Rat control strategies in organic pig and poultry production with special reference to rodenticide resistance and feeding behaviour

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Abstract

Once rats have invaded farm buildings, efficient rat control usually requires the application of rodenticides. Efficacy of control measures may be lost by physiological resistance to anticoagulant rodenticides and by behavioural reactions of the target rat population. On a farm within the area of anticoagulant resistance in north-west Germany, two consecutive rodenticide treatments were carried out against rats, using different anticoagulant bait preparations. Bait consumption was monitored in combination with direct individual video-monitoring of bait uptake behaviour. Almost half of the rats survived the first three-week treatment using coumatetralyl bait. This result was ascribed to the high overall degree of anticoagulant resistance prevailing in the rat population. The second treatment of the same population using difenacoum bait totally failed to reduce population numbers. Dietary preferences, neophobia, social interactions and habitat structure are important behavioural parameters determining bait uptake. They are discussed in relation to the results of the treatment and a conceptual model for the factors determining rodent control efficacy is presented. The combined results of the two monitoring techniques applied demonstrate the significance of resistance and bait uptake behaviour for the efficacy of rat control measures and suggest the need for adapted rat-control strategies to reduce hygienic problems and the risk of non-target poisoning hazards for livestock and wildlife. This can be achieved if the choices of bait base and active ingredient as well as the methods of bait positioning are adapted to the behavioural peculiarities of the rats and the specific structural conditions on each farm.

Additional keywords: Norway rat, *Rattus norvegicus*, anticoagulants

Introduction

Livestock farming is prone to rodent infestations as it provides optimal feeding conditions and shelter especially for the commensal species rat and house mouse. In organic pig and poultry production, where areas with free-ranging animals adjacent to the stables constitute an integrated element of the production system, the risk of rodent infestations is even more pronounced. Besides their considerable damage to stored products and materials, rodents are known to transmit pathogens to man and livestock (e.g. Gratz, 1994). With the spread of rodent-borne diseases in organic pig and poultry production, prevention of rodent infestations and efficient rodent control receives increasing attention.

In field situations, contacts between farm animals and rodent remnants seem mostly inevitable. In contrast to farm buildings, where rodents are usually not tolerated, the area surrounding the farm buildings constitutes an element of the natural environment where rodents cannot be eliminated easily. Some of the rodent species concerned may also be protected by nature conservancy legislation that impedes control measures. However, it may well be possible to develop specific farming/cultivation practices to reduce the occurrence of problem rodent species to a minimum in areas where farm animals are ranging.

Where rodents are not tolerated, as is the case in and closely around farm buildings, all efforts should be made to prevent rat infestations from developing. This can be done most efficiently by removing food and shelter for rodents or by minimizing potential food sources. Rodent proofing of buildings and tidying up the site are the most important preventive measures. If commensal rats or house mice have already invaded and settled in the farm buildings, efficient control can usually only be achieved by the application of rodenticides. This is particularly true for rats (*Rattus norvegicus*) taking into account their behavioural adaptation and flexibility. In this paper we analyse on-farm rat control experiments and discuss the implications for on-farm rat control strategies. We focus on rat control problems originating from behavioural peculiarities concerning bait uptake and from physiological resistance to anticoagulant rodenticides.

Materials and methods

Rat control trials

Rat control trials were conducted in north-west Germany on a medium-sized farm (50 ha) with dairy cattle and pig fattening. Six bait stations in different farm buildings were fitted with transponder-readers (GFTmbH, Bordesholm, Germany). For visual observation of the rats the bait stations in the pigsty and at the granary were additionally fitted with infrared sensitive video equipment (Panasonic WV-BP 500, WV-72 and AG-TL300, infrared radiator 150W).

Anticoagulant bait preparations custom-made by a professional manufacturer were used. Qualitatively high-grade rolled oats formed the basis for preparing bait contain-

ing 375 ppm coumatetralyl or 50 ppm difenacoum, concentrations that both are equivalent to the common field strength of these compounds for use as rodenticide. Anticoagulant bait was laid out during two periods: April and May–June 1999. In April, coumatetralyl bait was offered for 21 days. In May–June, after a three-week break, difenacoum bait was provided for 43 days. Each of the two treatment periods was preceded respectively followed by a one-week pre- or post-baiting period with plain rolled oats. The bait points were checked and refilled daily and consumption was determined by weighing back to the nearest gram. On the last day of the pre-baiting periods the rolled oats was removed and replaced by anticoagulant bait and on the last day of the treatment period the anticoagulant bait was removed and replaced by plain rolled oats. The consumption during the last 24 hours of the pre- and post-baiting periods was used for calculation of relative treatment efficacy.

