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A comparative field trial, conducted without pre-treatment census baiting, of the rodenticides zinc phosphide, thallium sulphate and gophacide against *Rattus norvegicus*

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SUMMARY

The effectiveness of the single-dose poison treatments of farm rat infestations, analysed by comparing the weights of the post-treatment census bait takes in covariance with the weights of the prebait takes, showed that treatments with 2·5% zinc phosphide, 0·3% thallium sulphate or 0·3% gophacide were equally effective and significantly better than were treatments with 1% zinc phosphide or 0·1% thallium sulphate. The methodology and sensitivity of different analyses are also considered.

INTRODUCTION

The occurrence and spread, since 1959, of Norway rats resistant to warfarin in England and Wales has not only stimulated interest in alternative rodenticides but also interest in methods of comparing and evaluating candidate compounds. A method of field testing anticoagulant or other multiple-dose poisons, which can be expected to give 100% control of rats has been described by Drummond and Rennison (1973) and used to test calciferol (Rennison, 1974) and difenacoum (Rennison & Hadler, 1975). The testing of single-dose, acute, poisons in the field is less simple, because in general 100% control cannot be achieved and trials have consequently to be designed and conducted in a way that will allow variable degrees of control to be measured and compared.

To measure the effect of single dose poison treatments Chitty (1954) recommended that the relative size of rat infestations before and after poison baiting should be obtained by census baiting. However, the several days of pre-treatment census baiting that are necessary, even when carried out with a bait different from that used for poisoning and also at different bait points, serve to condition the rats to baiting and the effect can probably not be counteracted completely by leaving an interval of as long as 2–4 weeks between the census and the treatment. Thus experimental single-dose poison treatments that are preceded by census baiting are likely to be more effective than normal control treatments that are not. In most cases results obtained under such experimental conditions probably do not differ significantly from normal, but it is possible that they could, particularly if the acceptance of poison bait by rats depends positively on the amount of conditioning they undergo, as might be the case when relatively fast acting or unpalatable poisons are tested.

This paper describes a replicated field trial that was designed to compare, without pre-treatment census baiting, two well known single-dose rodenticides, zinc phosphide and thallium sulphate and a candidate acute poison, gophacide, against warfarin resistant rats. The first of these compounds is probably the most widely used single-dose rat poison. Although it is also toxic to all other animals it has a very good safety record and is now recommended by the World Health Organization (WHO, 1973). Doty (1945) found 0·5% zinc phosphide compared well with 0·5% thallium sulphate against several species of rat in Hawaii. Becker (1952) recommended its use at 0·75–1·0% against rats in Germany, and in the USA Brooks (1973) recommends 1% and Howard & Marsh (1974) 1–2% concentrations. Gratz (1973) in a review of single-dose rodenticides gives 1% as the commonly used concentration. In Denmark it has been approved for use against warfarin resistant rats at concentrations of 1·5% or 2·0% (Lund, 1971). The recommended concentration in the United Kingdom which is based on the work and experience of the Bureau of Animal Population (Chitty & Southern, 1954) is currently 2·5% (Davis, 1970).

Thallium sulphate is also a rodenticide of long standing which is generally used at concentrations between 0·5 and 1·5% (Gratz, 1973). However, being practically tasteless, odourless, relatively slow to act and cumulatively toxic it has a very bad safety record and is not recommended as a rodenticide by WHO (WHO, 1973). Its use as a rodenticide has been banned in the USA (Howard & Marsh, 1974). In Denmark it has been tested and approved for use at 0·5% against warfarin resistant rats (Lund, 1971). Thallium sulphate is not recommended but has been considered for the control of warfarin resistant rats in the United Kingdom and has been tested under laboratory conditions at the Pest Infestation Control Laboratory. The tests indicated the optimum concentration in rat bait should be between 0·3 and 0·1% (Greaves, personal communication).

Gophacide [0,0-bis(*p*-chlorophenyl)acetimidoylphosphoramidothioate] is an organophosphorus compound that is marketed in the USA by Farbenfabriken Bayer A.G. for the control of pocket gophers. Laboratory tests by Redfern, Greaves & Tinworth (1975) indicated that it would be more effective against the house mouse than the Norway rat and that 0·3% would be a near optimal concentration for use against both species. However, the compound is not currently available for use as a rodenticide in Britain and no recommendations about its use have been made under the Pesticides Safety Precautions Scheme.

