A REVIEW OF THE RESULTS FROM LABORATORY TESTS OF SOME RODENTICIDES AGAINST EIGHT RODENT SPECIES

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ABSTRACT: The susceptibility of eight rodent species to a range of widely used and candidate rodenticides was determined in laboratory feeding tests. No choice and choice tests were used to assess toxicity and effect on palatability of the rodenticides to *Meriones shawi* (Shaw's gerbil), *Arvicanthis niloticus* (Nile rat), *Acomys cahirinus* (Egyptian Spiny mouse), *Mastomys natalensis* (Multimammate rat), *Sigmodon hispidus* (Cotton rat), *Rattus exulans* (Polynesian rat), and *R. rattus* (Ship rat) which responded differently to each chemical. The results of these tests suggest possible rodenticides suitable for control of each species. Field trials are now needed to assess the effectiveness of these compounds under practical conditions.

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INTRODUCTION

Apart from man, the most successful and abundant mammals are the commensal rats and mice, *R. norvegicus* (Norway rat), *R. rattus* (ship rat), and *Mus musculus domesticus* (house mouse). There are many other rodent species which can be considered pests and cause problems locally, especially in tropical regions. These are field rodents, which apart from causing considerable problems in the field, may come into buildings and cause similar damage to the commensal species. We have in the past maintained breeding colonies of tropical rodent pests in our laboratory, in order to study the effectiveness of potential control agents.

M. auratus, though not a pest in its native Syria, has escaped and lived ferally in at least two areas in the UK, causing control problems for the local authorities. *M. shawi* is found in the coastal zone of North-West Africa from Morocco through Northern Algeria to Tunisia and Egypt. Its economic importance is mainly due to its periodic population explosions which are sometimes classed as national disasters when up to 70% cereal crop losses have been recorded. Vegetables and fruit are hoarded in underground burrows, and olive trees damaged above or below ground. *A. niloticus* is widely distributed throughout Africa and parts of the Arabian Peninsula. It is a serious pest of agriculture in grassland areas, damage being most severe to rice, cereals, sugar cane and root crops in the field. It transmits diseases dangerous to both man and animals, including leishmaniasis and intestinal schistosomiasis. *A. cahirinus* inhabits agricultural land near the Nile, is found in houses and fields, and attacks both crops in the field and stored food, as well as transmitting human diseases. *M. natalensis* is the most widespread rodent in Africa, attacking many crops in the field and damaging young trees. It is an important reservoir of plague and also carries Lassa fever and spirochaetoses. *S. hispidus*, our only representative of American rodents, is found from Southern United States through Central and South America to Peru. This species damages cereals, sugar cane, cotton, vegetables, palm and fruit trees, and burrowing in river banks causes breaching and flooding. *R. exulans* is the third most widely dispersed rat in the world after *R. norvegicus* and *R. rattus*. Its range includes Burma, Thailand, Malaysia, Philippines, New Zealand and Hawaii, and in some areas it lives in association with man. In South East Asia and the Pacific Islands, it is a major rodent pest attacking rice, sugar cane, cocoa and root crops. In other areas such as Hawaii, pineapples and macadamia nut orchards are damaged, while in the Tonga Islands ground crops, peanuts, sweet potatoes and tapioca are attacked.

Since 1950, control of commensal rodent species has been mainly carried out by first-generation anticoagulants. Second-generation anticoagulants were developed in the 1970s to overcome resistance problems to the first-generation anticoagulants in Europe and the USA. Calciferol, which is a slow acting non-anticoagulant affecting calcium metabolism, was screened in 1972. More recently flupropadine was submitted to our laboratory by Rhone-Poulenc (Brentwood, Essex, UK) for screening as a candidate rodenticide. It has not yet been registered for use in any country. Bromethalin is a non-anticoagulant which is marketed for control of rats in the USA. As candidate rodenticides, both poisons were tested against several species as part of our general screen.

This paper reviews the results of a number of laboratory feeding tests using rodenticides against eight tropical rodent species. These previously published and unpublished tests took place over 10 years and as the supplies of each rodent varied over this time, not all species were tested against all poisons listed.

METHODS

The species were obtained mostly from other laboratories, commercial breeders in the UK, or from the wild, in which case the colony was kept in quarantine for six months. *M. shawi* were obtained from the Laboratorie de Recherches Sur Les Ronguer Nuisibles, Marrakech, Morocco, *A. niloticus* from wild-caught individuals from Kenya, *A. cahirinus* from animals caught in Egypt, and *M. natalensis* from a breeding colony at the Hammersmith Medical School, UK. The *S. hispidus* colony originated from animals obtained from the London Hospital Medical School and the National Institute for Medical Research, Mill Hill, UK. *M. auratus* were wild-caught in the UK and also obtained from a commercial breeder and *R. exulans* were wild-caught in New Caledonia, South Pacific. *R. rattus* were bred from warfarin-susceptible stock trapped in Manchester and Bristol, UK. Breeding colonies of all the eight rodent species were established using monogamous pairs, in either wire or plastic cages depending on their docility. The males were left in the cage throughout the breeding cycle. Breeding pairs were maintained on a standard laboratory breeding diet FFG(M) (Dixons and Sons Ltd., Ware, Hertfordshire, UK) and tap water *ad libitum*. All rodents were

Table 1. Summary of feeding tests carried out by Central Science Laboratory, MAFF with anticoagulant rodenticides against eight rodent species at the concentrations of active ingredient recommended for use against commensal species.