Before the start of the trials a number of rats had been live-trapped, weighed and sexed and marked individually with transponders (Trovan ID 100, Dasmann Agrarelektronik GmbH, Tecklenburg, Germany). During the trials the marked rats were registered automatically at the bait stations by transponder-readers. By a combination of video and transponder techniques it was possible to identify individuals and measure individual bait uptake at the bait stations. The daily food quantities of the registered individuals at the two stations were determined by counting the 'feeding nods' that could be identified on the video tape as head movements into the bait tray (1 nod = 0.02 g bait) (Klemann & Pelz, 2005).

Resistance testing

Resistance status of the rat population was checked in a sample of 18 rats using blood clotting response (BCR) resistance tests. The tests were conducted with the active ingredients warfarin, bromadioline, difenacoum and coumatetralyl. Rats had been live-trapped on the farm two months before the start of the control trials and kept singly caged in the laboratory during the testing period. BCR-resistance testing with warfarin was done according to the method described by Martin *et al.* (1979), slightly amended as suggested by MacNicoll & Gill (1993). BCR testing with bromadiolone and difenacoum was done according to the methods suggested by Gill *et al.* (1993) and Gill *et al.* (1994), respectively. Testing for coumatetralyl was done following Pelz & Endepols (1999). The testing solutions were administered by intraperitoneal injection instead of oral gavages, which had proved equally effective (H.-J. Pelz, unpublished results) but would not detect any mechanism of reduced intestinal absorption. To check the activity of the testing solution a Wistar albino rat was included in each series of tests as a known susceptible individual.

Blood samples were taken from the tip of the tail under light diethylether anaesthesia, and mixed with citrate buffer solution. Clotting times were determined with a 'coagulometer' (Amelung), using Epato-Quick reagent (Boehringer Mannheim GmbH, Mannheim, Germany).

Individuals were tested sequentially, starting with warfarin and coumatetralyl. Only animals showing resistance to one of these compounds were tested further for bromadiolone resistance, and those resistant to bromadiolone were tested for difenacoum

resistance. Several spot checks carried out to look for individuals susceptible to bromadiolone but resistant to difenacoum were negative. So rats found to be susceptible to the low-potency compounds were regarded as also being susceptible to the compounds with a higher potency, taking into account the common hierarchical resistance scheme in the area (Pelz *et al.*, 1995). The recovery period following testing was at least one week after the warfarin or coumatetralyl test and three weeks after the bromadiolone test.

Manipulations on animals were done in compliance with relevant federal and state regulations (permit A56/90).

Results

Anticoagulant resistance

The overall degree of anticoagulant resistance on the farm was high: only 2 of the 18 rats tested were found to be susceptible (Table 1). Sixteen rats showed at least resistance to warfarin. The degree of resistance to coumatetralyl (10 individuals) was lowest, while 15 rats were classified resistant to bromadiolone. None of the rats tested was resistant to difenacoum.

Table 1. Rodenticide resistance in rat samples taken from the farm two months before the start of rat control trials.

No. of rats tested	Susceptible		Resistant to					
	n	%	Warfarin		Coumatetralyl		Bromadiolone	
			n	%	n	%	n	%
18	2	11	16	89	10	56	15	83

Rat control trials

Coumatetralyl

Rolled oats consumption on the last day of the first pre-treatment baiting period was 4645 g, indicating relatively high rat numbers. The uptake of coumatetralyl bait during the first and second night of the subsequent treatment phase was 2905 g (63%) and 3519 g (76%), respectively (Figure 1). During the first 3 days 77% of the total amount of bait distributed in the course of the treatment was consumed. During the 4th and 6th night, consumption dropped to 769 g and 581 g, respectively, and remained at that level until day 21. The post-treatment census (2120 g) showed that compared with the first pre-treatment period, 45% of the initial rat population was still present. During