METHODS

Poison and baits

Zinc phosphide was used in the trial at the concentration recommended for rat control in the UK, 2·5%, and also at the more widely used concentration, 1%. Thallium sulphate was tested at the maximum and minimum optimum concentrations 0·3 and 0·1% respectively, suggested by the laboratory tests. Gophacide was used only at 0·3% as recommended by Redfern *et al.* (1975).

All the poisons were mixed in pinhead oatmeal bait that contained also 5% 'Mazola' corn oil. The operators who carried out the trial treatments prepared 2·5% zinc phosphide poison bait by adding one part by weight of the poison to 39 parts by weight of the bait; but when they made up the other poison baits they used laboratory prepared concentrates containing 20 times the working concentration of poison in fine oatmeal, and so mixed 1 part by weight of concentrate into 19 parts of bait. The thallium sulphate concentrates included 1% chlorazol sky blue dye and the gophacide a red dye that had been incorporated by the manufacturer.

Method and organization of treatments

The treatments were carried out against warfarin resistant rat infestations in farm buildings in the Welsh county of Powys (Montgomeryshire District). Each farm was a plot for the purposes of treatment. The farms were selected to exclude obviously very heavily and very lightly infested premises but otherwise they, and the poison baits to be used on them, were allocated at random to two operators who worked independently so that after 30 farms had been treated each operator had used each poison bait formulation on three of them.

Before an infestation was poison baited it was prebaited for 5 days with surplus amounts of the plain pinhead oatmeal/corn oil bait distributed on wooden trays at protected bait points. A record was kept of the number of spoonfuls of bait that were laid at each point and of the approximate number of spoonfuls that were eaten by rats each day. The total weight of the bait that was laid on one day and recovered the next was also recorded so that the total weight of bait eaten by rats each day could be accurately measured. Freshly prepared poison bait was laid on the day that the prebait was taken up and left down for 24 hr. When laying the poison baits, the operators referred to the prebaiting records and put at each point at which rats had taken the prebait, an amount of zinc phosphide or gophacide bait that was equivalent to half the maximum day's take of prebait or an amount of thallium sulphate bait that was equal to the maximum day's prebait take. This rule was observed to ensure that adequate but not excessive amounts of poison bait were laid at each point, knowing that Norway rats would be likely to eat from 10 to 50% as much poison bait as plain when the former contained between 2·5 and 1% zinc phosphide (Thompson, 1954; Becker, 1952) or 0·3% gophacide (Redfern, personal communication) but between 50 and 90% as much poison bait as plain when it contained 0·3 or 0·1% thallium sulphate (Becker, 1952).

Assessment of effect of treatments

Eight days later, by which time all lethally poisoned rats should have died and sublethally poisoned ones recovered, the prebaiting procedure was repeated on each farm using dry whole wheat on clean bait trays placed as far as was practicable at new points. The sizes of the takes at individual points and the total weights of wheat eaten were recorded daily as they had been during prebaiting. The

Table 1. *The maximum weights of prebait (pinhead oatmeal +5% corn oil) and post-treatment census bait (dry whole wheat) eaten in one day by rats during trials of the rodenticides zinc phosphide, thallium sulphate and gophacide on thirty farms*

		Farms treated by Operator A		Farms treated by Operator B		Total	
Poisons		Prebait (g)	Wheat (g)	Prebait (g)	Wheat (g)	Prebait (g)	Wheat (g)
2·5% zinc phosphide		1100	200	600	150		
		700	350	1320	240		
		2550	300	1380	0		
	Total	4350	850	3300	390	7650	1240
	Mean	1450	283	1100	130	1275	207
0·3% thallium sulphate		700	400	600	120		
		700	400	2620	0		
		700	200	2860	160		
	Total	2100	1000	6080	280	8180	1280
	Mean	700	333	2027	93	1363	213
0·3% gophacide		900	150	1810	300		
		3150	200	3680	680		
		5050	900	1140	180		
	Total	9100	1250	6630	1160	15730	2410
	Mean	3033	417	2210	387	2622	402
1% zinc phosphide		800	350	3060	1020		
		2300	500	2440	720		
		700	350	1240	680		
	Total	3800	1200	6740	2420	10540	3620
	Mean	1267	400	2247	807	1757	603
0·1% thallium sulphate		600	400	6060	1420		
		480	40	1540	760		
		900	150	720	160		
	Total	1980	590	8320	2340	10300	2930
	Mean	660	197	2773	780	1717	488
	Grand total	21330	4890	31070	6590	52400	11480
	Mean	1422	326	2071	439	1747	383

maximum of the daily values was used as an index of the number of rats left on each farm after poison baiting.