Poison and Concentration (w/w)		Warfarin 0.025%			Chlorophacinone 0.005%			Coumatetralyl 0.0375%			Difenacoum 0.005%		
		Mort	Days	Pre	Mort	Days	Pre	Mort	Days	Pre	Mort	Days	Pre
M. shawi	NC	0/2	28	—	—	—	—	0/4	15	—	1/4	22	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
A. niloticus	NC	20/20	6	—	TD	5-15	—	TD	4-14		20/20	3	—
	C	5/10	4	NS	—	—	—	—	—	—	6/10	2	NS
A. cahirinus	NC	5/10	28	—	—	—	—	—	—	—	9/10	24	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
M. natalensis	NC	10/10	13	—	—	—	—	10/10	8	—	10/10	5	—
	C	2/10	4	*CP	—	—	—	7/10	4	NS	1/10	2	***PP
S. hispidus	NC	10/10	6	—	—	—	—	10/10	5	—	20/20	5	—
	C	3/10	2	*PP	—	—	—	4/10	2	NS	0/10	2	NS
M. auratus	NC	0/8	28	—	—	—	—	—	—	—	5/11	21	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
R. exulans	NC	10/10	5	—	TD	4-8	—	TD	3-9	—	10/10	3	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
R. rattus	NC	9/10	21	—	9/9	18	—	9/9	13	—	40/40	3	—
W-S	C	—	—	—	—	—	—	—	—	—	10/10	4	*CP

(Equal number of both sexes used in most tests),
NC=no choice test C=choice test
PP=poison preferred CP=control preferred
W-S=warfarin-susceptible paired Students 't' test

P<0.05=* P<0.005=** P<0.001=***
NS=Not significant TD=Time to death for 100% mortality
Days=No. of days feeding Mort=mortality (dead/tested)
Pre=preference

kept at a temperature of 20°± 3°C and the lighting regime was natural daylight. Litters were weaned at 21 days old, the sexes separated and given standard laboratory diet 41B (Oxoid Ltd., London, UK) and tap water *ad libitum*. When at least 60 days old, the rodents were weighed and caged individually in wire cages for a few days of acclimatization before the start of the tests.

Poisoned baits were prepared by dispersing poison in wholemeal flour to form a mastermix. Feeding tests followed standard procedures (EPPO 1975, 1982) using a bait consisting of pinhead oatmeal (90%, w/w) mixed with corn oil (5%, w/w) and 5% (w/w) of the mastermix of the poison to be used. With calciferol liquid concentrate (Sorex Ltd., London, UK) the bait was made up as pinhead oatmeal (95% w/w) and calciferol oily concentrate (5% w/w). In the initial tests with *R. exulans* however, a dry mix of medium oatmeal (95% w/w) and mastermix (5% w/w) was used with the anticoagulants and as above, pinhead oatmeal, (95% w/w) with calciferol oily concentrate (5% w/w). Plain bait in choice tests for calciferol was pinhead oatmeal (95% w/w) and corn oil (5% w/w).

In no choice tests, rodents were prebaited with the unpoisoned bait base until feeding freely and then allowed unrestricted feeding on a diet of poisoned bait for a specified number of days, or until death. In choice tests, the prebait was a neutral unweighed bait base for a few days followed by presentation of plain and poisoned baits, the position of which was interchanged daily. The plain bait was the same base as the poisoned bait without the poison. In all feeding tests, bait consumption was measured daily.

Toxic effects and time to onset of visible symptoms were recorded in all tests. Rodents were observed for at least 14 days after removal of diet containing the poison and maintained on diet 41B and water *ad libitum* from the end of the test. Any that died were given a visual post-mortem examination to check for obvious signs of poisoning.

RESULTS AND DISCUSSION

Feeding Tests With *M. shawi*

This species was very tolerant to anticoagulants such that no animal died even after 15 days feeding on 0.0375% (w/w) coumatetralyl, 28 days feeding on 0.025% (w/w) warfarin, 21 days feeding on 0.005% (w/w) bromadiolone (Gill and Redfern 1983) and 1 days feeding on 0.005% (w/w) floucoumafen (Gill in press; Tables 1 & 2). After 22 days feeding on 0.005% (w/w) difenacoum, 1/4 *M. shawi* died. Complete mortality was obtained with 0.005% (w/w) brodifacoum only after feeding no choice for 8 days, but this concentration did not kill any animals on a 4 day choice test (Gill and Redfern 1983; Table 2). Non-anticoagulants were more toxic than anticoagulants (Table 3). Calciferol at 0.1% (w/w) though very toxic in no choice tests (100% mortality in 4 days) was totally ineffective on a 2 day choice test probably because of significant unpalatability. Zinc phosphide at 2% (w/w) gave 100% mortality in a 1 day no choice test and 80% mortality in a 2 day choice test at 5% (w/w) (Gill and Redfern 1983). Flupropadine at 0.2% (w/w) (Table 4), gave 100% mortality after 3 days feeding no choice and 60% mortality in

Table 2. Summary of feeding tests carried out by Central Science Laboratory, MAFF with anticoagulant rodenticides against eight rodent species at the concentrations of active ingredient recommended for use against commensal species.