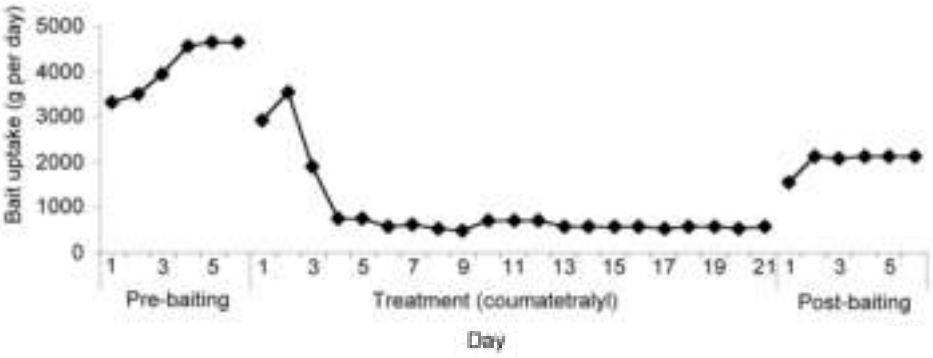

Figure 1. Daily bait uptake during a 21-day period, using coumatetralyl as active ingredient. The treatment period was preceded and followed by a 6-day census period during which plain rolled oats were offered.

the last days of the treatment period, takes of coumatetralyl were around 30% of the post-treatment census.

Monitored individual consumption varied among individuals and bait stations (Figure 2). Average consumption was 1.35 g per 100 g body mass (range 0.08–6.50 g) per 24 hours. Of the 17 rats monitored individually, 9 consumed a dose equivalent to the LD_{50} (15 mg a.i. per kg body mass in a single dose or five times 0.3 mg a.i. per kg

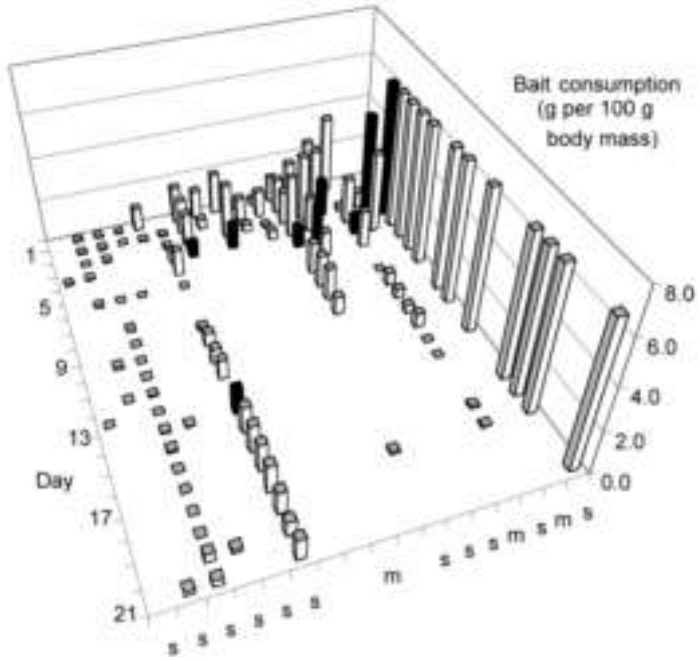

Figure 2. Individual daily bait takes (a.i. coumatetralyl) by 18 Norway rats during a 21-day period. Black bars indicate the days when individual rats had taken an amount of bait equal to or exceeding the LD50. s = survival as confirmed through video-observation; m = carcass found.

body mass) with two of them taking that amount in a single dose and 7 in multiple doses. Six of these 7 rats reached the LD_{50}-dose between the 3rd and 5th day of treatment (Figure 2) and one on the 14th day.

During the treatment, the carcasses of three rats with typical symptoms of anticoagulant poisoning were found, whereas 11 individuals survived the treatment. Four survivors had taken a dose exceeding the LD_{50}, whereas seven took only small amounts of bait and did not reach the LD_{50}. Five of the monitored survivors of the treatment consumed sufficient bait to surpass the LD_{50}, and one of these surpassed the LD_{50} by 37%. The fate of three individuals that had disappeared after the 4th day of treatment is not clear. Only one of them had consumed an amount of bait corresponding to the LD_{50}.