The operators each treated and census baited three farms at a time and completed the trial in 11 weeks. Had they had to census bait the infestations both before and after treatment they would have taken at least 9 weeks longer to complete the work.

Analysis of results

Two analyses of the data recorded in the trial were carried out. The first was an analysis of the weights of the maximum day's wheat takes in covariance with the weights of the maximum day's prebait takes; the second was of the numbers of

Table 2. *The analysis of variance of the weights of the prebait takes*

Source	D.F.	M.S.	F	P
Poisons	4	1704059	0·91	0·48
Operators	1	3162254	1·69	0·21
Poisons × operators	4	2204562	1·18	0·35
Error	20	1870157	—	—

Table 3. *The analysis of covariance of the weights of the post-treatment takes of wheat on the weights of the prebait takes*

Line	Source of variance	D.F.	M.S.	F	P
1	Error in post-treatment weights	20	75803	—	—
2	Regression on prebait weights in error	1	958651	32·7	< 0·001
3	Deviations from regression in error	19	29338	—	—
4	Poisons (adjusted)	4	144845	4·94	< 0·01
5	Between 2·5Z, 0·3T & 0·3G	2	561	< 1·0	NS
6	Between 1·0Z & 0·1T	1	35375	1·21	NS
7	2·5Z + 0·3T *vs* 1·0Z + 0·1T	1	542938	18·51	< 0·001
8	Operators (adjusted)	1	609	< 1·0	NS
9	Poisons × operators (adjusted)	4	129842	4·43	< 0·05

NS, not significant.

census bait points at which the wheat was eaten in covariance with the numbers of points at which the prebait was taken. Both analyses gave similar results but the first was clearly the more sensitive and only the former data are presented (Table 1) and discussed below.

The prebait values had to be used as independent covariables in the analyses of covariance, which were carried out in the manner of Snedecor & Cochran (1967, ch. 14), in order to take account of the variance in the weights of the wheat takes that was correlated with the number of rats at risk on each farm. The latter variance exists because in practice it is harder to bait adequately, and so poison effectively, heavier than less heavy infestations.

RESULTS AND DISCUSSION

An analysis of variance (Table 2) of the prebait weights in Table 1 showed that before the farms were poison baited the average infestation size varied only insignificantly both in relation to the subsequent treatments and to the operators. It confirmed, therefore, that the random allocation of farms and treatments succeeded in ensuring that each operator poison-baited groups of infestations that initially differed in size only insignificantly.

The analysis of covariance (Table 3), of the weights of wheat showed that a very significant ($P < 0{\cdot}001$) linear relationship existed between them and the prebait weights (Table 3; Line 2) and also that the mean wheat weights, when appropriately adjusted by covariance, differed significantly ($P < 0{\cdot}01$) depending on the poison bait that had been used (Line 4). The breakup of the adjusted 'poisons' mean square into orthogonal components (Lines 5–7) showed that the

