective rodenticide for rat control, field trials were initiated with the paste delivered in the field in Philproof® and Striker® bait stations. Monitoring of rat numbers before and after application of toxic bait was undertaken at three trial sites, Lions Hut, Mangaone and Pakoakoa, in Te Urewera National Park in the North Island of New Zealand. Rat population density was assessed using tracking tunnels. Philproof® bait stations containing 200 g of Feracol® were placed 50 m apart on grids at Lions Hut and monitoring was undertaken at one location per hectare using tracking tunnels. At Mangaone and Pakoakoa, two Striker® bait stations containing 18 g of Feracol® were sited at 25-m intervals on lines 150 m apart, and monitoring was undertaken with five lines of 10 tunnels at 50-m intervals. At Lions Hut, rat tracking decreased from 78% to 3% of tunnels tracked; at Mangaone the reduction was 51% to 0%; and at Pakoakoa from 36% to 0%. These trials demonstrate that Feracol® is effective at reducing both moderate and high concentrations of ship rats in the Philproof® and Striker® bait station delivery systems.

Keywords: cholecalciferol; Feracol®; Norway rats; *Rattus*; rodenticide; ship rats

Introduction

New Zealand has few native but many introduced mammals (King 2005), which cause problems as predators and grazers on native flora and fauna. New Zealand has therefore become heavily reliant on anticoagulants and 1080 (sodium monofluoroacetate) for broadscale pest control (Eason et al. 2008). However, 1080 use remains controversial (Hansford 2009), and second-generation anticoagulants bioaccumulate and have resulted in wildlife contamination (Eason et al. 2002). They are very persistent and have been detected in a range of non-target species including game (i.e. feral pigs *Sus scrofa*; deer, e.g. *Cervus* spp.) and native birds (e.g. kiwi *Apteryx* spp.). In the face of increasing incidence of brodifacoum contamination of wildlife and secondary poisoning in New Zealand and overseas (Eason et al. 1999, 2002; Stone et al. 1999; Ticknell 1999; Dowding et al. 2006), there is increasing demand for alternatives to this toxin for field control of rodents. The present study was conducted to provide further information on a potential alternative tool for control of rodents as well as possums.

Feracol® paste (manufactured by Connovation Ltd, Manukau, Auckland, New Zealand) contains cholecalciferol at 0.8%. Cholecalciferol (vitamin D_3) was developed in the 1980s as a rodenticide (Marshall 1984; Tobin et al. 1993). It is registered under the trade name of Quintox® (0.075% cholecalciferol) in the USA, and in Europe it has been added to baits (Racumin® plus) to overcome anticoagulant resistance in rats and mice (Pospischil & Schnorbach 1994). It has been recommended as an alternative to brodifacoum for use against rats in island conservation (Donlan et al. 2003). In 1999, it was registered in New Zealand as paste bait containing 0.8% cholecalciferol (Feracol®). This was based on work in the early 1990s that demonstrated the susceptibility of possums to cholecalciferol (Eason 1991; Eason et al. 1996).

Cholecalciferol is synthesised in animal skin by the action of sunlight on its precursor, 7-dehydrocholesterol (Horst et al. 1982). Natural dietary sources of vitamin D_3 include liver, fish oils, egg yolk, and milk fat (Horst et al. 1982). Cholecalciferol in toxic doses raises blood calcium levels (hypercalcaemia), and causes metastatic calcification of the blood vessels (Marshall 1984; Marsh & Tunberg 1986). Death usually results from heart failure. These effects are comparatively rapid when compared with anticoagulant rodenticides; animals normally take 3–7 days to die from cholecalciferol poisoning (Marshall 1984; Marsh & Tunberg 1986; Jolly et al. 1995). The acute LD_{50} is 43.6 mg/kg for Norway rats *Rattus norvegicus* (Marshall 1984) and 16.8 mg/kg for possums *Trichosurus vulpecula* (Jolly et al. 1995). While a higher dose on a mg/kg basis is required to kill rats than possums, possums regularly weigh between 2 and 4 kg whereas rats weigh less than 500 g (King 2005). Hence between 0.5 g and 3.0 g of Feracol®, which contains 0.8% (or 8000 mg/kg) cholecalciferol, should kill most rats in a weight-range of 100–500 g. This amount of bait should be equivalent to or exceed the LD_{50}.