Difenacoum

Rolled oats consumption on the last day of the pre-treatment baiting period was 2078 g. On the first day of the treatment phase bait consumption dropped to 566 g (27%) (Figure 3). The highest amount of difenacoum bait taken was 1309 g (63%) in the third night of the treatment period. During the first 3 days 55% of the total amount of bait distributed in the course of the treatment was consumed. Daily consumption decreased to less than 100 g on day 15 and to less than 40 g after day 32. During the last week of the trial less than 20 g was taken per day. The post-treatment census (2396 g) revealed that the treatment had not resulted in a population reduction. The difenacoum bait proved to be highly unpalatable with less than 1% consumed compared with the post-treatment food uptake.

Individual bait consumption varied among individuals and bait stations (Figure 4). Average consumption was 0.05 g per 100 g body mass (range 0.01–0.27 g) per 24 hours.

None of the 10 individuals monitored consumed an amount of bait equivalent to the LD_{50}-dose (1.8 mg a.i. per kg body mass in a single dose or 5 times 0.16 mg a.i. per kg body mass). After the 43-day treatment phase only two rats were confirmed to be alive.

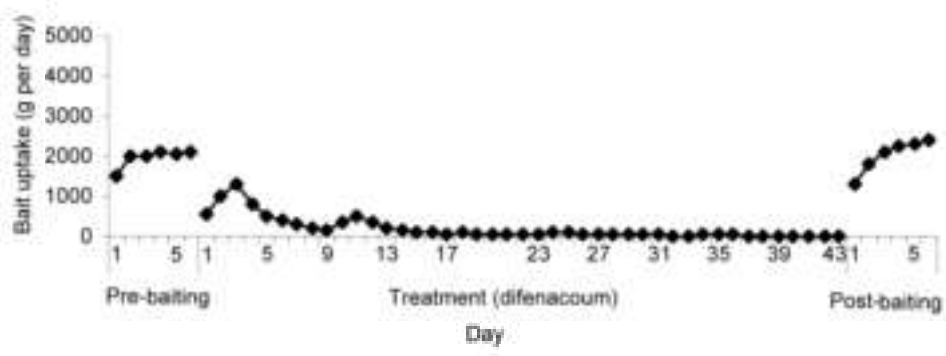

Figure 3. Daily bait uptake during a 43-day period, using difenacoum as active ingredient. The treatment period was preceded and followed by a 6-day census period during which rolled oats were offered.

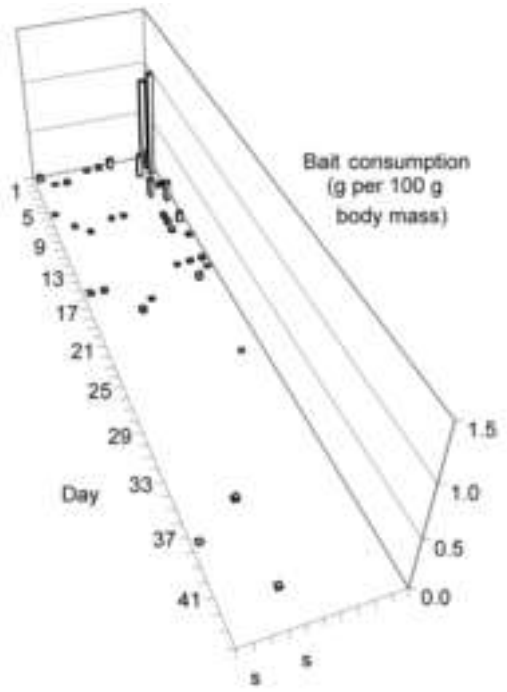

Figure 4. Individual daily bait takes (a.i. difenacoum) by 10 Norway rats during a 43-day period. None of the individuals took an amount of bait equal to or exceeding the LD50. s = survival as confirmed through video-observation.