Poison and Concentration (w/w)		Bromadiolone 0.005%			Brodifacoum 0.002%			Brodifacoum 0.005%			Flocoumafen 0.005%		
		Mort	Days	Pre	Mort	Days	Pre	Mort	Days	Pre	Mort	Days	Pre
M. shawi	NC	0/4	21	—	—	—	—	10/10	8	—	0/10	1	—
	C	—	—	—	—	—	—	0/10	4	NS	0/20	2	NS
A. niloticus	NC	—	—	—	27/30	2	—	—	—	—	10/10	1	—
	C	—	—	—	0/10	2	*CP	—	—	—	12/20	2	NS
A. cahirinus	NC	—	—	—	10/10	23	—	7/10	15	—	1/10	1	—
	C	—	—	—	—	—	—	—	—	—	0/20	2	***CP
M. natalensis	NC	20/20	5	—	20/20	4	—	—	—	—	—	—	—
	C	10/10	4	NS	2/10	2	NS	—	—	—	—	—	—
S. hispidus	NC	20/20	5	—	20/20	3	—	—	—	—	—	—	—
	C	8/10	2	NS	0/10	2	NS	—	—	—	—	—	—
M. auratus	NC	—	—	—	—	—	—	10/10	3	—	0/10	1	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
R. exulans	NC	—	—	—	9/10	3	—	—	—	—	—	—	—
	C	—	—	—	—	—	—	—	—	—	—	—	—
R. rattus	NC	15/15	3M 5F	—	40/40	3	—	20/20	2	—	14/15	1	—
W-S	C	10/10	4	NS	9/10	2	NS	16/20	2	*CP	10/10M	2	**CPM
											5/5F	2	NSF

(Equal number of both sexes used in most tests)
NC=no choice test C=choice test
PP=poison preferred CP=control preferred
W-S=warfarin-susceptible paired Students 't' test
P<0.05=* P<0.005=** P<0.001=***
NS=not significant M=male F=female
Days=No. of days feeding Mort=mortality (dead/tested)
Pre=preference

the 4 day choice test (Table 5). Bromethalin at 0.01% (w/w) (Table 5) in a choice test gave 7/10 mortality after feeding for 2 days. Field trials would indicate if anticoagulant-tolerant *M. shawi* could be controlled with bromethalin or flupropadine.

Feeding Tests With *A. niloticus*

Mortality was 100% with warfarin, coumatetralyl, chlorophacinone, difenacoum and calciferol at concentrations recommended for use with *R. norvegicus* and none of these compounds reduced bait palatability (Gill and Redfern 1977; Tables 1 & 2). Brodifacoum at 0.001% (w/w) was ineffective when fed for 3 days, but 0.002% (w/w) gave 27/30 deaths after 2 days feeding no choice (Table 6). However, 0.002% (w/w) brodifacoum was totally ineffective in the 2 day choice test possibly because it was significantly unpalatable. Zinc phosphide at 3% (w/w) fed for 1 day gave 100% mortality (Table 6) but 3% (w/w) zinc phosphide only gave 7/10 mortality in the 2 day choice test (Table 7). Flocoumafen at 0.005% (w/w) was totally effective after 1 day and gave 60% mortality in a 2 day choice test (Gill in press; Table 2). Flupropadine at 0.2% (w/w) both in the 4 day no choice (Table 6) and 4 day choice tests (Table 7) gave 100% mortality. There was wide variation in flupropadine ingestion among individuals in the no choice test, and it was significantly unpalatable in the choice test. Bromethalin at 0.01% (w/w) gave 100% morality in the 2 day choice test (Table 7). Trials of both flupropadine and bromethalin in the field may show if a higher level of control would be achieved than with anticoagulants.

Feeding Tests With *A. cahirinus*

This species was very tolerant to anticoagulants (Mahmoud and Redfern 1981: Tables 1 & 2) and only 70% mortality was achieved even after 15 days feeding on 0.005% (w/w) brodifacoum (Table 8). Flocoumafen at 0.005% (w/w) for 1 day was totally ineffective (Gill in press). The results of the no choice tests with non-anticoagulants showed that calciferol at 0.1% (w/w) was totally effective after 1 day and flupropadine at 0.2% (w/w) after 4 days, but again with a wide variation in dose ingested (Table 8). In the 2 day choice tests, zinc phosphide at 2.5% (w/w) and bromethalin at 0.01% gave good mortality but flupropadine was significantly unpalatable and ineffective in a 4 day choice test (Table 9). Bromethalin field trials are recommended, but it has been shown (Mahmoud and Rennison 1986) that calciferol (0.1%, w/w), and zinc phosphide (2.5%, w/w) both only gave 77% control.

