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ABSTRACT: Toxins are a major component of rabbit control campaigns in New Zealand, with sodium monofluoroacetate (1080) being the primary toxin in use since the 1950s. However, landowners can use 1080 only under the direct supervision of a licensed operator, and rabbit populations in regularly-poisoned areas have become increasingly resistant to this form of control. A new, cost-effective toxin that does not cause persistent residues in livestock is required by landowners who wish to undertake their own rabbit control. Several recent trials have demonstrated the potential of the anticoagulant pindone (2-pivalyl-l,3-indandione) to meet these requirements. In 1992, the New Zealand Pesticides Board granted full registration to cereal pindone pellets, so that for the first time the New Zealand public has access to a rabbit bait that does not require a licence for its use. The bait is being used with apparent success in a wide range of situations, with sales of the product exceeding 100 ton in 1993.

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INTRODUCTION

Rabbits *(Oryctolagus cuniculus)* were introduced to New Zealand by European settlers in the early 1800s. Many pastoral areas of New Zealand provided excellent habitat and rabbit populations soon exploded. By the late 1800s rabbits were having such devastating impacts in some areas that farmers were forced to abandon hundreds of thousands of hectares of grazing land. As a result, extensive rabbit control programs were initiated and these have continued in various forms until the present day (Gibb and Williams 1990).

Rabbit control in New Zealand has incorporated shooting, trapping, fencing, habitat modification and the introduction of a range of vertebrate predators, with varying degrees of success. An attempt in the 1950s to introduce myxomatosis failed due to the lack of a suitable arthropod vector (Filmer 1953), and public opposition has stalled subsequent proposals for its reintroduction.

As a consequence, toxins remain a major component of rabbit control campaigns in New Zealand. Strychnine was the main toxin used initially, followed by arsenic trioxide and later by phosphorus. In the 1950s, sodium monofluoroacetate (1080) poison was introduced and, with no indigenous land mammals at risk, proved highly effective (Douglas et al. 1959). 1080 has subsequently remained the main toxin in use for rabbit control in New Zealand, particularly as the first step in sustained control programs.

Since the late 1980s however it has been recognized that rabbit populations in areas poisoned annually or bi-annually for a number of years can develop pronounced 1080 bait aversion, which has markedly reduced the success of some control operations (Hickling, in press). This has led to concern over the reliance of current control strategies on a single toxin.

Demand for an alternative to 1080 has also arisen from recent diversification of New Zealand's horticultural and agricultural industries. Rabbits now threaten tree plantings and other crops in small areas where intensive operations by professional control staff are not cost-effective. Concurrently, policy changes have shifted much of the responsibility and expense of rabbit control from local government organizations to landowners. The latter have limited access to 1080, which under current legislation is available only to operators licensed by the Pesticides Board. Only staff of approved organizations who have trained and completed formal examinations can be licensed. Farmers, horticulturalists and the general public cannot purchase 1080 bait and can use it only under the direct supervision of a licensed operator. A suitable alternative toxin for rabbit control is therefore being sought that is cost-effective, unlikely to cause persistent residues in livestock, and available for use by landowners for their own rabbit control.

The observed tolerance of ruminants to some anticoagulants led Oliver and Wheeler (1978) to investigate pindone in Australia as a rabbit toxin that had the potential to meet these requirements. Pindone is a slow-acting anticoagulant that is far more effective with repeated doses than as a single dose (Eason and Jolly 1993). The toxin reduces the clotting power of blood by blocking the synthesis of vitamin-K dependent clotting factors, causing internal hemorrhage. Death occurs 4 to 11 days after bait consumption. Technical data on the compound are given in Table 1.

Pindone has several features that make it a suitable candidate toxin for rabbit control:

- animals feel no ill-effects prior to consuming a lethal dose, thereby preventing learned bait or toxin aversion;
- prefeeding with non-toxic bait is not required (see below);
- being an anticoagulant, pindone is relatively humane;
- an antidote (Vitamin K) is available, thereby reducing the risk to pets and livestock;
- in New Zealand, pindone is available for purchase and use by unlicensed operators.

In 1984, the Western Australian Protection Board registered pindone for rabbit control. As a result, New Zealand researchers decided to conduct further residue and efficacy trials on pindone; a number of these are described below.

Table 1. Technical specifications for Pindone.