Discussion

Parameters determining control efficacy

If rat control operations with anticoagulants are professionally planned and carried out they may result in three general types of pattern:

1. *Successful control*. Good bait takes initially, decreasing bait takes after one week; complete eradication of the rat population after two to three weeks of treatment. No bait takes during post-baiting.
2. *Rodenticide resistance problems*. Good bait takes initially, decreasing bait takes after one week, but stabilizing at a certain level; continuous consumption until the end of the treatment period (Figure 1).
3. *Bait uptake problems*. Low bait takes initially, decreasing bait takes and very low takes over the entire treatment period; post-baiting shows no decrease in population size (Figure 3).

A conceptual model for the factors determining rodent control efficacy is depicted in Figure 5.

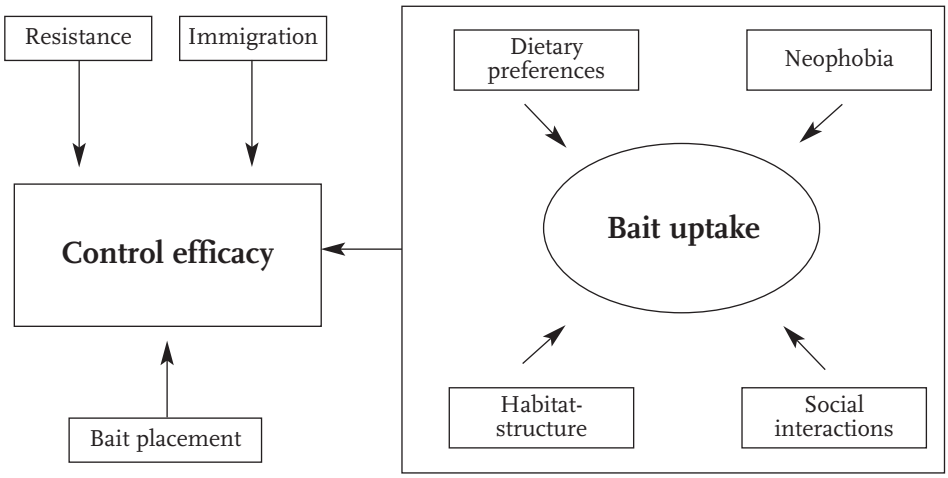

Figure 5. Factors determining efficacy in rat control.

Resistance

In Germany, resistance to anticoagulant rodenticides in rats has been determined in a restricted area in the north-west of the country (Pelz, 2001). Resistance is also known to occur in certain areas in Belgium (K. Baert, personal communication), Denmark (Lodal, 2001), France (A.-S. Walker, personal communication), the Netherlands (De Jonge, 1994) and the United Kingdom (Kerins, 2001). But it is also found outside Europe (Siddiqi & Blaine, 1982; Jackson & Ashton, 1986). Anticoagulant resistance is a heritable trait (Greaves, 1994); recently in the German rat population a point mutation in a gene called VKORC1 was identified to be causative for anticoagulant resistance (Rost *et al.*, 2004).

Our investigations were carried out in Germany on a farm within the area harbouring a rat population with a high proportion of rodenticide-resistant individuals. Practical implications of resistance for the outcome of control measures have been a matter of discussion. With a control efficacy of only 55% after three weeks of treatment with good bait uptake, our coumatetralyl trial demonstrated to what extent resistance may spoil the effect of rat control measures. As the blood clotting resistance testing methods have been developed independently for each of the anticoagulant compounds, levels of resistance are not directly comparable among compounds (Anon., 2003). However, our experience in a number of trials (H.-J. Pelz, unpublished results) shows that a high level of resistance precludes efficient rat control with a number of compounds (warfarin, chlorophacinone, coumatetralyl, bromadiolone). So in these conditions compounds with higher potency that are not affected by resistance are required to solve the problem.

Remarkably, individual monitoring showed that all individuals that succumbed later took up the lethal dose during the first days of the trial. This indicates strongly that two weeks of treatment should usually be sufficient to control a rat population, provided bait consumption is good and individuals of the target population are not

resistant to the compound selected. Prolonged treatment periods with compounds of insufficient efficacy would unnecessarily increase the risk of primary or secondary poisoning and promote selection for resistance.

Behavioural parameters

The behaviour of the specific rat population plays a significant role in determining bait uptake. Predominant elements are dietary preferences and the degree of neophobia shown by the rats. Social interaction and habitat structure are important additional elements affecting bait uptake (Figure 5).