Feeding Tests With *M. natalensis*

Although all poisons tested no choice were toxic at concentrations used against *R. norvegicus* (Gill and Redfern 1979), only bromadiolone at 0.005% (w/w) gave 100% mor-

Table 3. Summary of feeding tests carried out by Central Science Laboratory, MAFF with non-anticoagulant rodenticides against eight rodent species at the concentrations of active ingredient recommended for use against commensal species.

Poison and Concentration (w/w)		Calciferol 0.1%			Zinc phosphide				Flupropadine 0.2%			Bromethalin 0.005%		
		Mort	Days	Pre	Mort	Days	Conc%	Pre	Mort	Days	Pre	Mort	Days	Pre
M. shawi	NC	10/10	4	—	10/10	1	2.0%	—	10/10	4	—	—	—	—
	C	0/10	2	***CP	8/10	2	5.0%	NS	6/10	4	*PP	7/10	2	NS
A. niloticus	NC	20/20	2	—	10/10	1	3.0%	—	10/10	4	—	—	—	—
	C	8/10	2	NS	7/110	2	3.0%	***CP	9/9	2	**CP	9/9	2	NS
A. cahirinus	NC	10/10	1	—	10/10	1	3.0%	—	10/10	4	—	—	—	—
	C	—	—	—	4/6	2	2.5%	NS	1/10	4	**CP	8/10	2	NS
M. natalensis	NC	10/10	1	—	10/10	1	4.0%	—	—	—	—	—	—	—
	C	5/10	2	*CP	9/10	1	4.0%	NS	—	—	—	—	—	—
S. hispidus	NC	10/10	2	—	10/10	1	4.0%	—	—	—	—	—	—	—
	C	7/10	1	NS	6/10	1	4.0%	NS	—	—	—	—	—	—
M. auratus	NC	10/10	1	—	10/10	1	5.0%	—	—	—	—	—	—	—
	C	7/10	2	*CP	10/10	2	5.0%	NS	—	—	—	—	—	—
R. exulans	NC	10/10	1	—	—	—	—	—	—	—	—	—	—	—
	C	—	—	—	—	—	—	—	—	—	—	—	—	—
R. rattus	NC	10/10	7	—	—	—	—	—	8/8	7	—	—	—	—
W-S	C	2/10	4	*CP	—	—	—	—	2/10	4	NS	8/10	2	NS

(Equal numbers of both sexes used in most tests)
NC=no choice test C=choice test
PP=poison preferred CP=control preferred
W-S=warfarin susceptible paired Student 't' test

P<0.05%=* P<0.005=** P<0.001=*** NS=not significant
Days=No. of days feeding Mort=mortality (dead/tested)
Conc%=concentration % Pre=preference

Table 4. Mortality and bait consumption of *M. shawi* given a sole diet of flupropadine in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean Body wt (g)	Mortality/ No. tested	Dose of active ingredient (mg/kg body wt) consumed by animals which				Days to death	
					Died		Survived			
					Mean	Range	Mean	Range	Mean	Range
Flupropadine 0.2%	1	M	172	1/5	189	—	119	108-138	4.0	—
		F	143	3/5	107	86-138	139	125-152	6.7	6-7
	2	M	227	4/5	156	141-174	143	—	5.8	5-6
		F	171	5/5	171	123-254	—	—	6.6	5-9
	3	M	197	5/5	186	169-209	—	—	6.4	5-8
		F	125	5/5	220	142-350	—	—	5.4	3-8
	4	M	247	5/5	220	157-275	—	—	6.8	5-8
		F	170	5/5	206	141-283	—	—	7.8	4-16

tality in the 4 day choice test and coumatetralyl at 0.0375% (w/w) was partially effective. Calciferol at 0.1% (w/w) was unpalatable, and warfarin (4 day choice) and both brodifacoum and difenacoum (2 day choice) were relatively non-toxic, possibly because the duration of the test was only 2 days. Zinc phosphide gave greater mortality at 4% (w/w) no choice than at 3% (w/w), and a choice test was carried out at 4% (w/w) giving 90% mortality (Gill and Redfern 1979; Tables 1-3). Provided that suitable bait bases are used, second-generation anticoagulants should give good control in the field. With calciferol and zinc phosphide, poison-shyness could develop before complete control is achieved.

Feeding Tests With *S. hispidus*

Again all poisons tested no choice were effective at concentrations used against *R. norvegicus* (Gill and Redfern 1980; Tables 1-3). However, in the 2 day choice test bromadiolone at 0.005% (w/w) gave 80% mortality and was the most effective poison. But there was no mortality in the 2 day choice tests with difenacoum (0.005%, w/w) and

Table 5. Bait consumption and mortality in *M. shawi* of both sexes given a choice between plain and poisoned bait.