Fortunately, the toxicity to birds is low, e.g. the LD_{50} for mallard ducks is 2000 mg/kg (Marshall 1984; Eason et al. 2000). The risk of secondary poisoning to non-target species is also low compared with 1080, probably because most animals take several days to die and lose their appetite so the stomachs of poisoned rodents and possums are not full of bait (Marshall 1984; Eason et al. 1996, 2000; Booth et al. 2004). Concentrations of the active metabolite in tissues of poisoned animals (Eason et al. 1996) are no higher than those found in fish (Kenny et al. 1998). Here, we report data from cage and field trials on the effectiveness of a possum bait product containing cholecalciferol at 0.8% (Feracol®) as a rodenticide.

Methods

The effectiveness of Feracol®, a possum control paste bait containing 0.8% cholecalciferol, as a rodenticide was assessed in both cage and field trials. Field trials were undertaken by different research teams. The Lincoln University Animal Ethics Committee gave approval to carry out both cage and field trials (approval numbers: AEC 52, cage; AEC 127, field).

Cage trials

Norway and ship rats (*Rattus rattus*) were housed at the Pest Control Research animal facility in Lincoln in individual cages, which contained a small nesting tube and shredded paper as nesting material. Temperature at the facility was 18–20°C during the study and humidity approximately 50%, with light during the working day and lights switched off overnight. Daily feeding comprised grain pellets (Weston Milling, Rangiora, NZ). Feed hoppers were topped up each day during the acclimatisation period. Clean drinking water was continuously available. A total of 35 rats were exposed to toxic bait, comprising 15 laboratory-sourced Sprague-Dawley Norway rats weighing 230–405 g, and 20 wild-caught ship rats weighing 108–184 g (Table 1). All animals were acclimatised in the animal facility and cages for three weeks before being presented with 30 g of Feracol® over 24 h. Prior to presentation of toxic baits, animals were monitored daily to ensure they had acclimatised and that they were eating pellets. They were weighed once during acclimatisation, immediately prior to being presented with toxic bait, to minimise handling stress. This bodyweight value enabled mg/kg of cholecalciferol ingested to be calculated. It was estimated that Norway rats ate approximately 30–40 g of pellets per day, whereas the smaller ship rats were eating approximately 15–30 g per day.

All 15 of the Norway rats and four of the ship rats were offered a choice between 30 g Feracol® and a non-toxic equivalent paste over 48 h (Table 1). The remaining 16 ship rats were presented with 30 g Feracol® alone, equivalent in weight to the amount of pellet rations given daily. Consumption of bait, signs of toxicity and time until death were recorded.

Field trials

Monitoring of rat numbers before and after application of Feracol® baits was undertaken at three trial sites, Lions Hut, Mangaone and Pakoakoa, in Te Urewera National Park. These areas of native forest were known to have moderate to high populations of ship rats and the Department of Conservation (DOC) desired less persistent toxins than the brodifacoum baits used there in the past for native species protection. Monitoring was undertaken (following Gillies & Williams 2002) using 34 unbaited tracking tunnels (Black Trakka) for presence of rats, and the result expressed as a percentage of tunnels tracked. The percentage tracking rate prior to application of Feracol® baits ranged from 36 to 78%. The target was to achieve a <5% mean rat tracking rate per line following control.

Lions Hut: Field sites included paired treated and untreated blocks, which were at least 500 m apart. The treated block was 34 ha and the untreated (Control) block was 40 ha. Baseline monitoring was undertaken in both blocks on 15 September 2006. Follow-up monitoring occurred between 9 and 11 January 2007 following prefeeding on 24 November 2006 and placement of toxic baits on 8 December 2006. Philproof® bait stations were placed on a 50-m grid with 200 g of bait placed in each bait station. Monitoring was undertaken at one location per hectare using tracking tunnels (Black Trakka). Tracking tunnels were located with the same distribution in the untreated block following DOC standard system protocols with five lines of 10 tunnels at 50-m intervals.

Table 1. Mortality of Norway (*Rattus norvegicus*) and ship rats (*R. rattus*) (n = 35) presented with 30 g of Feracol® for 48 h in cholecalciferol toxicity cage trials.