Common Name:	**Pindone**
Other Names:	**Pival® (calcium salt)** **Pivalyn® (sodium salt)**
Type of Compound:	**Indandione**
General Use:	**Multiple dose anticoagulant for the control of rats and mice.**
Chemical Description:	
Compound name:	**2-pivalyl-1, 3-indandione**
Molecular formula:	$C_{14}H_{14}O_2$
Physical State:	**Yellow crystalline solid, melting point 109.5 C ± 10 C, molecular weight 230.28**
Odor:	**Odorless and tasteless**
Solubility:	**Only slightly soluble in water (18 ppm), soluble in most organic solvents, calcium and sodium salts freely soluble in water.**

METHODS

Residue Trials

Trial 1. In 1986, the Agricultural Pest Destruction Council conducted a trial to determine the retention of anticoagulants in sheep tissue (J. Bell, E. Johnstone and P. Nelson, unpublished data).

The three anticoagulants tested were flucoumafen and bromodialone (diluted in monopropylene glycol) and pindone (in methyl cellulose). The trial consisted of 52 sheep, divided randomly into three treatment groups of 16 and one control group of 4. The treatment sheep were weighed and dosed individually with either bromodialone at 2 mg active ingredient per kilogram body weight (mg/kg), flucoumafen at 0.2 mg/kg, or pindone at 10 mg/kg. Two sheep from the control group received equivalent doses of monopropylene glycol, the other two methyl cellulose.

The four groups were grazed in separate paddocks to prevent cross-contamination from excreted anticoagulant. Two sheep from each treatment were then slaughtered 2, 4, 8, 16, 32, 64, 128 and 256 days after dosing (the control sheep were all slaughtered on day 2). Samples of liver and other tissues were taken from each sheep for analysis at the Central Animal Health Laboratory, Wallaceville.

Trial 2. In 1989, Pest Management Services Ltd obtained an experimental users permit for Pindone Cereal Rabbit Pellets in New Zealand. A condition of this permit was that a small trial be conducted to determine the persistence of pindone in the fat of sheep that gained access to the bait.

The trial consisted of five sheep dosed with 30 ml of a pindone suspension containing 2 mg/ml active ingredient in methyl cellose. Sheep were slaughtered 1, 2, 4, 8 and 16 days after dosing and samples of abdominal fat collected for analysis at Landcare Research NZ Ltd, Christchurch.

Efficacy Trials

In 1980, a New Zealand field trial on the anticoagulant diphacinone showed that it was readily accepted by rabbits in cereal pellets, that acceptance remained high when prefeeding was omitted, and that good kills could be achieved with two toxic applications three to four days apart (J. Bell, T. Broad and E. Johnstone, unpublished data). Following this field protocol, later trials showed that cereal pindone pellets could kill > 90 % of the rabbit population in treated areas. Based on these trials (unpublished data), full registration of pindone cereal baits was granted by the New Zealand Pesticides Board in 1992. Subsequent trials to assess carrot as a lower-cost alternative to cereal pollard as a bait material are reported here.

Pin-25 trials. Over the last two years a number of trials have been carried out by Local Government pest control staff using pindone powder applied at 250 ppm, using castor sugar and cornflower as an adhesive to hold the pindone to the carrot (Parker and Brassington, 1988). Details of this "Pin-25" formulation are given in Table 2. Trials using carrot baits coated with Pin-25 were undertaken in two areas (A and B) where 1080 operations had failed, apparently as a result of 1080 bait avoidance. (In area A, for example, pre- and post-1080 surveys suggested that only 44% of rabbits had been killed.)

Table 2. Composition of the pindone formulation "Pin-25" used to apply pindone powder to carrots (from Croft 1988). The indicated amounts produce 200 g of an odorless, green powder that can be used to surface-coat chopped carrot bait.

Constituent	Weight (g)	% of Total
10% wt/wt pindone	50	25
Corn flour	74	37
Castor sugar	74	37
Green vegetable dye	2	1

Pindone concentrate trials. Additional trials have been conducted using a liquid pindone solution instead of the Pin-25 formulation. The concentrate contains "Pival Sodium Salt" instead of the "Pindone Technical" used in Pin-25, allowing it to be sprayed onto bait with conventional equipment or applied to small amounts of bait in a portable concrete mixer. The standard 250 ppm field preparation consists of 250 g of pival salt dissolved in water with a sweetener and 170 g of green vegetable dye. The dye is added to deter birds but has the added benefit that allows coverage of the carrot with concentrate to be checked visually.

Preliminary trials with 250 ppm baits achieved high kills, so subsequent trials were conducted with reduced loadings. For example, Area C received 12 kg/ha carrot loaded with 170 ppm pindone. Field inspections showed that half the bait had been consumed by day 2 and all bait had been consumed by day 4. On day 5, the area received a second feed (12 kg/ha, 150 ppm).