Poison and Concentration (w/w)	Duration of test (days)	Mean body wt (g)	Mean daily bait intake (g)[a]		Significance (P) of paired Student's 't'	No. of animals preferring poison	Mortality/ no. tested
			Poison	Plain			
Flupropadine 0.2%	4(2)[a]	240	13.4	8.4	<0.05	7/10	6/10
Bromethalin 0.01%	2(1)[a]	242	6.4	7.4	>0.5	5/10	7/10

[a]Figures in parentheses indicate the number of days of bait consumption used in calculations because of the onset of toxic symptoms of the poison affecting bait consumption.

Table 6. Mortality and bait consumption of *A. niloticus* given a sole diet of three different rodenticides in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean body wt (g)	Mortality/ no. tested	Dose of active ingredient (mg/kg body wt) consumed by animals which				Days to death	
					Died		Survived			
					Mean	Range	Mean	Range	Mean	Range
Brodifacoum	2	M	123	0/5	—	—	1.6	1.2-1.9	—	—
0.001%		F	88	0/5	—	—	1.8	1.7-2.1	—	—
	3	M	181	1/5	2.3	—	2.3	2.1-2.5	9.0	—
		F	134	1/5	2.4	—	2.5	2.2-3.4	9.0	—
Brodifacoum	1	M	140	1/5	1.6	—	1.7	1.5-1.9	6.0	—
0.002%		F	103	3/5	2.4	—	1.8	1.7-1.8	8.7	8-9
	2	M	119	14/15	3.5	2.9-4.2	2.1	—	7.3	6-9
		F	105	13/15	3.8	2.5-5.0	2.5	2.1-2.9	6.3	5-9
Flupropadine	2	M	146	3/5	193	172-234	80	16-144	9.0	7-12
0.2%		F	84	5/5	263	147-331	—	—	5.6	4-6
	3	M	209	4/5	74	66-141	21	—	10.8	5-16
		F	110	3/5	128	79-171	15	13-17	3.7	3-4
	4	M	107	5/5	278	127-470	—	—	5.4	3-8
		F	76	5/5	418	135-720	—	—	5.2	4-6
Zinc Phosphide	1	M	189	1/5	231	—	82	70-104	1.0	—
1.0%		F	123	3/5	93	43-152	76	63-88	4.7	1-8
Zinc Phosphide	1	M	197	3/5	209	91-432	162	92-233	1.0	1
2.0%		F	124	5/5	223	112-311	—	—	1.2	1-2
Zinc Phosphide	1	M	165	5/5	354	303-500	—	—	1.0	1
3.0%		F	135	5/5	272	185-378	—	—	1.0	1

brodifacoum (0.002%, w/w), (Gill and Redfern 1980; Tables 1 & 2). Zinc phosphide at 4% (w/w) and calciferol at 0.1% (w/w) were reported to be totally effective in no choice tests and partially effective in 1 day choice tests (Table 3). As complete mortality of *S. hispidus* was achieved with all the poisons tested in no choice tests, provided that suitable bait bases are used, it may be assumed that good control would be achieved by using any of these poisons in the field. Trials are needed to assess which poisons are most appropriate under practical conditions.

Feeding Tests With *M. auratus*

M. auratus is another species that is tolerant to anticoagulants (Table 1 & 2). Warfarin (up to 0.5% w/w) and difenacoum (0.005%, w/w) were ineffective (Bradfield and Gill 1984) and was flocoumafen at 0.005% (w/w) after 1 day's feeding (Gill in press). But complete mortality was obtained with 0.005% (w/w) brodifacoum after feeding for 3 days. Calciferol (0.1%, w/w) and zinc phosphide (5%, w/w) in no choice tests produced complete mortality but only zinc phosphide was effective in the choice test (Bradfield and Gill 1984; Table 3).

Feeding Test With *R. exulans*

The concentration of all poisons used were those normally recommended for rat and mouse control, and brodifacoum, chlorophacinone, coumatetralyl, difenacoum, warfarin and calciferol were all toxic in no choice tests (Tables 1-3, 10 & 11). There were no choice tests carried out with this species, but

Table 7. Bait consumption and mortality in *A. niloticus* of both sexes given a choice between plain and poisoned bait.

Poison and Concentration (w/w)	Duration of test (days)	Mean body wt (g)	Mean daily bait intake (g)[a]		Significance (P) of paired Student's 't'	No. of animals preferring poison	Mortality/ no. tested
			Poison	Plain			
Flupropadine 0.2%	4(2)[a]	140	1.5	4.6	<0.005	0/9	9/9
Brodifacoum 0.002%	2	123	3.7	7.0	0.01-0.005	2/10	0/10
Bromethalin 0.01%	2(1)[a]	193	3.9	7.5	0.1-0.2	3/9	9/9
Zinc phosphide 3.0%	2(1)[a]	174	0.6	1.4	<0.001	2/10	7/10

[a]Figures in parentheses indicate the number of days of bait consumption used in calculations because of the onset of toxic symptoms of the poison affecting bait consumption.