Rat	Study type	Bait eaten (g)	Mortality
Norway	Choice	0–20.4	14/15
Ship	Choice	1.6–6.3	4/4
Ship	No-choice	0.7–16.1	16/16

Mangaone: Baseline monitoring of the 180-ha core area was undertaken on 8 August 2007. Follow-up monitoring occurred on 11 September 2007 following prefeeding on 10 August 2007 and placement of toxic baits on 18 August 2007. Striker bait stations were placed 25 m apart on a 150 × 25 m grid. This provided control lines at 150-m spacing. Monitoring was undertaken following DOC standard operating system protocols, with five lines of 10 tunnels at 50-m intervals.

Pakoakoa: Baseline monitoring of the c. 220-ha core area was undertaken on 23 August 2007. Follow-up monitoring occurred on 18 October 2007 following prefeeding on 7 September 2007 and placement of toxic baits on 27 September 2007. Striker bait stations were placed 25 m apart on a 150 × 25 m grid. This provided control lines at 150-m spacing. Monitoring was undertaken following DOC standard operating system protocols, with five lines of 10 tunnels at 50-m intervals.

Results

Cage trials

Thirty-four of the 35 rats (97%) died (Table 1) in an average of 4.0 days. Deaths first occurred after one day and most deaths occurred between 2 and 4 days (Tables 2 & 3). Only one Norway rat survived; this rat did not eat any toxic bait (Table 2). The average amount of bait consumed by Norway rats was 7.26 g ± 0.61 SEM, and for ship rats 9.22 g ± 0.65 SEM, equating to an average of 58.11 ± 48.5 mg/kg and 73.74 ± 51.9 mg/kg toxin consumed for Norway and ship rats, respectively. The amount of toxic bait eaten over 24 h was less than that eaten during the acclimatisation period, which could be the result either of detection of the toxin or of neophobia. Feracol® was effective when given alone or in the choice test when presented alongside non-toxic feed pellets, and was equally effective at killing both rat species. Death occurred between 1 and 7 days. Onset of symptoms was noted in most animals after 24 h, which included increasing loss of appetite and lethargy until death occurred. There was some bodyweight loss but this did not exceed more than 30%, except in one Norway rat; 30% loss being a performance criterion set before the trial began. The signs and symptoms were consistent with cholecalciferol-induced toxicosis. The high doses ingested ensured that death occurred as quickly as possible, with 67% of the deaths in Norway rats and near 50% in ship rats occurring in 1–3 days.

Field trials

At all three sites, Feracol® was extremely effective at reducing the mean tracking rate per line from 36–78% to <5%. At Lions Hut, the rat tracking rate was reduced by 96% to 3% (±3)% SEM); at Mangaone and at Pakoakoa rat tracking was reduced by 100% (Table 4).

Baseline pretreatment monitoring revealed a rat tracking rate of 93% in the 'control' untreated block at Lions Hut. Follow-up monitoring approximately one month after toxic bait had been dispensed revealed a rat tracking rate of 59%. The mean tracking rate decreased by 34% in the untreated block, in line with normal seasonal fluctuations in rat tracking indices in the area (D. Baigent, unpubl. data). However, the rat tracking rate of 59% at the end of the study was still 10 fold greater than the acceptable target level of 5%, indicating high rat numbers in the control compared with very low numbers in the treated area.

Discussion

Feracol®, consisting of 0.8% cholecalciferol, shows considerable promise as a rodenticide as well as a product that effectively kills possums. It is therefore an alternative to anticoagulants or could be integrated into pest control operations with anticoagulants. The high mortality demonstrated here in both Norway and ship rats is not surprising given the published acute LD_{50} is 43.6 mg/kg for Norway

Table 2. Results of cholecalciferol toxicity choice tests in the Norway rat (*Rattus norvegicus*) (*n* = 15). * = days until death.

Sex	Weight (g)	Days*	Bait eaten (g)	Toxin consumed (mg)	Amount causing death (mg/kg)
Female	230	3	2.4	19.2	83.48
Female	242	3	1.8	14.4	59.50
Male	410	3	8.9	71.2	173.66
Female	271	13	0.7	5.6	20.66
Male	416	3	18.6	148.8	357.69
Female	234	4	3.7	29.6	126.50
Female	242	3	4.2	33.6	138.84
Male	386	3	20.4	163.2	422.80
Male	390	3	8.5	68	174.36
Male	389	3	11.1	88.8	228.28
Male	393	3	2.8	22.4	57.00
Female	302		0	0	0.00
Female	242	5	5.1	40.8	168.60
Male	387	4	4.1	32.8	84.75
Male	405	2	9.4	75.2	185.68

Table 3. Results of choice and no-choice tests for cholecalciferol toxicity in the ship rat (*Rattus rattus*) (*n* = 20). * = days until death.