Similar operations, with minor variations in bait loading and coverage, were undertaken in Area D (which had a history of 1080 poisoning every three to four years), Area E (moderately steep country), and Area F (close to a holiday beach). The success of each operation was assessed by standardized pre- and post-control counts of the number of live rabbits visible in a spotlight beam along marked transects in each area. When kills are high (>90%), the accuracy of this technique is normally within ±5% (Hickling and Frampton 1991).

Cost-Effectiveness of Pindone Control

The relative costs of pindone-carrot and 1080-carrot control were compared by compiling parallel costings for a hypothetical high-country control operation. These were based on data compiled by Local Government pest control staff during recent field operations.

RESULTS

Residue Trials

Trial 1. Anticoagulant residues in sheep persisted for longer in liver than in heart or other muscle. Bromodialone was detectable in liver for at least 256 days (the end of the trial) and flucoumafen for at least 125 days. In contrast, pindone was undetectable in liver after 16 days (Table 3).

Trial 2. Pindone was undetectable in sheep abdominal fat within 16 days of dosing, with the rate of elimination being somewhat higher than for liver tissue in the previous trial (Table 4).

Efficacy Trials

The results of six field operations using pindone carrots are summarized in Table 5. Operations using 250 ppm Pin-25 baits achieved a mean kill of 97 % (range 94 to 100), while those using the lower-strength (170/150 ppm) Pindone Concentrate baits achieved a mean kill of 94% (range 89 to 98).

Cost-Effectiveness of Pindone Control

The relative effectiveness of pindone-carrot and 1080-carrot operations is difficult to determine because the success of both will vary with local conditions. For example, 1080 operations often kill >90% of rabbits but, for various reasons, are sometimes much less successful than this (references in Hickling 1994). However, at present the costs of the two forms of control appear to be similar ($20.38 per ha for pindone control, $21.09 per ha for 1080 control; Table 6).

Table 3. Concentration (/*/g) of bromodialone, flucoumafen and pindone in sheep liver (n = 2 per day) over 256 days following dosing (ND=not detectable at a 0.09 *fi/g* limit of detection. No residues were detected in four control sheep.

Days after Slaughter	Bromodialone (2 mg/kg)	Flucoumafen (0.2 mg/kg)	Pindone (10 mg/kg)
2	2.0	0.7	8.1
	0.5	1.4	11.8
4	0.9	0.7	4.9
	1.3	2.0	4.8
8	1.1	2.3	1.0
	1.5	1.6	2.1
16	0.6	2.3	ND
	0.7	1.0	ND
32	1.4	0.8	ND
	3.1	0.5	ND
64	1.8	1.0	ND
	1.5	1.1	ND
128	2.1	ND	ND
	3.0	1.0	ND
256	0.8	ND	--
	--	ND	--

Table 4. Concentration (ju/g) of pindone in sheep adbominal fat (n=l per day) over 16 days following dosing (ND = not detectable).

Days after Slaughter	Pindone (60 mg/sheep)[1]
1	19.6
2	5.1
4	1.6
8	0.1
16	ND

[1]Equivalent to 240 g of 250 ppm cereal rabbit bait.

DISCUSSION

Pindone is much less likely to cause persistent residues in livestock than is bromodialone or flucoumafen, although it is somewhat more persistent than 1080 (cf. Eason et al. 1993). These trials suggest that sheep will be free of detectable residues within 16 days, even if they have eaten several hundred grams of toxic baits. Pindone pellets are consequently sold with the

Table 5. Efficacy of rabbit control operations using Pin-25 and Pindone Concentrate formulations on carrot baits. Bait was spread on two occasions (lst/2nd) separated by a three to four day interval.

	Area (ha)	Pindone loading 1st/2nd (ppm)	Bait coverage (kg/ha)	Spotlight counts Pre (rabbits/km)	Spotlight counts Post (rabbits/km)	Decrease
a) Pin-25 trials:						
Area A	1500	250/250		18.0	0.5	97%
Area B	5663	250/250	19			
-Subarea 1				9.2	0.3	97%
-Subarea 2				2.4	0.0	100%
-Subarea 3				1.7	0.1	94%
b) Pindone concentrate trials:						
Area C	100	170/150	12	32.8	0.8	98%
Area D	80	170/150	13	25.8	1.3	95%
Area E	50	170/170	18	12.5	0.5	94%
Area F	10	170/170	10	15.0	1.7	89%

Table 6. Comparative costs ($NZ) of pindone and 1080 control, based on a hypothetical South Island high country property of 1400 hectares. The application rate of pindone carrot (250 ppm) was assumed to be 18 kg/ha, applied twice with no prefeeds. The 1080 operation was assumed to require two nontoxic prefeeds followed by application of toxin at 25 kg/ha.