Table 8. Mortality and bait consumption of *A. cahirinus* given a sole diet of three different rodenticides in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean body wt (g)	Mortality/ no. tested	Dose of active ingredient (mg/kg body wt) consumed by animals which				Days to death	
					Died		Survived			
					Mean	Range	Mean	Range	Mean	Range
Brodifacoum	2	M	30	1/2	10.8	—	11.8	—	9.0	—
0.005%		F	23	2/2	14.2	12.3-16.1	—	—	14.0	6-22
	3	M	31	2/2	15.0	14.8-15.2	—	—	8.0	7-9
		F	30	1/2	14.2	—	12.5	—	16.0	—
	4	M	38	0/2	—	—	15.3	14.3-16.3		
		F	22	2/2	28.5	27.2-29.7	—	—	17.0	11-23
	5	M	21	1/2	37.7	—	34.0	—	13.0	—
		F	22	1/2	35.0	—	40.3	—	17.0	—
	6	M	27	4/5	33.0	31.7-36.9	30.6	—	17.0	9-25
		F	25	4/5	25.7	16.5-31.2	39.4	—	12.5	8-19
	7	M	34	0/2	—	—	31.2	29.6-32.8		—
		F	26	1/3	31.1	—	33.6	25.7-41.5	9.0	—
	15	M	30	3/5	54.5	49.1-60.6	75.9	72.4-79.3	14.0	10-18
		F	30	4/5	56.2	29.2-87.3	70.9	—	11.8	10-15
Flupropadine	4	M	30	1/2	142	—	254	—	6.0	—
0.1%		F	23	0/2	—	—	336	317-354	—	—
Flupropadine	2	M	33	1/5	239	—	278	134-355	15.0	—
0.2%		F	26	3/5	207	164-242	334	255-410	5.7	2-13
	3	M	31	1/5	545	—	263	125-345	22.0	—
		F	32	2/5	375	354-396	297	271-335	5.5	5-6
	4	M	31	5/5	359	268-475	—	—	4.2	4-5
		F	30	5/5	474	329-650	—	—	5.6	3-10
Calciferol	1	M	29	5/5	91	73-113	—	—	4.8	3-7
0.1%		F	24	5/5	88	75-113	—	—	3.0	2-4
	2	M	28	5/5	127	88-161	—	—	3.8	3-5
		F	29	5/5	159	104-291	—	—	4.0	3-5

Table 9. Bait consumption and mortality in *A. cahirinus* of both sexes given a choice between poisoned and plain bait.

Poison and Concentration (w/w)	Duration of test (days)	Mean body wt (g)	Mean daily bait intake (g)[a]		Significance (P) of paired Student's 't'	No. of animals preferring poison	Mortality/ No. tested
			Poison	Plain			
Flupropadine 0.2%	4(2)[a]	29	1.7	3.7	<0.005	0/10	1/10
Bromethalin 0.01%	2(1)[a]	30	0.9	1.6	0.2-0.4	4/10	8/10
Zinc phosphide 2.5%	2(1)[a]	35	0.1	0.2	not calculable	1/6	4/6

[a]Figures in parentheses indicate the number of days of bait consumption used in calcuations because of the onset of toxic symptoms of the poison affecting bait consumption.

Table 10. Results of the no-choice feeding tests to death with *R. exulans* using two anticoagulants in medium oatmeal.

Poison and Concentration (w/w)	Sex[a]	Mean body wt (g)	Mean intake of bait (g)		Lethal dose of active ingredient (mg/kg body wt) consumed by animals which died		Days to death	
			Last day prebait	First day poison	Mean	Range	Mean	Range
Chlorophacinone	M	64	6.0	5.2	13.6	8.9-18.2	5.8	4-7
0.005%	F	48	4.2	5.6	15.3	7.9-23.5	5.2	4-8
Coumatetralyl	M	58	6.0	6.2	96	73-122	5.6	4-9
0.0375%	F	42	4.2	5.0	115	80-154	5.4	3-7

[a]Five males and five females were used for each test.

provided that suitable bait bases are used, anticoagulants could be expected to give adequate control in the field, but field trials are needed to confirm this.