Dietary preferences

Farm conditions usually provide a continuous surplus of food for rats. During control operations bait is in competition with the usual food resources on the farm and must at least match their palatability. Food preferences are partly genetically determined and partly based on the animal's experience (Marsh, 1988). They can be ascribed to socially induced traditions (Galef & Wigmore, 1983) and are passed on, for example, from the mother to the pups through her milk and saliva scent (Galef & Clark, 1972). Food preferences are spread by associative learning or observational learning. Priyambodo & Pelz (2003) found that rats live-trapped on different kinds of farms showed long-lasting farm-specific bait preferences.

Rolled oats are known to be a highly attractive food for rats, while rodenticides to some extent tend to reduce its palatability (Palmateer, 1974). This effect is most obvious when the first day of treatment is compared with the last day of pre-baiting; our coumatetralyl bait also had a much better palatability than our difenacoum bait.

In rat control trials using bait markers, Quy *et al.* (1992b) found that only 13% of the surviving animals had taken a dose of bait that would be lethal to susceptible rats. In our experiment we followed day by day bait uptake behaviour by visual observation of part of the rat population. In the coumatetralyl trial only about half of the individuals took a lethal dose of bait, while none of the 10 individuals observed took a (computational) lethal dose of difenacoum bait. But it is likely that the eight individuals that did take difenacoum bait during the first days of the trial, but did not show up later, succumbed as a result of bait takes. However, after an extraordinarily long treatment period of 43 days two rats survived, most probably because of insufficient bait uptake, as there was no indication of difenacoum-resistance in the population.

Quy *et al.* (1996) pointed out that the method of bait positioning and the structure of the farm may be more significant for the success of pest control than the quality of the bait. However, our comparison of two treatments indicates that the use of highly attractive bait should not be neglected as an important element in a successful strategy to achieve optimal bait uptake.

Neophobia

Low bait uptake often occurs in connection with enhanced neophobia (Berdoy, 1994). There is, however, no evidence for a genetic basis of different levels of neophobia in rat populations (Macdonald *et al.*, 1999). Rats show initial caution towards unfamiliar

bait and new bait boxes in a familiar environment (Barnett, 1958). As observed in our trials, bait acceptance usually increases during the first days of treatment due to a gradual reduction of the initial caution towards unfamiliar food (Thompson, 1948; Lund, 1988). Our observations of individual rats at the bait stations show fast exploration of the new food source within the first days of availability.

Habitat structure and social interaction

Differences in acceptance of bait are not only found between regions or types of farm (Quy *et al.*, 1992a) but also between the different environments in the functional compartments of a specific farm (Klemann & Pelz, 2005), causing changes in the rats' behaviour (Berdoy & Macdonald, 1991). Such differences in habitat structure may be reflected by a different frequency of visits and varying duration of stay of individual rats at the bait stations (Klemann & Pelz, 2005).

Concluding remarks: Rodent control strategies

Successful rodent management is built on three basic elements: preventive measures, monitoring and, if necessary, control measures (Meerburg *et al.*, 2004). In this study we analysed factors influencing the third element, which comes into effect if the use of chemical compounds for rat management has become inevitable. In this study, standard treatment-monitoring techniques in combination with direct individual monitoring of bait-uptake behaviour were used for the first time in a wild rat population. Although our study was non-replicated and without experimental controls, the combined results of the two monitoring techniques show the significance of resistance and behaviour for the efficacy of rat control measures. The results furthermore show that successful rat control strategies need to be based on a profound knowledge of the resistance situation and the behavioural reactions of the target population to the selected bait. Knowledge of the resistance situation is a prerequisite for an adequate choice of rodenticide in order to achieve optimum efficacy and to avoid primary and secondary non-target hazards. The choices of bait base and active ingredient as well as methods of bait positioning have to be attuned to the behavioural peculiarities and specific structural conditions on each farm. By selection of the appropriate active ingredient and close supervision of the treatment, farmers or pest controllers should make sure that the use of rodenticides, if inevitable, will be effective. This is particularly true for organic farming systems, where the use of anticoagulant rodenticides is accepted but less appreciated than in other farming systems.

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