Item	Pindone operation		1080 operation	
Carrot bait (ton) @ $51.00 per ton	(66)	$ 3,366	(105)	$ 5,355
Carrot cutter @ $9 per ton		$ 594		$ 945
1080 (litre) @ $50 per litre		--	(35)	$ 1,750
Pindone and dye @ $230 per ton bait		$11,730[1]		--
Dye (kg) @ $70 per kg		--	(5.25)	$ 367
Aircraft time (hours) @ $420 per hour	(17)	$ 7,140	(35)	$14,700
Bait cartage (km) @ $0.22 per km per ton	(140)	$ 2,032	(140)	$ 3,234
Labor (hours) @ $35 per hour	(80)	$ 2,800	(72)	$ 2,520
Plant and incidentals		$ 883		$ 658
TOTAL PRICE		$28,545		$29,529

[1]Assuming 51 ton of chopped bait prepared from the raw carrot.

recommendation that stock gaining access to baits must be moved immediately to untreated land and held there for a minimum of three weeks to allow potential residues to be eliminated.

Cereal Baits

Two types of cereal baits, both containing 250 ppm pindone, are now available to the New Zealand public. One is made from a standard cereal pollard mix, the other is a sweeter pellet made from maize meal. The pellets are packed in 2 kg, 10 kg and 25 kg bags, which can be purchased from plant nurseries, stock and station agents and some general hardware shops.

Each bag contains a pamphlet with recommendations for use; an extract from which reads as follows:

Directions for Use

1. Remove all domestic stock from the area being treated. Keep all stock out of the area until the bait has been removed or has disintegrated.
2. Locate all rabbit sign: this is critical as the placement of bait is vital to the success of the operation. Sign includes droppings which are oval, about 1 cm in length, and often found in small heaps. Rabbits usually graze the pasture to a very low level and leave scraped areas.
3. Apply bait twice, with a three to four day interval, in all areas with rabbit sign. Provide excess bait: if all the bait is gone after the first night more is required.
4. Do not lay pellets if heavy rain is expected within a day.
5. Destroy all used pindone bags and unused bait by burning or burying to a minimum depth of 1 m.
6. Bait can be applied in three ways:
   (a) Apply in small heaps of 10 to 15 pellets on earth spits cut with a shovel, spade or grubber.
   (b) Broadcast by hand on rabbit sign.
   (c) Broadcast through all rabbit-infested areas at an application rate of two to three kilograms per hectare.

Carrot Baits

The trials listed in Table 5 suggest that effective control of rabbits can be obtained using carrot baits loaded with pindone at 170 ppm. This is lower than the currently recommended loading for cereal baits, and the success of these trials may reflect Rowley's (1963) observation that rabbits tend to eat larger amounts of carrot bait than oats or cereal pellets.

The trials' success also supports previous New Zealand research that recommended two applications of anticoagulant at a three to four day interval. This contrasts with an Australian recommendation that pindone carrots and oats be applied three times (Parker and Brassington 1988).

A series of large-scale aerial operations are planned in 1994 to further evaluate 170 ppm carrot baits prepared with liquid Pindone Concentrate (based on Table 6 this should reduce the cost to less than $18 per ha). Other smaller trials will be conducted to evaluate carrot baits with 150 ppm and 100 ppm loadings. If successful, these trials will form the basis of an application for full registration of liquid Pindone Concentrate.

Further work may be required to evaluate the risk of pindone to non-target species. Most landholders have a strong preference for pindone over 1080 because the latter presents a much greater risk of secondary poisoning to farm dogs (and has no antidote). To date there has been only one report of a farm dog killed by pindone rabbit baits. However, there is some concern that pindone may be secondarily hazardous to other scavengers such as the harrier hawk *(Circus approximans)* (Colvin and Jackson 1991).

CONCLUSION

For the first time in New Zealand, the public has access to a rabbit bait that does not require a license for its use. Pindone cereal pellets are now being used to control rabbits in urban and semi-urban areas, in market gardens, horticulture blocks, plant nurseries, golf courses, parks, beach areas, riverbanks, farm buildings, houses and gardens, and other areas of human habitation. They are also frequently used by landowners to treat small or scattered rabbit problem areas on grazing land that would not warrant large-scale 1080 control. In 1993, more than 100 tons of pindone pellets were sold in New Zealand. Full registration of liquid Pindone Concentrate, if obtained, is likely to further increase the usage of this toxin.

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