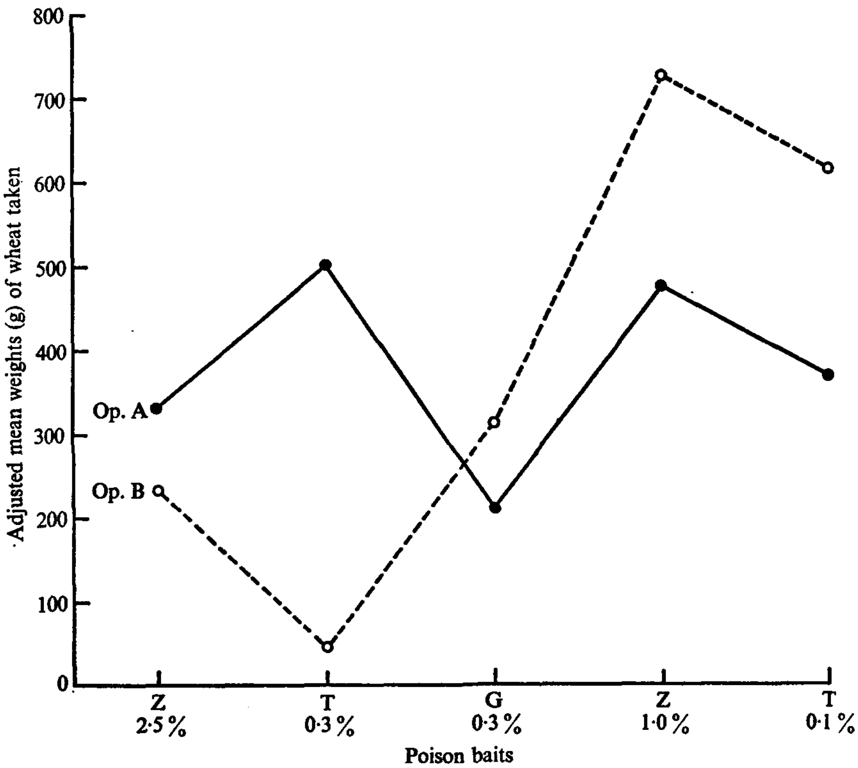

Fig. 1. The adjusted mean weights of the maximum daily takes of wheat by rats recorded after poison baiting with different concentrations of zinc phosphide (Z), thallium sulphate (T), or gophacide (G) had been carried out by different operators (Op. A and Op. B).

significance was due wholly to the difference between the relatively large takes of wheat that occurred on the farms that had been treated with 1% zinc phosphide or 0·1% thallium sulphate compared with those that occurred on the farms that had been treated with the higher concentrations of those poisons or with 0·3% gophacide. The treatments with the higher concentrations of zinc phosphide and thallium sulphate or 0·3% gophacide were, therefore, equally effective and significantly ($P < 0{\cdot}001$) more effective than were the treatments with 1% zinc phosphide or 0·1% thallium sulphate. The treatments with the latter two poison baits did not differ significantly. The adjusted values of the mean weights of the wheat takes that followed poison baiting with 2·5% zinc phosphide, 0·3% thallium sulphate and 0·3% gophacide were respectively 283, 274 and 262 g. The adjusted mean weight of the wheat take after the 1% zinc phosphide treatments was 601 g and after the 0·1% thallium sulphate treatments was 493 g.

Overall, both operators were equally efficient (Line 8) but the significance ($P < 0{\cdot}05$) of the mean square for the adjusted poisons × operators interaction (Line 9) indicated that they were not equally so with each poison bait. How they differed can be seen in Fig. 1. In the figure the only pair of adjusted mean weights that are significantly ($t = 3{\cdot}13$; $P < 0{\cdot}01$) different are those for 0·3% thallium sulphate. Operator A therefore achieved significantly poorer control with that poison bait than did Operator B. At the same time the adjusted weights recorded for Operator A did not vary significantly among themselves but of the weights recorded for Operator B, those following the 1% zinc phosphide and 0·1% thallium sulphate treatments were significantly high. Thus Operator B rather than Operator A was principally responsible for the differential effect that was recorded with the five poison baits in the trial.

Operator A was known to be more cautious with regard to bait placement than Operator B and the trial was designed to take account of this. What was unexpected, however, was that he would be influenced by his knowledge of zinc phosphide and thallium sulphate to the extent that he would be more cautious with the stronger concentrations of both poisons than with the weaker and be particularly cautious when using 0·3% thallium sulphate. His assessment of the risks attached to the use of the latter concentration of the poison was probably affected by the fact that he had to lay much larger baits than he was accustomed to laying when using zinc phosphide.