Feeding Tests With Warfarin-Susceptible *R. rattus*

Difenacoum at 0.005% (w/w) gave complete mortality after 3 days feeding (Table 12) and in the 4 day choice test, but was significantly unpalatable (Table 1) to *R. rattus* (Hadler et al. 1975). Bromadiolone at 0.005% (w/w) was toxic to *R. rattus* (Redfern and Gill 1980). Brodifacoum at 0.002% (w/w) gave complete mortality after 3 days feeding of *R. rattus* (Table 12) and 9/10 died in the 2 day choice test (Table 2). However, 0.005% (w/w) brodifacoum was significantly unpalatable causing incomplete mortality (16/20) with *R. rattus* (Redfern et al. 1976; Table 2). Flocoumafen at 0.005% (w/w) was totally effective in a 2 day choice test although unpalatable to males (Gill in press, Table 2). Flupropadine at 0.2% (w/w) gave 100% mortality only after 7 days feeding no choice (Table 13), but was ineffective in a 4 day choice test and also unpalatable at 0.3% (w/w) (Table 14). Calciferol was totally effective against *R. rattus* only after 7 days feeding on 0.1% (w/w) or after 2 days feeding on 0.2% (w/w) calciferol (Table 13). Calciferol at 0.1% (w/w) was very unpalatable to *R. rattus* in a 4 day choice test and at 0.2% (w/w) in a 2 day test but did not reduce palatability in a 2 day choice test at 0.15% (w/w). All three concentrations of calciferol gave 2/10 mortality (Table 14). Bromethalin at 0.01% (w/w) was toxic to *R. rattus* in a 2 day choice test (Table 14). Field trials would be needed to see if bromethalin is appropriate in practical conditions, and as it is not a non-anticoagulant, whether control of warfarin-resistant *R. rattus* could be achieved.

CONCLUSION

The rodenticides which are used for controlling the commensal species are generally recommended for use at the same concentrations against other rodent pest species, many of which have a different physiology and biochemistry to the commensal species. Consequently the same concentration of rodenticide may have different effects on each species and possibly sub-species. Laboratory no choice tests can only indicate if the rodenticide is toxic to a rodent species. Choice tests indicate whether the presence of a compound is likely to reduce palatability of the bait. In the field, rodents may have many other food sources beside the rodent bait, and if this is in any way unpalatable good control is unlikely, even if the rodent is susceptible to the poison. Field trials are a necessary further step for the evaluation of promising candidate rodenticides.

Laboratory tests may show variation in response to a poison among individuals of the same species. Individual variability may imply that some rodents would not eat enough poison bait to kill them and therefore would be successful in producing the next generation. If the variability is under genetic control, selection of resistant or tolerant populations may occur, as has been observed with the anticoagulants in some species.

There is much variation between species, and also within species, in their response to rodenticides. The results of laboratory tests presented and reviewed in this paper may form

Table 11. Mortality and bait consumption of *R. exulans* given a sole diet of four different rodenticides in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean body wt (g)	Mortality/ no. tested	Dose of active ingredient (mg/kg body wt) consumed by animal which Died Mean	Died Range	Survived Mean	Survived Range	Days to death Mean	Days to death Range
Warfarin [a]	2	M	90	0/5	—	—	36	26-48	—	—
0.025%		F	68	0/5	—	—	37	29-44	—	—
	3	M	101	5/5	46	32-70	—	—	6.0	3-9
		F	68	1/5	72	—	60	30-88	9.0	—
	4	M	58	5/5	90	64-123	—	—	5.6	5-6
		F	48	4/5	94	70-139	126	—	5.0	4-7
	5	M	71	5/5	66	27-98	—	—	5.2	3-9
		F	44	5/5	88	71-110	—	—	4.6	4-5
Difenacoum [a]	1	M	82	3/5	5.1	4.7-5.5	3.8	3.5-4.1	7.7	6-10
0.005%		F	50	3/5	4.3	4.0-4.6	5.4	5.0-5.6	6.3	6-7
	2	M	82	5/9	7.8	6.5-9.8	9.2	5.6-11.7	6.6	5-8
		F	63	6/10	10.5	5.4-14.8	7.4	6.9-8.2	6.1	5-9
	3	M	68	5/5	13.2	12.1-13.9	—	—	6.0	5-7
		F	49	5/5	17.3	14.6-20.1	—	—	7.2	6-9
Brodifacoum [a]	2	M	55	2/5	3.1	3.0-3.2	3.1	2.8-3.3	5.0	4-6
0.002%		F	64	4/5	2.4	2.3-2.6	2.2	—	6.5	5-7
	3	M	116	4/5	4.0	3.0-6.2	3.2	—	7.8	7-9
		F	66	5/5	4.2	3.1-4.9	—	—	8.0	7-9
Calciferol [b]	1	M	89	5/5	75	50-118	—	—	6.2	5-7
0.1%		F	68	5/5	89	59-117	—	—	7.2	5-9
	2	M	99	5/5	152	130-169	—	—	5.0	4-6
		F	60	5/5	188	97-249	—	—	5.0	4-6

[a]medium oatmeal bait. [b]pinhead oatmeal bait.