Sex	Weight (g)	Days*	Bait eaten (g)	Toxin consumed (mg)	Amount causing death (mg/kg)	Design
Male	148	4	3	24	162.16	Choice
Female	117	5	1.6	12.8	109.40	Choice
Male	139	3	6.3	50.4	362.59	Choice
Female	151	5	1.9	15.2	100.66	Choice
Male	184	4	10.55	84.4	458.70	No choice
Female	151	5	13	104	688.74	No choice
Male	158	3	16.15	129.2	817.72	No choice
Female	148	5	8.7	69.6	470.27	No choice
Male	192	5	10.35	82.8	431.25	No choice
Male	152	6	12.05	96.4	634.21	No choice
Male	131	2	12.5	100	763.36	No choice
Female	110	2	11.8	94.4	858.18	No choice
Female	108	7	0.7	5.6	51.85	No choice
Male	130	1	3.3	26.4	203.08	No choice
Male	148	3	26.5	212	1432.43	No choice
Female	108	5	2.7	21.6	200.00	No choice
Male	144	4	4.55	36.4	252.78	No choice
Male	147	4	12.5	100	680.27	No choice
Male	141	3	17.5	140	992.91	No choice
Female	127	6	8.7	69.6	548.03	No choice

Table 4. Cholecalciferol toxicity to ship rats (*Rattus rattus*) in field trials. Treatment regimen, monitoring systems and % rat tracking rate of the treatment and non-treatment areas before and after application of toxic bait. Standard errors of the means are given in brackets.

Site	Lions Hut	Mangaone	Pakoakoa	Control
Size (ha)	34	180	220	40
Bait station type	Philproof®	2 Strikers	2 Strikers	
Bait station arrangement	50 × 50 grid	25-m lines 150 m apart	25-m lines 150 m apart	
Bait amount (g)	200	18	18	
Monitoring regime	Random c. 1/ha	5 lines × 10 tunnels 50-m intervals	5 lines × 10 tunnels 50-m intervals	5 lines × 10 tunnels 50-m intervals
Rat tracking rate (% tunnels) before	77.9 (12.2)	51.0 (8.0)	36.0 (6.5)	92.5 (3.7)
Rat tracking rate (% tunnels) after	2.9 (2.9)	0	0	58.7 (6.7)
% reduction	96	100	100	34

rats (Marshall 1984), and this was exceeded in most animals. However, this should not be a concern as cholecalciferol, unlike 1080 and brodifacoum, does not bioaccumulate and cause secondary poisoning (Eason et al. 1996, 2000). In fact, the high dose consumed by most rats had a positive effect in that most animals died swiftly. Humaneness is an important consideration and the Feracol® formulation resulted in death in well under 7 days in most animals, which is an advantage when compared with the slower-acting anticoagulants. The average time to death in Norway rats was 3.9 days and in ship rats was 4.1 days. These values are at the low end of the range of 3–7 days published in previous literature (Marshall 1984).

Our field trials confirmed the effectiveness of Feracol® as a product that can kill rats, which is consistent with the use of cholecalciferol in the USA as a rodenticide for the last 25 years. It is therefore an alternative to anticoagulants, or suitable for integrated use with anticoagulants, to reduce reliance on these bioaccumulative poisons. Targeting rodents as well as possums will more effectively protect native fauna, and overcome any unexpected consequences of conventional control methods targeting single species, such as meso-predator release, as examined theoretically by Tompkins and Veltman (2006) and shown in a field situation by Bergstrom et al. (2009). Field trials exemplify the use of Feracol® in terms of the amount required and bait station placement under New Zealand field conditions.

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References

Bergstrom DM, Lucieer A, Kiefer K, Wasley J, Belbin L, Pedersen TK, Chown SL 2009. Indirect effects of invasive species removal devastate World Heritage Island. Journal of Applied Ecology 46: 73–81.

Booth LH, Fisher P, Hepplewaite V, Eason CT 2004. Risk of Feracol baits to non-target invertebrates, native skinks, and weta. Science for Conservation 239. Wellington, Department of Conservation. 18 p.

Donlan CJ, Howard GR, Tershy BR, Croll DA 2003. Evaluating alternative rodenticides for island conservation: roof rat eradication form San Jorge Islands, Mexico. Biological Conservation 114: 29–34.