CONCLUSIONS

The trial confirmed that equally good control of rats was possible with 0·3% gophacide, 0·3% thallium sulphate, or 2·5% zinc phosphide but that significantly less effective control resulted with the latter two compounds if the concentration in the bait was reduced to respectively 0·1% and 1%. If, as field trials of different baits suggest (Rennison, unpublished) rats in farm buildings eat insignificantly different amounts of dry whole wheat and pinhead oatmeal plus 5% corn oil, the average weight of the prebait take, 1747g (Table 1), is an index of the mean size of the 30 infestations before treatment that is directly comparable with the indices of mean infestation size provided by the adjusted average weights of wheat taken after treatment. The differences between the average prebait weight and the adjusted average wheat weights are, therefore, proportional to the average number of rats killed by each type of treatment. The 2·5% zinc phosphide, 0·3% thallium sulphate or 0·3% gophacide treatments were thus respectively 84, 84 and 85% successful, whereas the 1% zinc phosphide and 0·1% thallium sulphate treatments were respectively only 66 and 72% successful. The operators differed significantly in their ability in that B achieved 97% but A only 71% success with the 0·3% thallium sulphate.

All the treatments in the trial might have been more effective if the poisons had been used in a damp bait such as soaked wheat. Likewise treatments with stronger concentrations than those tested may possibly also have been more successful but the results of other trials (Rennison, Hammond & Jones, 1968) indicated that no significant improvement resulted with zinc phosphide when it was used at 2·5% in a damp bait or at 5% in either dry or damp baits. The use of higher concentrations of poison is not desirable for they must inevitably increase the risks of poisoning both to operators and non-target animals and the risks will be greater with thallium sulphate or gophacide than with zinc phosphide.

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REFERENCES

BECKER, L. (1952). Experiments in determining the usual doses for rat poison. *Schädlingsbekämpfung* **44**, (6), 98–105.

BROOKS, J. E. (1973). A review of commensal rodents and their control. *Critical Reviews in Environmental Control*, **3**, (4), 405–453.

CHITTY, D. (1954). In Chitty & Southern (1954), ch.4.

CHITTY, D. & SOUTHERN, H. N. (1954). *Control of Rats and Mice*, 3 vols. Oxford: Clarendon Press.

DAVIS, R. A. (1970). *Control of Rats and Mice*. M.A.F.F. Bulletin No 181, 2nd ed. London: H.M.S.O.

DOTY, R. E. (1945). Rat Control on Hawaiian Sugar Plantations. *The Hawaiian Planters Record*. XLIX, (2), 71–239.

DRUMMOND, D. C. & RENNISON, B. D. (1973). The detection of rodent resistance to anticoagulants. *Bulletin of the World Health Organization* **48**, 239–42.

GRATZ, N. G. (1973). A critical review of currently used single-dose rodenticides. *Bulletin of the World Health Organization* **48**, 469–77.

HOWARD, W. E. & MARSH, R. E. (1974). Rodent Control Manual. *Pest Control*, **42**, (8), D-U. Reprinted as *Rat Control Manual* with editorial corrections and extra figures and captions.

LUND, M. (1971). Annual Report 1970. Danish Pest Infestation Laboratory, Lyngby, Denmark.

REDFERN R., GREAVES, J. H. & TINWORTH, H. (1975). Laboratory evaluation of gophacide as a rodenticide for use against *Rattus norvegicus* and *Mus musculus*. *Journal of Hygiene* **73**, 103–8.

RENNISON, B. D. (1974). Field trials of calciferol against warfarin resistant infestations of Norway rat (*Rattus norvegicus* Berk.). *Journal of Hygiene* **73**, 361–7.

RENNISON, B. D. & HADLER, M. R. (1975). Field trials of difenacoum against warfarin resistant infestations of *Rattus norvegicus*. *Journal of Hygiene* **74**, 449–55.

RENNISON, B. D., HAMMOND, L. E. & JONES, G. L. (1968). A comparative trial of norbormide and zinc phosphide against *Rattus norvegicus* on farms. *Journal of Hygiene* **66**, 147–58.

SNEDECOR, G. W. & COCHRAN, W. G. (1967). *Statistical Methods*. 6th ed. Ames, Iowa, USA: Iowa State University Press.

THOMPSON, H. V. (1954). In Chitty & Southern (1954). Ch. 7.

WHO (1973). *Safe Use of Pesticides*. Technical Report No. 513. World Health Organization, Geneva.