Table 12. Mortality and bait consumption of wild warfarin-susceptible *R. rattus* given a sole diet of two different anticoagulants in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean body wt (g)	Mortality/ no. tested	Dose of active ingredient (mg/kg body wt) consumed by animals which Died Mean	Died Range	Survived Mean	Survived Range	Days to death Mean	Days to death Range
Difenacoum	1	M	174	9/20	4.6	2.9-6.4	3.5	1.9-5.3	9.7	6-14
0.005%		F	151	6/20	5.2	1.9-7.4	3.0	2.1-4.9	9.5	7-12
	2	M	164	15/20	6.6	4.1-12.1	7.2	3.9-9.9	9.7	4-13
		F	127	18/20	7.4	4.3-10.4	5.2	3.8-6.6	8.3	4-13
	3	M	187	20/20	8.8	4.9-13.7	—	—	8.7	6-13
		F	140	20/20	11.2	7.8-17.3	—	—	8.6	5-12
Brodifacoum	1	M	171	7/20	1.8	1.5-2.3	1.2	0.7-1.6	9.0	6-13
0.002%		F	139	10/20	1.9	1.3-3.1	1.3	0.5-2.2	8.4	4-12
	2	M	149	19/20	3.1	2.0-5.6	2.0	—	8.4	5-11
		F	143	19/20	2.9	1.3-4.3	0.9	—	9.8	5-16
	3	M	167	20/20	3.9	2.6-4.8	—	—	9.5	6-16
		F	136	20/20	4.9	2.5-6.5	—	—	9.9	7-14

Table 13. Mortality and bait consumption of wild warfarin-susceptible *R. rattus* given a sole diet of two different poisons in a cereal bait.

Poison and Concentration (w/w)	No. of days feeding	Sex	Mean body wt (g)	Mortality/ no. tested	Dose of active ingredient (mg/kg body wt) consumed by animals which				Days to death	
					Died		Survived			
					Mean	Range	Mean	Range	Mean	Range
Flupropadine	4	M	193	0/5	—	—	155	110-183	—	—
0.1%		F	150	1/5	140	—	216	177-253	7.0	—
Flupropadine	4	M	207	0/5	—	—	283	235-377	—	—
0.15%		F	160	2/5	238	231-244	271	184-404	8.5	8-9
Flupropadine	4	M	196	2/10	368	346-391	329	224-495	7.0	—
0.2%		F	157	5/10	419	318-560	435	270-637	6.0	5-7
	5	M	208	3/10	283	233-338	417	257-564	5.3	5-6
		F	138	8/10	478	206-694	675	623-728	6.8	6-9
	6	M	188	5/10	518	317-700	434	275-603	7.0	6-9
		F	143	8/10	400	264-665	724	610-837	5.9	5-7
	7	M	205	3/3	431	361-478	—	—	6.0	5-7
		F	130	5/5	388	232-514	—	—	6.2	6-7
Flupropadine	4	M	182	2/5	512	328-696	530	371-697	7.0	6-8
0.3%		F	134	3/5	445	138-651	531	523-540	5.0	4-6
Calciferol	2	M	168	13/15	109	57-156	66	46-86	6.4	4-10
0.1%		F	148	15/15	97	56-145	—	—	5.6	3-7
	3	M	219	8/10	75	58-89	80	73-86	8.9	6-16
		F	132	8/10	141	101-200	99	73-125	7.1	6-13
	4	M	220	5/5	87	60-135	—	—	4.6	4-5
		F	127	2/5	139	111-167	148	127-171	5.5	5-6
	5	M	182	9/10	104	62-133	64	—	7.0	5-10
		F	172	9/10	92	54-152	142	—	5.8	4-7
	6	M	218	7/10	103	55-135	63	50-80	8.4	4-17
		F	155	9/10	139	89-216	58	—	6.6	3-12
	7	M	206	5/5	91	64-135	—	—	6.2	4-9
		F	152	5/5	129	105-167	—	—	5.0	4-6
Calciferol	2	M	222	5/5	117	93-145	—	—	5.4	3-7
0.15%		F	144	4/5	114	83-130	96	—	5.0	4-6
Calciferol	2	M	207	5/5	123	99-148	—	—	4.4	3-6
0.2%		F	181	5/5	145	112-198	—	—	5.4	4-7

Table 14. Bait consumption and mortaility in wild warfarin-susceptible *R. rattus* of both sexes given a choice between plain and poisoned bait.

Poison and Concentration (w/w)	Duration of test (days)	Mean body wt (g)	Mean daily bait intake (g)[a]		Significance (P) of paired Student's 't'	No. of animals preferring poison	Mortality/ no. tested
			Poison	Plain			
Calciferol							
0.1%	4(2)[a]	226	3.8	7.2	<0.025	2/10	2/10
0.15%	2(1)[a]	172	4.0	6.3	>0.2	4/10	2/10
0.2%	2(1)[a]	191	1.2	8.6	<0.001	0/10	2/10
Flupropadine							
0.2%	4(2)[a]	179	6.9	11.4	>0.1	3/10	2/10
0.3%	4(2)[a]	164	4.6	11.5	<0.005	2/8	0/8
Bromethalin							
0.01%	2(1)[a]	177	5.5	5.6	>0.05	4/10	8/10

[a]Figures in parentheses indicate the number of days of bait consumption used in calculations because of the onset of toxic symptoms of the poison affecting bait consumption.

the basis for selection of candidate rodenticides to be evaluated in field trials for control of a range of rodent pests.

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