Dowding JE, Lovegrove TG, Richie J, Kast SN, Puckett M 2006. Mortality of northern New Zealand dotterels (*Charadrius obscurus aquilonius*) following an aerial poisoning operation. Notornis 53: 235–239.

Eason CT 1991. Cholecalciferol as an alternative to sodium monofluoroacetate (1080) for poisoning possums. Proceedings of the New Zealand Weed and Pest Control Conference 44: 35–37.

Eason CT, Wright GR, Meikle L, Elder P 1996. The persistence and secondary poisoning risks of sodium monofluoroacetate (1080), brodifacoum, and cholecalciferol in possums. In: Timm RM, Crabb AC eds Proceedings, Seventeenth Vertebrate Pest Conference. Davis, CA, USA, University of California. Pp. 54–58.

Eason CT, Milne L, Potts M, Morriss G, Wright GRG, Sutherland ORW 1999. Secondary and tertiary poisoning risks associated with brodifacoum. New Zealand Journal of Ecology 23: 219–224.

Eason CT, Wickstrom M, Henderson R, Milne L, Arthur D 2000. Non-target and secondary poisoning risks associated with cholecalciferol. New Zealand Plant Protection 53: 299–304.

Eason CT, Murphy EC, Wright GRG, Spurr EB 2002. Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. Ecotoxicology 11: 35–48.

Eason CT, Ogilvie S, Miller A, Henderson R, Shapiro L, Hix S, MacMorran, D, Murphy E 2008. Smarter pest control tools with low-residue and humane toxins. In: Timm RM, Madon MB eds Proceedings, Twenty-third Vertebrate Pest Conference. Davis, CA, USA, University of California. Pp. 148–153.

Gillies C, Williams D 2002. Using tracking tunnels to monitor rodents and other small mammals. Department of Conservation unpublished report HAMRO-60778, Hamilton, DOC Northern Regional Office.

Jolly SE, Henderson RJ, Frampton C, Eason CT 1995. Cholecalciferol toxicity and its enhancement by calcium carbonate in the common brushtail possum. Wildlife Research 22: 579–583.

Hansford D 2009. 1080. New Zealand Geographic 97: 52–63.

Horst R L, Napoli J L, Littledike ET 1982. Discrimination in the metabolism of orally dosed ergocalciferol and cholecalciferol by the pig, rat and chick. Biochemistry Journal 204: 185–189.

Kenny DE, Irlbeck NA, Chen TC, Lu Z, Holick MF 1998. Determination of Vitamins D, A, and E in sera and vitamin D in milk from captive and free-ranging polar bears (*Ursus maritimus*), and 7-dehydrocholesterol levels in skin from captive polar bears. Zoo Biology 17: 285–293.

King CM ed. 2005. The handbook of New Zealand mammals, 2nd edn. Melbourne, Oxford University Press. 630 p.

Marsh R, Tunberg A 1986. Characteristics of cholecalciferol. Rodent control: other options. Pest Control Technology 14: 43–45.

Marshall EF 1984. Cholecalciferol: a unique toxicant for rodent control. In: Clark DO ed. Proceedings, Eleventh Vertebrate Pest Conference. Davis, CA, USA, University of California. Pp. 95–98.

Pospischil R, Schnorbach H-J 1994. Racumin® plus, a new promising rodenticide against rats and mice. In: Halverson WS, Crabb AC eds Proceedings, Sixteenth Vertebrate Pest Conference. Davis, CA, USA, University of California. Pp. 180–187.

Stone WB, Okoniewski JC, Stedelin JR 1999. Poisoning of wildlife with anticoagulant rodenticides in New York. Journal of Wildlife Diseases 35: 187–193.

Ticknell O 1999. It's a rat trap: poison aimed at rodents is killing their predators instead. New Scientist (23 Jan.) 2170: 4.

Tobin ME, Matschke CH, Sugihara RT, McCann CR, Koehler AE, Andrews KT 1993. Laboratory efficacy of cholecalciferol against field rodents. DWRC Research Report No. 11-55-002. Washington, DC, U.S. Department of Agriculture, Animal and Plant Health Inspection Service. 15 p.

Tompkins DM, Veltman CJ 2006. Unexpected consequences of vertebrate pest control: predictions from a four-species community model. Ecological Applications 16: 1050–1061.

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